Modularity in Short-Term Memory: A Comparison between Olfactory, Visual and Auditory stimuli

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Summary

This thesis is concerned with memory modularity. Recognition and serial position recall for sequences of odours, unfamiliar-faces and pure-tones is examined and compared. In the first set of experiments, 2-alternative-forced-choice (2AFC) recognition produced qualitatively equivalent serial position functions across the three stimulus types. Recency in the absence of primacy was apparent for the backward testing procedure, in contrast, the forward testing procedure produced an absence of serial position effects. This item-based task, therefore, provides some evidence for amodal processing. A second set of experiments employed a single-probe serial position recall paradigm and produced qualitatively different functions for the three stimulus types. Unfamiliar-faces showed both primacy and recency, pure-tones showed recency only and, in contrast, odours showed neither recency nor primacy. These functions were consistent across sequence length, i.e. 4-6 items. Primacy for unfamiliar-faces was immune to articulatory suppression suggesting a non-verbally based representation. A third set of Experiments employed a modified serial order reconstruction paradigm in which test-items were presented sequentially rather than simultaneously. Unfamiliar-face and pure-tone stimuli demonstrated both primacy and recency, in contrast, odours demonstrated recency only. The absence of cross-stimuli functional equivalence for both order-based tasks contrasts with that for the item-based task, suggesting that item- and order-based memorial processes impact differentially upon arguments for modularity (see Guérard and Tremblay, in press). A fourth set of experiments investigated the role of verbal coding in modified-reconstruction. The functions produced for both odour and unfamiliar-face stimuli were shown not to be characteristic of verbal memory. A final study in this set employed nonwords presented both visually and aurally. Results showed that, regardless of modality of input, the functions replicated those reported above for nonverbal visual and auditory stimuli. The findings demonstrate that the functions for modified-reconstruction are not underpinned by the processes of verbalisation. In summary, the order-based tasks are consistent with modularity, where the item-based tasks support amodal processing. The findings suggest that for order memory at least, olfactory memory is qualitatively different to that of visual and auditory memory.

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"Nothing is serious except passion" - Oscar Wilde

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Thesis Overview

Chapter 1: Modularity in Short-Term Memory: A Review

A review of the literature is provided detailing evidence in support/opposition to the presence of stimuli-specific memory mechanisms/mnemonics. Chapter 1 also provides a detailed review of the olfaction literature, discussing olfactory-based findings/characteristics that differentiate olfaction from other senses.

Chapter 2: Statistical Methodology

Details the statistical tests employed within the thesis to assess the shape of the serial position function and how the presence of primacy and recency is defined. Chapter 2 also describes the standardisation employed prior to cross-stimuli assessments.

Chapter 3: 2-Alternative Forced Choice Recognition

A series of studies compare 2AFC recognition for sequences of 6-odours, unfamiliar-faces and pure-tones. Following the backward testing procedure recency but not primacy is found across the three stimuli types. A duplex account of recency is found to accommodate recency for the pure-tones but not for both odours and unfamiliar-faces.

Chapter 4: Single-Probe Serial Position Recall

A series of studies compare single-probe serial position recall for sequences of 4-, 5- and 6-odours, unfamiliar-faces and pure-tones. Following a correction for response bias, qualitatively different serial position functions were observed. An absence of serial position effects was observed for odours, unfamiliar-faces produced primacy and recency, whereas pure-tones produced recency but not primacy. Primacy following single-probe serial position recall of unfamiliar-faces was found not to be governed by verbal labelling/rehearsal.

Chapter 5: Modified-Reconstruction

A modified version of the serial order reconstruction task was developed and demonstrated to produce a qualitatively equivalent function to that of serial order reconstruction when unfamiliar-faces were employed in both tasks. Forward modified-reconstruction of odours produced a qualitatively different function (recency but not primacy) to that observed for unfamiliar-faces and pure-tones (primacy and recency).

Chapter 6: The Role of Verbalisation in Modified-Reconstruction

The functions produced following forward modified-reconstruction of unfamiliar-faces and odours were shown not to be underpinned through verbal labelling/rehearsal. However, employment of nonwords indicated that verbalisation does not qualitatively alter the serial position function compared to hard-to-name visual and aural stimuli.

Chapter 7: General Discussion

Evidence in support of modularity is found with order-based but not item-based tasks. Potential explanations for olfactory order-based serial position function differences are explored.

For a table summarising each experiment and the key statistical findings, see pp. 307-312.

CHAPTER 1

MODULARITY IN SHORT-TERM MEMORY: A REVIEW

1.1 Thesis Aims

Olfactory short-term memory (STM) has been a much neglected research topic in the Cognitive Psychology domain. Uncertain is the extent to which olfactory memory conforms to the serial position functions/constraints exhibited by stimuli from other modalities. Is there a specific olfactory memory system or are memorial representations processed/stored equivalently irrespective of the modality of stimuli presented? The present thesis, therefore, seeks to examine four main elements of memory research. First, inconsistency exists within the literature regarding the serial position functions produced by odour recognition. Furthermore, limited research exists with respect to olfactory order memory. Chapters 3-6 attempts to determine the serial position functions produced for both recognition and serial position recall of odours. The second related aim of the thesis is to ensure that the serial position functions produced for olfaction are characteristic of olfactory memory. More specifically, it is possible that participants re-code the odours into verbal labels and, therefore, the functions produced are characteristic of verbal labels for the odours rather than the odours per se. The third aim of the thesis is to compare functions produced for olfaction with that of stimuli from other modalities. Without a baseline comparison, it is impossible to formulate meaningful conclusions regarding olfactory memory. This comparison allows one to investigate modularity. In the context of the present thesis, modularity refers to the extent to which separate memorial systems/processes operate for stimuli from different modalities, or whether an amodal system operates irrespective of stimuli type. Ward, Avons, and Melling (2005) proposed that the serial position function is task, rather than stimulus, dependent. That is, if the task is identical, manipulation of the stimulus employed should not qualitatively change the serial position function. The extent of cross-stimuli functional equivalence is the focal point of the thesis and explored in the experimental Chapters 3-6. Finally, the fourth aim of the thesis is to determine methods of analysis such that a comprehensive and reliable assessment of primacy and recency can be computed. These statistical methods, and the rationale for inclusion, are detailed in Chapter 2.

The development of the thesis aims was, therefore, an organic process whereby an initial focus of olfactory memory fluidly shifted into comparison with other modalities, cumulating in a modularity investigation.

Chapter 1 begins by reviewing evidence of modularity in short-term memory. The serial position function evidence for amodal memorial processing is discussed (e.g. Ward et al., 2005) and then contrasted with the traditional conceptualisation of modal-specific memory (i.e. the Working Memory Model). An alternative account to the Working Memory Model is then discussed. Finally, the Chapter reviews evidence suggesting that olfactory memory/processing may operate qualitatively differently to that of other systems (e.g. visual/auditory) and then reviews evidence for olfactory memory independence.

1.2 The Serial Position Function: Effects of Task and Stimulus Modality

The serial position function, i.e. the distribution of accuracy for items within a sequence, can be employed in support/opposition to modularity. Qualitatively equivalent functions across stimuli type might imply identical/analogous memorial processes, whereas disparate functions might suggest that different memorial systems operate for different stimuli. The following section reviews the evidence for serial position function equivalence.

Free recall tasks have traditionally been employed in the study of memory for verbal stimuli. Typically, the participant is presented with a sequence of words and at test is required to recall as many words as possible from the previous list, in any order they choose (e.g. Craik, 1968; Glanzer and Cunitz, 1966). In contrast, memory for hard-to-name stimuli is typically probed via a two-alternative forced-choice (2AFC) recognition task. Participants are presented with a sequence of items and at test are presented with two items; one from the previous sequence (the probe) and a novel item. The participant is required to state which of the two items is familiar. The two tasks produce qualitatively different serial position functions. Free recall is characterised by a bowed function, i.e. comprising both primacy and recency (e.g.

Rundus, 1971). In contrast, 2AFC recognition is characterised by single-item recency in the absence of primacy (e.g. Phillips and Christie, 1977). Based upon these qualitatively different functions, a distinction has been made between the serial position functions for verbal and non-verbal stimuli. Verbal material is argued to be characterised by primacy due to the ability to verbally rehearse the material, whereas non-verbal material does not produce primacy due to an inability to verbally rehearse (Rundus, 1971).

However, Avons (1998) argued that this distinction between verbal and non-verbal functions is inherently misleading since the two paradigms measure qualitatively different memory functions. Free recall necessitates the recollection of items from a previously presented list. In contrast, the 2AFC recognition task requires a familiarity judgment based upon two items presented after the list items. Ward et al. (2005) investigated this proposal directly by employing verbal and non-verbal stimuli within identical experimental paradigms. They employed non-verbal stimuli (unfamiliar faces) and verbal stimuli (nonwords) in a 2AFC recognition paradigm and, for both stimulus types, reported recency in the absence of primacy. The authors concluded that the 2AFC recognition task is characterised by single-item recency irrespective of the ability to verbally label the stimuli. That is, the presence of recency is task, rather than stimulus, dependent.

To further investigate the extent of functional equivalence across stimuli, Ward et al. (2005) applied the unfamiliar-face and nonword stimuli to the reconstruction of serial order paradigm. In this task participants are presented with a sequence of items. At test these items are re-presented and the participant is required to indicate the order in which the items were originally presented. Ward et al. (2005) reported that both unfamiliar-faces (a finding confirmed by Smyth, Hay, Hitch, and Horton, 2005) and nonwords produced qualitatively equivalent functions, i.e. both primacy and recency. As demonstrated with the 2AFC recognition task, both types of stimuli produced the same function for the serial order reconstruction task. Therefore, for both the 2AFC recognition and serial order reconstruction tasks, employment of verbal or non-verbal stimuli did not qualitatively affect the serial position function. The shape of the functions were, therefore, task, rather than stimuli dependent.

Qualitatively equivalent functions, irrespective of the extent to which the stimuli can be verbalised (Ward et al., 2005), indicates that an amodal, or at least an analogous, sensory-specific mechanism/mnemonic underpins memory of these visually presented items. If different functions are produced for the verbal and non-verbal stimuli types it suggests that different memory mechanisms/systems are in operation (the role of verbalisation is explored in more detail in Chapter 6, Experiments 4.1-4.3).

1.3 Evidence for Modular Systems: Dual-Task Paradigms

The findings of Ward and Avons suggest that an amodal, or at least analogous sensory-specific memory system/mechanisms, operates for the memory of both unfamiliar-faces and nonwords. This suggestion is underpinned through qualitatively equivalent serial position functions cross-stimuli. In contrast to this view, other commentators have argued that the mechanisms underpinning memory for different stimuli are modular-specific. For instance, in the Working Memory model (e.g. Baddeley and Hitch, 1974; Baddeley, 1986, 2001), modality specific slave systems, specifically the phonological loop and visuo-spatial sketchpad, are argued to operate independently of each other under the attentional control of the central executive. Evidence for this model has emerged from dual-task paradigms demonstrating that capacity load on one slave system (i.e. a modality-specific system) does not work to the detriment of the other system (e.g. Baddeley, Lewis, and Vallar, 1984).

One example of this dual-task paradigm can be found in Meiser and Klauer (1999). In this experiment participants performed either a verbal serial order task or the spatially-dependent Corsi Blocks Task. In conjunction with the task, participants received either an irrelevant verbal task (articulatory suppression) or an irrelevant spatial task (concurrent finger tapping). The concurrent finger-tapping task was found to be more disruptive of the Corsi Blocks Task than it was of the verbal serial order task. Conversely, verbal serial recall was more disrupted by articulatory suppression than was the spatial Corsi Blocks Tasks. In the dual-task paradigm, these findings are taken as evidence that the verbal and spatial tasks are dependent on two distinct/separate modules.

In addition to Meiser and Klauer (1999), further evidence exists for this separation between memory systems. For example, Shah and Miyake (1996) investigated spatial ability, spatial memory span, verbal ability and verbal memory span. Spatial span was assessed by a task in which a letter was spatially rotated a number of times throughout a trial. At the end of a trial, the participant was required to report the initial orientation of the letter and each orientation that occurred throughout the trial. The maximum number of accurate rotations defined the participant's spatial span. For the verbal span task, participants were required to read a series of unrelated sentences and, at test, recall the terminal word from each sentence. Spatial ability was measured by a battery of spatial psychometric tests that required reconstruction of patterns and mental rotation of shapes. For verbal ability, self-reported scores for the Scholastic Aptitude Test (SAT; a verbal and reading comprehension measure) were employed. Shah and Miyake (1996) reported a relatively high correlation (r=0.66, p<.01) between spatial span measure and spatial ability measures. However, verbal ability measures did not correlate with spatial span measures (r=0.07). Reading span was found to significantly correlate with performance on a Verbal Scholastic Test (r=0.45, p<.01), but reading span did not significantly correlate with spatial performance (r=.12). That is, memory span for verbal and spatial memory was differentially mediated via verbal and spatial abilities, respectively. If stimuli were processed amodally, one might predict uniform span across stimulus types with no evidence of memorial facilitation through stimuli-specific abilities. That is, spatial and verbal span should be equivalent irrespective of verbal and spatial abilities. It is argued that these data provide "preliminary evidence for separate pools of cognitive resources for the two working memories (one for spatial thinking and the other for language processing) beyond the peripheral subsystems" (Shah and Miyake, 1996, p. 12).

Further evidence for modularity was reported by Andrade, Kemps, Werniers, May, and Szmalec (2002) who employed both word recall and abstract pattern recall paradigms. In the visual-verbal task (Experiment 1) participants received a list of words paired with either a number in the sequence or a pegword mnemonic. At test they were cued to recall a word by either the position in the sequence or the paired pegword. In the visual-spatial task (Experiment 2) participants viewed a 5x5 matrix pattern and, following a retention interval, were instructed to fill in the squares of a blank matrix pattern to correspond with the to-be-remembered pattern. By presenting irrelevant visual material during the retention interval, the authors found that irrelevant visual material differentially affected memory for the two stimulus types. Specifically, irrelevant visual material disrupted word recall, whereas in contrast, irrelevant visual material did not impair recall (or recognition, using a yes/no recognition paradigm, Experiment 4) of visual patterns. It is concluded that visual working memory may not be analogous to verbal working memory and that different cognitive mnemonics may operate for visual and verbal STM.

The aforementioned studies support a modular conceptualisation of memory (e.g. Working Memory) since a concurrent distracter task (e.g. articulatory suppression) disrupts memory for one type of stimuli (e.g. verbal) to a greater extent than another stimuli type (e.g. spatial). The finding implies that when performing a spatial memory task, articulatory suppression does not impair performance as to distinct memory modules are employed (i.e. the phonological loop and visuo-spatial sketchpad). These findings contrast the apparent evidence of amodal memory produced by Avons, Ward and colleagues. However, one possible re-evaluation of the Ward et al. (2005) study might be that analogous, yet separate, memory systems are in operation. Such a conceptualisation would predict both qualitatively equivalent functions (e.g. Ward et al., 2005) and dual-task double dissociations (e.g. Meiser and Klauer, 1999).

Guérard and Tremblay (under review) argued that the conflicting evidence on modularity (e.g. serial position function equivalence and dual-task data) is dependent upon the task employed. Guérard and Tremblay argued that observations of STM modularity, i.e. stimuli-specific memory systems/processes, are reported when the tasks necessitates item processing, e.g. recognition. In contrast, evidence for equivalence between stimuli, e.g. qualitatively equivalent serial position functions, is found when order-based tasks are employed, e.g. serial order recall. For example, Farmer, Berman, and Fletcher (1986) reported that articulatory suppression (continuous recital of digits 1-4) had a selectively disruptive effect on the performance of a verbal reasoning task but not upon a spatial reasoning task. In contrast, spatial suppression (continuous sequential finger-tapping) selectively impaired performance on the spatial reasoning task but not the verbal reasoning task. In the verbal reasoning tasks participants were presented with a statement about the order of the letter pair AB followed by the letter pair AB or BA. The participant had to indicate whether the statement was correct or incorrect. In the spatial reasoning task, participants viewed a manikin with a square in one hand and a circle in the other. Participants were required to indicate which hand held which object. Guérard and Tremblay (under review) argued that the findings support their proposal, i.e. item-based tasks produce evidence in support of separate memory systems/processes (modularity). However, although the spatial task necessitates item information with respect to which hand of the manikin contains which object, the verbal task does appear to contain an order element. If the participant processed the letter pair as a 2-item sequence one might argue that the reasoning task necessitates order. However, if the letter pair is processed holistically as a single item, the reasoning task is item-based as the participant is required to differentiate which side of the pair each letter is situated.

Consistent with the Guérard and Tremblay (under review) proposal, evidence in support of modularity has been demonstrated neurologically following a spatial/verbal item-based recognition task. Smith, Jonides, and Koeppe (1996) conducted Positron Emission Topography (PET) scans on participants whilst they performed verbal and spatial tasks. Participants were required to indicate whether an item (a letter from a verbal task or position from the spatial task) was present during the preceding presentation phase. The verbal task was shown to principally activate the left hemisphere, whereas the spatial task principally activated the right hemisphere. Smith et al. (1996) argued that verbal and spatial working memories are underpinned by different neural structures. In Experiment 2, Smith et al. (1996) investigated the extent to which stimuli-specific characteristics may have induced the neurological dissociation. Participants received a continuous stream of letters in upper and lower case, wherein each letter was presented in a different spatial location. In the verbal task participants had to decide if each letter matched the letter presented (regardless of spatial position) three back (irrespective of case of letter). That is, participants were required to continually remember the item that was presented three items previously in the sequence and determine if that item matched the current letter. In the spatial task, participants had to decide if each letter was in the same spatial position (irrespective of what the letter was) to the item presented three back. Therefore, participants were required to continually remember the spatial position of the item that was presented three items previously in the sequence and determine if that spatial position matched the position of the current item. The task, therefore, necessitated continual updating of verbal or spatial working memory but ensured that the same stimuli were employed in each task. The task differed only with respect to the participants' instructions: they were required to remember the identity of the letters or the position of the letters. As in Experiment 1, the right-left hemispheric dissociation was replicated for the spatial and verbal tasks, respectively. That is, once again in an item-based memory task, performance on a spatial item memory task activated the right hemisphere of the brain and performance of a verbal-item memory task activated the left hemisphere of the brain. The finding further illustrates separate neurological locations underpinning memory of verbal and spatial stimuli.

In contrast to the evidence for modularity produced by item-based memory tasks, Guérard and Tremblay (under review) argued that the findings from tasks necessitating the retention of order information support an amodal memory mechanism. That is, memory for different stimuli types operates via an amodal system, or at least via analogous systems. As described earlier, a bowed serial position function has been observed following serial order reconstruction of hard-to-name stimuli (e.g. Avons, 1998; Smyth et al., 2005; Ward et al., 2005) and serial order reconstruction of verbal (nonword) stimuli (Ward et al., 2005).

Consistent with Ward et al. (2005), Jones, Farrand, Stuart, and Morris (1995) found a bowed serial position function following serial order reconstruction of the spatial position of dots (Experiment 1). In Experiment 2, consistent with an amodal account, both verbal suppression and spatial tapping tasks were found to interfere equally upon the reconstruction of spatial order. Under a modularity account, a selective effect of the concurrent spatial tapping task is predicted, since finger-tapping interferes with the operations of a spatial memory system, i.e. the visuo-spatial sketchpad, e.g. Baddeley and Hitch (1974). Against predictions, e.g. Baddeley and Hitch (1974), the verbal concurrent task interfered with the operation of the spatial task, suggesting that the task is performed by an amodal mechanism/process.

One might argue that the finding of disruption to spatial serial order reconstruction by the concurrent verbal task found by Jones et al. (1995) was not due to the articulatory suppression per se, but rather, due to increased demands upon the central executive.

Under this interpretation, the central executive is involved in manipulating stimuli from all stores. The increased demands of organising both verbal and spatial stimuli may have resulted in memory impairment. Jones et al. (1995) investigated this counter-argument in Experiment 4. In this experiment participants were instructed to ignore irrelevant speech presented during performance of the spatial task. Since the central executive was not required to organise these to-be-ignored stimuli, this manipulation eliminated any additional load placed on the central executive by the irrelevant speech. Therefore, if the central executive experienced no additional load, central executive capacity could not explain the performance decrement. Irrelevant speech was, nevertheless, found to impair performance of the spatial task. The impairment was, therefore, not due to overloading of the central executive. Jones et al. (1995) concluded that the detrimental effect of irrelevant speech on the serial spatial memory task offers powerful support for a theory of interference that is based on an equivalence of memory for different stimulus types. The findings of Ward et al. (2005) and Jones et al. (1995), therefore, provide evidence of an amodal memory system following employment of an order-based task.

As previously described Guérard and Tremblay (under review) proposed that support or lack of such for modularity is dependent upon the task, i.e. either item- or order-based. However, the findings of Ward et al. (2005) provide one notable exception to this proposition. Ward et al. (2005) reported functional equivalence following 2AFC recognition for nonverbal stimuli (unfamiliar-faces) and verbal (nonword) stimuli. This 2AFC recognition task is reliant upon participants remembering item information regarding the sequence, i.e. was that test item presented in the previous sequence? The task does not necessitate any recall of order information. Despite the hypothesis that item-based tasks produce evidence in favour of cross-modal memorial differences, Ward et al. (2005) reported functional equivalence between 2AFC recognition for both unfamiliar-faces and nonwords. This finding suggests that an amodal, or analogous memory systems, operates for item memory of two different types of stimuli (this finding is further explored and replicated in Chapter 3). However, as previously argued, Ward et al.'s equivalent serial order reconstruction functions do not permit generalisation beyond cross-stimuli equivalence within the visual domain. The extent of cross-stimuli functional equivalence is the focal point of the thesis and explored in the experimental Chapters 3-6.

The existence of an amodal memory for order and a modular-specific memory for items is not the most parsimonious interpretation of the review of studies provided by Guérard and Tremblay (under review). Guérard and Tremblay (under review), therefore, investigated the hypothesis that order-based tasks produce evidence in support of an amodal memorial system, whereas item-based tasks produce evidence in support of memory modularity. In Experiment 1 the authors employed both serial recall and order reconstruction tasks in which 7-item lists of spatial and verbal stimuli were presented. In the spatial serial recall task, the participant was required to indicate where on the screen each dot was presented (a radius of acceptance around each dot of 50pixels was employed). An interaction between task and serial position was found, but crucially no effect of modality was found, nor was a three-way interaction between task, modality and serial position observed. These findings are important for two reasons. First, the null effect of modality demonstrates that changing the stimuli (verbal versus spatial) did not quantitatively impact performance. A main effect of modality may suggest that the stimuli are stored by separate processes. However, such a difference may also be due to stimuli-specific characteristics. Second, the lack of an interaction between task, modality and serial position is important because it further supports amodal processing. If the modality of stimuli qualitatively changed the serial position function for the reconstruction and serial recall tasks, then an interaction should have been observed. This was not found, indicating qualitatively equivalent functions were produced for the verbal and spatial stimuli in the reconstruction and the serial recall tasks. This finding supports an amodal, or at least analogous memory, interpretation.

Guérard and Tremblay (under review) investigated the pattern of order errors, i.e. recalling to-be-remembered items in the incorrect serial position, and item errors, i.e. recalling erroneous items – an error that can only be investigated following serial recall. For both modalities and both tasks, order errors were found predominantly in middle serial positions, in contrast, item errors increased for later serial positions. The finding demonstrates a dissociation between item and order memory, such that a different pattern of errors was observed for the two tasks. However, the finding is consistent with an amodal interpretation because both spatial and verbal modalities produced similar patterns of order and item errors following the reconstruction and serial order tasks.

However, the distribution of intrusion errors, i.e. erroneously responding for an item that was not presented in the to-be-remembered sequence, provided some evidence for the modularity account. Intrusion errors increased as a function of serial position for the spatial stimuli but not for the verbal stimuli, for which a bowed distribution of intrusion errors was demonstrated. If the verbal and spatial stimuli were processed amodally a similar pattern of intrusion errors should be observed. This was not found.

In Experiment 2 of the Guérard and Tremblay (under review) study, participants performed serial order recall of both verbal and spatial material. In addition to the serial order recall task, participants were instructed to perform a concurrent verbal distracter task (continuous repetition of the letters "A-B-C-D"). Importantly, an interaction between modality, articulatory suppression and serial position was found, such that articulatory suppression impaired item and order processing for the verbal task but exerted no impairment on the spatial processing task. The interaction demonstrates that articulatory suppression had qualitatively different effects on the serial position functions produced for verbal and spatial stimuli. If the stimuli were processed amodally, it is predicted that concurrent articulatory suppression has similar effects on both stimuli types.[1] This was not found.

In Experiment 3 of Guérard and Tremblay (under review), spatial suppression (finger-tapping counter-clockwise employing the non-dominant hand) disrupted spatial recall but had no effect on verbal serial recall. Guérard and Tremblay, therefore, produced, superficially at least, dichotomous findings. On one level, similar patterns of error distributions and serial position functions for the two tasks were observed for verbal and spatial stimuli. The findings suggest that the same memory system/process may be utilised in processing of the two stimuli types. However, the double dissociation found in Experiments 2 and 3, with respect to the selective effects of articulatory and spatial suppression, indicate modularity consistent with a working memory architecture. That is, modality specific subsystems exist that predict no costs

[1] See Jones et al. (1995) for an alternative interpretation. Also see the section entitled 'An Alternative Account to Modular Memory' on p. 14.

associated with simultaneous operations (with the caveat that both do not require resources from the central executive). However, when the simultaneous operation involves stimuli from the same modules, e.g. both the memory and distracter task is verbal, performance is impaired.

The findings of Guérard and Tremblay (under review) conflicts the unparsimonious interpretation that order-based memory is amodal whilst item-based memory is modular. Their analysis of erroneous responses and dual-task manipulation indicates that qualitatively equivalent functions produced for order-based tasks were misleading in suggesting amodal memory. Specifically, a different pattern of intrusion errors and a dissociative effect of concurrent tasks suggest different memory processes were in operation cross-modally.

The equivalent error distributions for spatial and verbal tasks demonstrated by Guérard and Tremblay indicate that although the systems may operate separately (as suggested by the selective effects of distracter tasks), processes employed may indeed be analogous. From an evolutionary perspective it is unclear why duplicate processes in separate memorial systems exist. Speculatively, separate modality-specific processes may have evolved to allow dual-tasking (indeed, domains may have evolved at different stages in human development, wherein the verbal component presumably developed later). The analogous processes employed for each domain may merely be due to that process being the most efficient across stimuli and evolving similarly for each modality. However, this conjecture is extremely preliminary.

1.4 An Alternative Account to Modular Memory

Guérard and Tremblay (under review) detail a memorial architecture in which different modality specific systems exist but operate analogously. However, there exist two problems with such a rationale. First, there are arguments against the interpretation of double dissociations as evidence for separate memorial systems. Second, there are researchers who support an account whereby the core constraint on STM performance relates to the organisation of the to-be-remembered material rather than the modality of the stimuli per se (e.g. Jones, Macken, and Nicholls, 2004). Under such an interpretation, the authors propose that the dual-store evidence of modularity can be explained without the necessity for separate modal-specific systems.

The dissociable effects of distracter tasks are used as evidence that separate modal-specific systems exist. As previously stated, in Guérard and Tremblay (under review) verbal suppression was found to impair verbal but not spatial serial recall, whereas spatial suppression was found to impair spatial but not verbal serial order recall. However, Brown and Lamberts (2003) have argued that such a double dissociation does not provide unambiguous evidence for dual mechanisms. They use the example of the immediate free recall (IFR) paradigm, in which the selective primacy decrement exhibited by amnesic patients and the selective recency decrement in span-impaired patients is interpreted in terms of separate short-term and long-term memory stores. Brown and Lamberts (2003) explain that in SIMPLE (Brown, Neath, and Chater, 2002), a unitary-store temporal distinctiveness model, impairment to the rehearsal mechanism selectively impairs the primacy component of the serial position function. Brown and Lamberts (2003) demonstrated that output order effects can impact the presence of both primacy and recency (i.e. the item recalled first has a recall advantage). Their simulation demonstrated that when not recalled immediately, recency is greatly attenuated irrespective of rehearsal. However, primacy persists if rehearsal occurs regardless of order of recall. The simulation permits, to some extent, the finding of a double dissociation under a unitary-store model. Specifically, the simulation demonstrates that an effect (recency), which has previously been employed as evidence of a dual memory system, is, rather than underpinned via a separate memory system, symptomatic of task constraints. That is, output effects provided spurious evidence of a double dissociation. The study suggests, therefore, that a double dissociation can be reported but it does not necessarily follow that separate systems are producing the effect.

Notwithstanding the Brown and Lamberts (2003) rationale, Jones and colleagues argued that STM performance is dependent upon the organisation of events into sequences rather than modal-specific/amodal processing. Their conceptualisation of amodal operations differs from the traditional notion of amodal processing. Rather than investigating the extent to which representations of items are amodal/modal-specific, i.e. how items are represented, the Jones and colleagues account (e.g. Jones et al., 2004) focuses upon the mechanism by which items are assembled into sequences. Their account of interference from dual-task performance is amodal in the sense that concurrent stimuli of any modality should interfere with task performance if the same mechanisms (e.g. rehearsal/) are being employed. Simply, the distracter task competes for control of the mechanism that is employed for both the distracter and main task. Therefore, the finding of dissociative effects of interference (e.g. Baddeley, et al., 1984) might be explained by the employment of different mechanisms in both the main experimental and distracter tasks.

In relation to the proposed verbal-specific module of memory (the phonological loop), Jones et al. (2004) highlight that the key constraint in determining the disrupting impact of irrelevant material is not the identity of the stimuli per se. Rather, it is the organisation of that material. That is, presentation of the distracting stimuli via a different stream, e.g. via a different ear, to that of the to-be-remembered material has less of a distracting effect than a condition where both are presented via the same stream, e.g. Jones, Macken, and Murray, 1993. Same stream presentation is, therefore, argued to disrupt the rehearsal of the to-be-remembered sequence. Stream of presentation is qualitatively different to that of modality of presentation; therefore, the work of Jones and colleagues is not evidence for amodal processing per se. However, their research does provide an alternative account for the previously described dual-task evidence for separate modality-specific systems.

Jones, Hughes, and Macken (2007) propose that STM task performance is governed by the organisation of events into sequences (either automatically or deliberately). It is the extent to which stimuli from different modalities lend themselves to these organisational processes that dictates cross-modal STM performance. STM is conceptualised as a motor planning activity, whereby the motor system generates models of the list in the order of presentation in preparation for response.

One core finding in support of the Working Memory model is the phonological similarity effect (PSE). The PSE refers to the finding that similar sounding items are harder to remember (e.g. Conrad, 1964) and has been employed as evidence in support of the modular working memory model (specifically a phonologically dedicated module). Recall accuracy within the phonological loop is dependent upon discrimination between the phonological code representations. The more similar the phonological codes, the more confusability between traces and poorer subsequent recall (e.g. "jab" and "cab" are more confusable that "jab" and "sin"). This PSE is argued to occur because phonologically similar items become confused when retrieved from within the phonological store. This effect has been shown to survive articulatory suppression when the items are presented aurally but not when presented visually (e.g. Baddeley et al., 1984). The finding has been used to support the existence of an explicit verbal component in memory, specifically the existence of the phonological loop. The assumption is made that aurally presented words have direct access to the phonological store, whereas visually presented words necessitate transformation into phonological code. Articulatory suppression disrupts the conversion of visually presented words into phonological code and, therefore, averts the confusability of phonologically similar words, i.e. the PSE. Since aurally presented words have direct access to the phonological store, phonological confusability occurs despite articulatory suppression.

However, Jones, Hughes, and Macken (2006) provide an alternative interpretation to the PSE that does not necessitate a phonological store. Jones et al. (2006) describe how evidence for the PSE is derived using a three-way interaction between modality (visual versus auditory), similarity (phonologically similar versus phonologically dissimilar) and articulatory suppression (articulatory suppression versus non-articulatory suppression). An important element of the interaction is the significant difference between recall of auditory lists under articulatory suppression when the stimuli are phonologically similar compared to when they are phonologically dissimilar. That is, despite articulatory suppression, memory for aurally presented phonologically similar items is impaired compared to that for phonologically dissimilar items. This difference is not found for visual stimuli due to articulatory suppression preventing the conversion of grapheme representations to phoneme representations and, therefore, not being held within the phonological store. From a phonological store perspective, one might argue that this difference is due to items possessing direct access to the phonological store and experiencing increased confusability when phonologically similar but not when phonologically dissimilar.

However, Jones et al. (2006) abolished the PSE for auditory stimuli under articulatory suppression via the employment of a prefix and suffix. They, therefore, argued that the strong memory performance for the last two items in the dissimilar list produced the significant difference between phonologically dissimilar and similar auditory lists when under articulatory suppression. That is, similarity (i.e. phonological similarity or dissimilarity) has no effect on recall levels of the auditory lists except at the recency component. If the difference was genuinely due to the phonological confusability of items held within the phonological store, one might predict a detriment throughout the list and not just at the recency component. Jones et al. (2006) claimed that this finding casts doubts upon the phonological origins of this effect between phonologically similar and dissimilar lists. The difference in recall accuracy between visual and auditory stimuli for the recency component of lists is a well documented finding (the modality effect, e.g. Beaman, 2002; Cowan, Saults, and Brown, 2004; Frankish, 1989) and, therefore, might explain the difference in recall under articulatory suppression between visual lists (of both dissimilar and similar lists) and auditory lists (of similar lists).

Jones et al. (2006) propose that the recency benefit for the auditory stimuli is acoustic rather than phonological in origin. They argue that participants exploit perceptual organisation to encode order at the end of the sequence, such that the silence following the terminal item operates as a salient boundary that promotes the preservation of order for the terminal item(s). However, it is argued that this preservation of order for the recency component is disrupted when the items are acoustically similar.

If the survival of the PSE under articulatory suppression for auditory stimuli is due to acoustic rather than phonological similarity, then presentation of a suffix should abolish the PSE. Under such circumstances the suffix will prevent the silence following the terminal sequence item being employed as a boundary. However, if the effect is governed by storage within a phonological store, employment of a suffix should not impact the PSE as phonologically similar items held within the phonological store should still experience confusability. Indeed, Jones et al. (2006, Experiment 2) found that employment of both a prefix and suffix abolished the PSE under articulatory suppression, suggesting that the effect was governed by these list boundary cues, rather than by phonological confusion within the phonological store. The prefix and suffix removes the facilitative effect of silence at each end of the sequence, negating the benefit afforded to auditory presentation.

Furthermore, the ability of both a prefix and suffix to abolish the PSE under articulatory suppression is reduced by presenting these irrelevant items in different voices (Jones et al., 2006; Experiment 3). The finding is argued to be consistent with the survival of the PSE via acoustic encoding rather than phonological encoding of items at the sequence boundary. Jones et al. (2006) propose that when the prefix and suffix are perceptually similar (i.e. presented in the same voice as the list), they are perceptually grouped such that the participant is unable to use perceptual processing to disambiguate the order of the terminal items and, therefore, preventing the phonological similarity effect. However, when presented in a different voice, the prefix and suffix is automatically separated from the list such that the acoustic boundaries of the list remain intact. It is argued that strong boundary markers, before and following the sequence, facilitate order retrieval of auditory stimuli; employment of a same voice suffix removes this benefit. According to Jones et al. (2006), the PSE, a fundamental source of evidence in favour of the working memory model, is, therefore, consistent with a system not reliant upon separate memory modules. Survival of the PSE under articulatory suppression of the auditory, but not visual lists is argued to be mediated by perceptual (acoustic) differences rather than a separate phonological memorial component.

Baddeley and Larsen (2007) counter these findings and propose that use of the phonological store is abandoned when the task becomes too difficult (e.g. in Jones et al., 2006, a five item list with 2 additional irrelevant items induced phonological store abandonment). However, Jones et al. (2007) highlight the circular and flawed logic of such an argument. That is, the PSE is fundamental evidence in favour of the phonological store. Absence of the PSE is evidence that the phonological store has been abandoned. By this reasoning it becomes impossible to falsify the presence of the phonological store. In summary, Jones and colleagues have provided evidence against one of the core findings used to support a modular system of memory and proposed a memory process that is not reliant upon separate stores but governed via perceptual and monotonic organisation of the lists. Jones et al. (2006) demonstrated that a finding used as support for modularity can be explained without the requirement of a stimuli-specific memory store.

1.5 Olfactory Modularity

Two fundamental aims of the current thesis are to (1) establish the hitherto neglected olfactory recognition and recall serial position effects and (2) determine the extent of concordance that olfactory serial position effects demonstrate in comparison to visual and auditory stimuli. The remainder of the chapter, therefore, reviews the evidence for potential olfactory modularity, i.e. why one might predict olfactory serial position effects to contrast with visual and auditory functions.

1.5.1 Working Memory Conceptualisation

As previously detailed, a debate continues regarding evidence for the presence of separate modality-specific systems. Under the working memory conceptualisation, two modality-specific slave systems operate under the control of the central executive. These subsystems process verbal (phonological loop) and visual/spatial material (visuo-spatial sketchpad). Andrade and Donaldson (in press) investigated the extent to which this architecture might accommodate an additional subsystem responsible for the processing of olfactory material. Their paper investigated two key components of olfactory memory. First, Andrade and Donaldson examined the extent to which olfactory STM was reliant upon verbal coding. Second, the authors investigated the presence of a separate olfactory subsystem in working memory. Such an olfactory STM architecture that is not reliant on verbalisation produces a clear hypothesis in a dual-task paradigm. Providing verbal labelling of odours is prevented, verbal STM should be disrupted to a far lesser extent by a concurrent olfactory STM task compared to that of a concurrent verbal STM task.

Andrade and Donaldson employed a dual-task paradigm in order to assess the extent to which modality specific sub-systems can operate simultaneously without a performance decrement. In Experiment 1, participants were required to recall a series of 8-digit lists. Digit recall was performed in 4 different conditions: i) independently, ii) in conjunction with a verbal memory task (recall of a list of letters), iii) in conjunction with a visual memory task (reproduction of a 4x4 matrix pattern) or iv) in conjunction with an olfactory memory task. The olfactory memory task comprised the sequential presentation of two odours, followed at test by a single odour probe. The participant was required to state if that item was presented in the to-be-remembered pair and, if presented previously, was the odour presented first or second within that pair. A recognition task was employed for odours in order to discourage a verbal labelling-based strategy. The visual and verbal tasks were qualitatively different from the odour recognition task as they necessitated item and order recall, i.e. recall of the letter list for the verbal task and reconstruction of the 4x4 matrix for the visual task. Despite the tasks differing qualitatively, the difficulty of the tasks was manipulated (presumably through altering list length, although this is not explicitly stated) so that performance was at 80% across the visual, verbal and olfactory tasks.

The findings demonstrated that digit recall levels were more impaired following the concurrent verbal task than following either the concurrent visual or olfactory tasks. Nonetheless, although a smaller detrimental effect than the concurrent verbal task, both the concurrent olfactory and visual tasks significantly impaired verbal memory. However, the difference in verbal memory impairment induced by the concurrent visual and olfactory task did not differ significantly. It is argued, therefore, that odours can be stored without verbal mediation. If odours were stored via verbal coding it is argued that the concurrent olfactory memory task should impair verbal memory to a similar extent to that of the concurrent verbal memory task. This is because both concurrent tasks are de facto employing the phonological loop component of working memory. However, this similarity was not found, implying that the olfactory task was not dependent on verbal coding (this finding is explored in more detail in Chapter 6, Experiment 4.2). In fact, the concurrent olfactory memory task produced a similar level of verbal memory impairment as the concurrent visual memory task, wherein (under a working memory architecture) the visual task is employing the separate (non-verbal) visual-spatial component.

In Experiment 2, Andrade and Donaldson compared the effects of concurrent odour, visual and verbal memory tasks on odour memory. The authors argued that if olfactory recognition is dependent upon a STM store that is neither verbal nor visual in origin, then (i) an additional olfactory memory task should interfere to a greater extent than either a verbal or visual memory task, and (ii) any interference following the additional visual and verbal memory tasks should be equivalent. The results demonstrated a selective detrimental effect of the concurrent olfactory task relative to the impact of concurrent visual and verbal tasks. The authors argued, therefore, that the findings support the presence of a specialised olfactory subsystem in memory, rather than an olfactory memory system underpinned by verbal recoding. Andrade and Donladson concluded that olfactory information can be stored temporarily in a dedicated olfactory subsystem of working memory analogous to the visuo-spatial sketchpad. Furthermore, they proposed that olfactory representations held within the store can be rehearsed, possibly by the amodal central executive component of working memory.

Consistent with the proposal of an olfactory module, neuroimaging studies have revealed evidence of modality specific differences in cerebral blood flow during olfactory and visual working memory tasks. Dade, Zatorre, and Jones-Gotman (2002) observed engagement of the dorsolateral and ventrolateral frontal cortex during both olfactory and visual working memory tasks. However, only visual working memory produced increased activity in the left superior parietal cortex, whereas olfactory working memory produced specific bilateral activation of the orbitofrontal cortex. Dade et al. (2002) postulated that working memory engages frontal cortical areas irrespective of stimulus modality but neuron populations specific to the modality are activated within the dorsolateral and ventrolateral cortices. The finding is consistent with the working memory conceptualisation of olfactory memory proposed by Andrade and Donaldson (in press). Bilateral activation of orbitofrontal cortex specific to olfactory memory tasks is consistent with the proposed specialised olfactory subsystem of memory (Andrade and Donaldson, in press). However, activation of frontal areas irrespective of stimuli modality is consistent with operation of general executive processes applied to all stimuli.

In contrast to the finding of olfactory memory operating differentially to verbal memory (Andrade and Donaldson, in press), White (1992) and White and Treisman (1997) have provided some evidence that olfactory memory operates analogously to verbal memory. In both studies, participants were given an item recognition and order recognition task. In the recognition task a sequence of items was followed by three single yes/no recognition probes. The order task comprised a sequence of items followed by two adjacent items taken from the preceding sequence. The participant was required to state if the items were in the same or reversed order to original presentation. Both studies found that sequences of 5-odours and 10-consonants showed recency and that performance increased linearly as a function of serial position for both the item and order task. The finding suggests that even if a separate olfactory subsystem exists, the system works analogously to verbal memory, thereby producing serial position function equivalence.

1.5.2 Role for Olfaction

There is evidence demonstrating qualitative differences in olfactory operations/memory that supports the distinct olfactory slave-system proposed by Andrade and Donaldson (in press). For example, early findings indicated that olfactory STM operates qualitatively differently to that for other stimuli. For instance, Engen, Kuisma, and Eimas (1973) found that recognition levels were unaffected by the duration of retention interval (3-30seconds). Similarly, Engen and Ross (1973) found that despite numerous errors at immediate testing, limited subsequent retention loss followed increased intervals of up to 3 months. Such findings suggest that a distinct olfactory-specific memory module may exist. Moreover, an anonymous reviewer has suggested that the chemical origins of olfaction may make the sense an unsuitable one in which to study cross-modal memory comparisons. It is argued that unlike visual and auditory cues, olfactory cues are delivered along chemical channels and that these chemical cues remain within the organ for some time following stimuli presentation. It is proposed that the lingering presence of these items may induce interference and produce misleading findings. The presence of interference may, therefore, result in inherently unstable findings. This additional confound of interference negates any meaningful comparison between non-chemical senses.

One possible explanation for the observed differences is that the role is olfaction is fundamentally different to that of other senses. It has been argued (Schab, 1991) that olfaction has evolved for qualitatively different purposes to that of other senses. These different evolutionary demands produced an olfactory memory system that is qualitatively different to that of other stimuli. Schab (1991) argued that evolutionary demands did not necessitate olfactory identification per se, but rather, evolved to facilitate judgements based upon familiarity and hedonic factors of the stimuli.

Indeed, this view is consistent with Engen and Pfaffman (1960) who investigated the extent to which participants can recognise odour qualities. This was assessed by manipulating the degree to which odours differed, the intensity of the odours and the number of odours presented. The authors trained participants to verbally label odours and found that participants were capable of identifying 16 different verbalised qualities.

More recently, Møller, Wulff, and Köster (2004) have argued that odour memory is organised for a different type of perceptoion compared to that of other senses, specifically that olfaction is tuned to detecting changes in the environment rather than precise recognition/identification of stimuli. This function of olfaction complements the evolutionary argument of olfaction development (Schab, 1991), in that the primary function of olfaction is to detect changes, since inhaling odours not previously encountered constitutes a potential danger. Møller et al. (2004) proposed that in olfaction familiarity with an odour is much more important than identification of the odour, whereas when processing visual and auditory stimuli the opposite is true.

Köster (2005) made the distinction between 'near' and 'far' senses. Olfaction is categorised as a 'near' sense, whereas vision and audition are grouped as 'far' senses. In 'near' senses it is argued that little time exists for complex identification but only an immediate single reaction to danger is required (e.g. fleeing, spitting out, or retracting). For example, items processed though the chemical sense of olfaction can only be perceived once within the nasal cavity. Consequently, in a situation of danger an immediate single response is required. However, in far senses it is possible to perceive the stimuli at a distance (e.g. visually perceive or hear a stimulus) allowing time in which to identify the stimuli and formulate an appropriate reaction from a variety (e.g. hiding, hitting, running, freezing). As a 'near' sense, olfaction does not require a measured identification-based response but necessities an immediate response defined by hedonic and familiarity factors. Köster (2005) concluded that if odour memory is tuned to detecting change, this has qualitative consequences in the study of olfactory memory compared to other senses.

The definition of olfaction as a 'near' sensory experience requiring an immediate response was explored in more depth by Wilson and Stevenson (2006). They argued that olfaction is employed for (1) ingestion, (2) disease avoidance, (3) sex/attachment and (4) hazard warning. These functions are consistent with Köster (2005), as they require an immediate, basic and instinctive, behavioural response that is directly related to survival or procreation (e.g. repulsion to odours such as decomposition due to an association with disease, Rozin, Haidt, and McCauley, 2000).

Köster (2005) argued that odours are not items in the sense that a face is an item, but that the memorial representation only has meaning when associated with a personal situation. It is proposed that studying odours as unitary items out of context may produce atypical and artificial findings not representative of the operations of olfactory memory.

Wilson and Stevenson (2006) provided a more flexible account of olfaction. They argued that olfactory perception is underpinned through plasticity, wherein odour perception relies upon continual learning. Under such an object recognition based account, a nearly endless combination of different odorants can be stored. During perception, the olfactory system is able to (1) encode the patterns of odour receptors that characterise a particular odour, (2) associate this pattern of receptors with a significant biological event, (3) recognise and discriminate that pattern of receptors from another pattern and against different chemical environments and (4) discriminate/recognise under conditions where the stimulus is faded. In Wilson and Stevenson's (2006) account, plasticity is central, such that the perception of odours changes with number of exposures of the same odour. For example, greater familiarity is linked to increased liking (e.g. Rabin and Cain, 1989) and palatable ratings for odours are related to satiety (Duclaux, Feishauer, and Cabanac, 1973, cited in Wilson and Stevenson, 2006). Olfaction is, therefore, conceptualised as more labile than other senses.

In summary, these studies suggest that the role of olfaction and stability of the perception differ qualitatively to that of other stimuli. Such an interpretation would support the existence of a separate olfactory memory system that operates independently.

1.5.3 Odour Encoding Differences

Both the encoding and representation of odours has been argued to influence the uniqueness of odour memory compared to other modalities (e.g. Chobor, 1992). Quantitative differences arise from weak and inefficient initial encoding. Unmylienated olfactory neurons contribute to sluggish perception (see Herz and Engen, 1996, for review) and thereby produce an increase in immediate errors for olfactory stimuli relative to other modalities. Engen and Ross (1973) proposed that odours are stored in a unitary/holistic manner. Specifically, olfactory representations are argued to be encoded as relatively structure-less stimuli. This unitary encoding promotes an all-or-none encoding of the odour, that Chobor (1992) argued, might encourage an increase in immediate errors. However, this same quality may make the olfactory representations more resistant to subsequent confusions; resulting in poor relative immediate memory but largely stable over time and impervious to interference (the interfering role of intervening items is investigated for odours, unfamiliar-faces and pure-tones throughout the experimental sections of this thesis).

The proposal that odours are stored as unitary entities (e.g. Engen and Ross, 1973) is consistent with neurological evidence. Stein and Meredith (1990) found that other modalities (such as visual, auditory and tactile) have a greater propensity for cross-modality interaction than odours. Such dual-coding of stimuli produces stronger memory traces via the combination of stimuli (e.g. Paivio, 1986). This cross-modal integration of stimuli has been shown to occur within the deep layers of the superior colliculus. Superior colliculus integration was demonstrated for visual, auditory and somatosensory information but not olfactory information. The finding illustrates that olfactory memory operates qualitatively differently to that of other senses as it does not appear to utilise cross-modal dual-coding as a means of facilitating memory.

This inefficient all-or-none encoding suggested by Chobor (1992) and Engen and Ross (1973) is evidenced by unreliable performance in odour identification. For instance, it has been demonstrated that participants are unable to identify a particular odour on one occasion, yet correctly identify the odour on a subsequent occasion (Cain, de Wijk, Lulejian, Schiet, and See, 1998).

Nevertheless, this test-retest unreliability reported by Cain et al. (1998) might be explained in terms of weak odour-verbal label associations rather than unstable olfactory representations. Engen and Ross (1973) have demonstrated that this all-or-none encoding produces stable long-term representations. Yes/no recognition of a set of 20+ odours was demonstrated to be relatively stable at approximately 70% over a 1-month retention interval (Engen and Ross, 1973). In this study, participants were presented with 48 different odours at the learning phase. The four groups were then tested either immediately following the experiment, 24h later, 7 days later or 1 month following the presentation phase. The test phase comprised 21 odour pairs from which participants were instructed to indicate the odour in each pair that had been presented in the previous list. Recognition performance was found to be relatively stable, such that the recognition difference between 0 and 30 days was non-significant. This flat odour recognition forgetting function has been replicated for retention intervals of 3-30s (Engen, Kuisma, and Eimas, 1973) and 10minutes to 28 days (Lawless and Cain, 1975). In a similar experiment to the Engen and Ross (1973) study, Shepard (1967) demonstrated that recognition of old versus new pictures began near asymptote for immediate testing but decreased to 50% following a 120-day interval. The finding suggests that olfactory and visual memory differ qualitatively with respect to the effect of retention interval.

However, this apparent disparity in forgetting rates may be due to stimulus-specific characteristics rather than modality differences per se. Lawless (1978) investigated the effect of stimulus complexity by presenting participants with sets of 12 odours, 12 pictures and 12 visual free forms, i.e. single-line shapes. Participants were tested following retention intervals of 20 minutes, 7 days, 4 weeks or 4 months. At test participants received a 2AFC recognition test on each of the 36 stimuli. Lawless (1978) reported parallel forgetting curves for odours and free forms, such that performance levels began at 85-90% and levelled off at approximately 70% following 20 days. Performance levels remained relatively stable over the next 100 days. However, in contrast to odours and free forms, recognition of pictures remained at asymptote following the first 20 days and then declined gradually to a level of approximately 80% after 4 months. The finding suggests that the initial disparity in retention interval effects between olfactory (Engen and Ross, 1973) and visual stimuli (Shepard, 1967) might be due to differences in stimulus complexity. Pictures contain multiple elements and, therefore, produce a qualitatively different forgetting function. However, when the olfactory and visual stimuli both comprise unitary elements, the forgetting functions are analogous. The Lawless (1978) study, therefore, indicates that when stimulus complexity is equivalent, then the evidence for qualitatively different olfactory and visual memorial systems is removed.

However, it is important to note that although complexity of visual imageries can be manipulated, it is not clear how one might define/manipulate olfactory complexity. In the Lawless (1978) paper it is assumed that common odours and free forms have a similar complexity level. However, the basis for this proposed complexity congruency is unclear. Indeed, the similar forgetting functions may not be related to complexity at all.

Nevertheless, the Lawless (1978) findings are supported by Desor and Beauchamp (1974) who argued that the complexity of the stimuli may have underpinned the observed differences between visual and olfactory memory (e.g. Engen and Ross, 1973; Shepard, 1967). Desor and Beauchamp (1974) argued that odours differ to pictures with respect to the level of information that comprises the stimuli. This difference is similar to the disparity in information between coloured patches/tones compared to that of highly patterned stimuli such as faces/melodies. Once more however, the proposition of odours as non-complex stimuli is conjecture as the measure for olfactory complexity is not defined. Nonetheless, this view indicates that comparisons between odours and pictorial stimuli might be fundamentally inequitable, wherein earlier conclusions have been confounded by stimuli complexity. Furthermore, Desor and Beauchamp (1974) also found that following extensive training, participants can greatly improve their differentiation of odours. The finding indicates that the initial quantitative differences at immediate recognition (e.g. Engen and Ross, 1973; Shepard, 1967) might not be due to an impoverished olfactory system relative to other senses but due to limited odour utilisation/training.

The aforementioned reported studies indicate that olfactory perception/memory is impoverished when compared to that of other stimuli. However, these quantitative differences do not, per se, indicate separate memory systems. Inefficient encoding would produce quantitative, but not qualitative memory differences. Such differences could be accounted for in respect to the stimuli or receptive organ, rather than the memory system.

1.5.4 Olfactory Memory Stores: A Long-Term but not a Short-Term Olfactory Store?

Some commentators have argued that olfactory memory may comprise only a long-term component (e.g. Engen, 1982, 1991). Such a unitary store structure differs fundamentally to that of other senses, for which multiple memory stores are proposed. In these multiple store accounts it is proposed that the stores vary in terms of differential decay rates (e.g. see Phillips and Christie's, 1977, duplex conceptualisation).[2] Indeed, Engen et al. (1973) found that the duration of the retention interval (3-30 seconds) exerted only a marginal effect on the ability to recognise a previously presented odour. This flat forgetting function has been replicated for longer retention intervals of between 10-minutes and 28-days (Lawless and Cain, 1975). Differences in the proposed number of memorial stores suggests modularity in olfactory memory, such that a qualitatively different memory system structure for olfactory memory may exist compared to that of other senses.

However, White (1998) argued that the presence of olfactory STM and indeed multiple memory stores in olfaction are demonstrated by four tests. Specifically, capacity differences across stores, coding differences across stores, neurological evidence of different stores and by serial position effects.

(i) White (1998) proposed that capacity disparities for different retention intervals provide evidence of separate short- and long-term memory stores. The existence of a long-term component for olfactory memory has been clearly established (e.g. interval of 10 minutes to 28 days, Lawless and Cain, 1975) and, therefore, the flat forgetting curve reported may simply represent a stable long-term system. In Engen et al. (1973) a flat forgetting function was demonstrated following intervals between 3 and 30 s. Since the olfactory sense is perceptually slower than other senses (in part due to unmylienated neurons, for review see Herz and Engen, 1996), one might argue that the retention intervals employed by Engen et al. (1973)

[2] The extent to which recency is truly reflective of the STS duplex conceptualisation is explored in detail in Chapter 3.

may only be indicative of a STM. It is, therefore, possible that the flat forgetting functions reported across 3-30 s (Engen et al., 1973) and 10 minutes to 28 days (Lawless and Cain, 1975) may be characteristic of storage within separate short-term and long-term memory stores, respectively. Furthermore, White (1998) highlighted that capacity differences are observed between the Engen et al. and Lawless and Cain studies. In Engen et al. (1973) over the 3-30 s retention intervals, memory of 1-odour was shown to be superior to memory for 5-odours. Conversely, when longer retention intervals are employed (e.g. 28 days, Lawless and Cain, 1975) a large number of odours (22-odours) can be retained (at a level of approximately 75%) seemingly independently of list length. The finding provides tentative evidence of capacity differences in short-term and long-term memory.

(ii) White (1998) proposed that short- and long-term memory can be differentiated through coding differences within each store. That is, items in the short-term component are stored qualitatively differently to items held within the long-term store. Jehl, Royet, and Holley (1994) reported that short-term retention of odours is dependent upon similarity judgements. In their study participants were presented with odour test-pair that were either similar or dissimilar and were required to state to what extent the pair comprised identical or different odours. It was found that similar test-pair items were more likely to result in errors than dissimilar items. White (1998) interpreted the finding as evidence that short-term olfactory memory is, at least partly, dependent upon the similarity between items.

In a further study, Jehl, Royet, and Holley (1997) examined the role of verbal labelling in both short- and long-term retention intervals. In this study participants were trained to verbally label odours. One week following the presentation phase, participants were presented with a sequence of 10-odours. A test phase followed either 20 minutes or 24h later, in which the 10 previous odours were presented amongst 10 distracter odours. Participants were required to state which of the 10 odours were presented in the previous list. Although verbal labelling was found to facilitate recognition of odours tested at both short and long intervals, the benefit was found to be greater for longer-term memory (particularly with respect to semantically-cohesive verbal labels). White (1998) argued that the Jehl et al. (1997) finding provides evidence that verbal labelling is an important component in long-term olfactory memory. However, such a finding is not necessarily indicative of multiple systems but merely suggests a strategy of verbal elaboration employed following lengthened intervals. Indeed, this shift in strategy appears intuitively sensible as increased retention intervals provides more time in which verbal elaboration and rehearsal may occur.

(iii) White (1998) argued that separate long- and short-term memory systems can be demonstrated by neuropsychological evidence. For example, with respect to verbal stimuli, amnesic patient H.M. demonstrated a dissociation between short- and long-term memory. Specifically, STM was predominantly intact, whereas H.M. demonstrated an inability to consolidate memories in long-term memory (Milner, 1966). Such a dissociation has yet to be established for olfactory stimuli. However, some evidence has emerged regarding the role of the right temporal lobe in the short-term retention of odours. Carroll, Richardson, and Thompson (1993) presented temporal lobe epilepsy patients with a sequence of 10 odours. At test the 10 odours were represented amongst 10 distracter odours and participants were required to state, on a scale of 1-5, how confident they were that the odour was presented in the previous sequence (i.e. odour recognition). It was found that, although both left and right temporal lobe epileptic patients were impaired relative to controls, right temporal lobe patients were less able to discriminate between nameable target odours and nameable distracter odours. Carroll et al. (1993) concluded that structures within the right temporal lobe are involved in short-term olfactory recognition memory.

The Carroll et al. finding is consistent with Abraham and Mathai (1983) who found a selective impairment to immediate olfactory matching in patients who had suffered damage to the right temporal lobe. In this task, participants were presented with two identical sequences of 4-odours. At test, they were required to match each identical odour from the two sequences. Right temporal lobe lesion patients produced a greater number of errors than left temporal lobe and fronto-parietal lobes lesion patients. The poorer performance in the right temporal lobe group was not due to impaired perception since patients were able to describe the odours.

In contrast, Eskenazi, Cain, Novelly, and Mattison (1986) were unable to replicate the selective impairment to olfactory memory following a right temporal lobe lesion. In this experiment participants were presented with a sequence of 14 odours. At test, these odours were represented amongst 14 distracter odours and the patients were required to recognise the odours that were presented in the original list. The recognition task was given after retention intervals of both 10 and 40 minutes. Lobectomy was found to reduce overall performance but no difference was found between lesions to the right or left temporal lobe. However, it should be noted that the retention interval differed markedly to that of both Carroll et al. (1993) and Abraham and Mathai (1983). In those experiments olfactory memory was tested immediately following the presentation phase, whereas in Eskenazi et al. (1986) the recognition tasks followed intervals of 10- and 40-minutes. It is possible, therefore, that neurological differences between the Eskenazi et al. study and the Carroll et al. (1993) and Abraham and Mathai (1983) studies may be due to the employment of different (short-term and long-term) memorial components. However, these studies fail to investigate short and long-term retention dually and, therefore, have yet to demonstrate convincingly the type of dissociation exhibited by H.M.

(iv) White (1998) cited serial position functions as evidence of memorial distinctions. Specifically, it has been argued that the primacy and recency components of serial recall reflect distinct neurological processes (e.g. Talmi, Grady, Goshen-Gottstein, and Moscovitch, 2005). As reviewed in greater detail later, (see Chapter 3 Introduction) initial claims of an absence of serial position effects in olfactory memory (Gabassi and Zanuttini, 1983, cited in White, 1992; Lawless and Cain, 1975) have been strongly countered (Miles and Hodder, 2005; Reed, 2000; White and Treisman, 1997). Repeated replications of recency in olfactory recognition (e.g. Miles and Hodder, 2005; Reed, 2000; White and Treisman, 1997) might be interpreted as evidence for the existence of a limited capacity highly-accurate olfactory short-term store (STS).

Indeed, White (1998) suggested that a single-store olfactory memorial system should produce a flat serial position function as each item is held identically in the unitary system. However, with respect to serial order effects, such a conclusion is questionable, as factors unrelated to separate stores may produce serial position effects. For example, the probability of transposition errors (i.e. recalling an item in an erroneous, often adjacent, position) is reduced for terminal items (e.g. Smyth and

Scholey, 1996). Since a positional error can only be made to one side of the terminal positions, the probability of making an erroneous response is reduced and consequently accuracy for that item increases. Such an effect is possible within both multiple and unitary memory architectures. Nonetheless, in reviewing the evidence, White (1998) argued that sufficient data exists to support multiple olfactory memory systems, wherein olfactory memory is qualitatively, if not quantitatively, analogous to other modalities.

In reviewing the evidence, olfactory does appear to operate differentially to that of other stimuli. However, the extent to which cross-modal memorial differences demonstrated in the olfactory domain are determined by perceptual difficulties (i.e. qualitative differences induced by encoding difficulties) is yet to be determined. Equally, the extent to which memorial differences constitute a unique olfactory memory module remains currently unresolved.

1.6 Experimental Sections

The current thesis, therefore, reports a series of experiments designed to compare olfactory recognition and serial position recall with that of visual (unfamiliar-faces) and auditory memory (pure-tones). The assumption is made, although this is debated in greater detail in the discussion, that qualitatively different serial position functions for the different stimuli types indicate separate memorial processes.

Prior to the experimental sections of the thesis, there follows a short comment on the range of statistical methodologies employed in the thesis.

CHAPTER 2
STATISTICAL METHODOLOGY

The following chapter outlines the statistical procedures employed throughout the present thesis and the rationale underpinning their use. The shape of the serial position function is analysed via three core analyses, 1) analysis of variance, 2) trend analyses and 3) a primacy/recency analysis. Furthermore, an additional analysis is employed to assess the extent to which an interference-based account might accommodate the function. These analyses are detailed below. Finally, this section also provides details/rationale for the analysis of erroneous responses and employment of *Z*-scores to standardise for performance disparities.

2.1 Serial Position Effects

The present thesis is concerned with the presence of primacy and recency in item recognition and serial position recall. The thesis compares the serial position functions produced for olfactory, visual and auditory stimuli. On the basis of serial position function equivalence/disparity conclusions are drawn with respect to the extent to which the mnemonics are cross-modally equivalent.

However, the statistical method by which one describes the serial position function can have a profound impact upon the theoretical interpretations of serial position functions and the extent to which serial position function congruency/disparities is reported. That is, one analysis may be more stringent in its definition of primacy/recency than another and, therefore, indicate, for example, cross-stimuli differences, whereas another analysis may indicate equivalence.

The serial position literature does not employ a standard analysis employed to determine the presence of primacy and recency. In the recognition domain, recency is clearly defined as a single-item phenomenon: a condition in which recognition for the terminal item is significantly greater than that for pre-recency items (Phillips and Christie, 1977). In Avons et al. (2004) linear contrasts were employed. Here, 2AFC recognition for the terminal item was compared to the mean of the pre-recency items.

In both Reed (2000) and Miles and Hodder (2005), an ANOVA on the serial position function was conducted in conjunction with a trend analysis.

However, how primacy and recency is defined in the serial recall paradigm is less clear. Rundus (1971) described recency as "high recall probability of the last few items of a list" (p. 64) and primacy as the "high probability of recall observed for initial list items" (p. 64). This vague definition is reflected by Kerr et al. (1999) who defined recency as a function "whereby memory is superior for one or more items at the end of the list compared with earlier items" (pg. 1475) and primacy when "memory is superior for one or more items at the beginning of the list in comparison with last items" (pg. 1475).

In the serial order recall domain, therefore, that which constitutes primacy/recency is less clear. Nevertheless, in more recent serial order reconstruction studies, a more consistent method of serial position analysis has emerged. This incorporates an ANOVA on the recall scores and, if a main effect of serial position is found, further analyses are conducted to determine those positions that exhibit significantly greater recall levels (e.g. Smyth et al., 2005; Ward et al., 2005). However, such an analysis may not necessarily provide insight into the shape of the functions. For example, the function may be curved, indicating the presence of primacy and/or recency but the effect of serial position may not reach significance.

A lack of clarity, therefore, exists within the literature with respect to (a) how primacy/recency is defined and (b) how it is statistically determined. In the present thesis three primary statistical analyses have been employed to provide a broader understanding of the shape of the serial position function. Cross-stimuli functional equivalence is determined via an assessment across the three statistical methods and conclusions drawn based upon general trends of equivalence/disparity between the functions. It is conceded that a degree of subjectivity is employed with respect to the acceptance/rejection of functional equivalence when conflict arises between statistical tests. However, the three analyses are reported for each paradigm, in order to give transparency with respect to the conclusions drawn Of course, one might object to such an approach, legitimately arguing that employment of these multiple analyses complicates interpretations. However, in a domain wherein the statistical test can determine their conclusion, multiple analyses provide a richer picture of the serial positions produced.

The serial position effects are analysed via (1) an ANOVA on the serial positions, and, if a significant main effect is evident, further analyses (Newman-Keuls), (2) a trend analysis in which the shape of the serial position function is determined and (3) a primacy/recency analysis whereby recognition/recall for the first and terminal list item is compared to the mean of the non-terminal items (from now on referred to as the "middle" of the function).

(1) Serial Position Analysis

An ANOVA is a common method in which to compare performance for each serial position within a sequence of stimuli (e.g. Avons, 1998; Miles and Hodder, 2005; Reed, 2005; Smyth et al., 2005; Ward et al., 2005). It should be noted that, although widespread, the employment of an ANOVA within this domain violates one of the three primary assumptions underpinning this analysis. For an ANOVA, it is assumed that scores are independent of each other within a treatment (e.g. see Keppel, Saufley and Tokunaga, 1998).

There are two clear reasons why this assumption may be violated. First, for participants' responses to be independent of each other the assumption of independence necessitates that participants have no memory for previous responses. For example, in the 2AFC recognition paradigm participants may consider that they have not made a positive recognition judgement for some time and respond with a positive recognition on that basis (e.g. participants may assume that 50% of test probes are from the previous list). More overtly, in a single-probe serial position recall paradigm, a participant might introspect that they have not responded with serial position 1 for some time, or, have been frequently responding with serial position 2 and, therefore, alter their response accordingly. Therefore, memory for previous responses/patterns of responses (regardless of its veridicality) may govern future answers. This violates the assumption of independence. A second, and more explicit violation, is apparent in the serial order reconstruction (e.g. Smyth et al., 2005; Ward et al., 2005), serial recall (e.g. Miles and Jenkins, 2000) and the modified reconstruction paradigms (described in Chapters 5 and 6). In these tasks the participant is required to recall the serial position of all the items in the preceding sequence. Once a position/item has been responded with, it cannot be employed again. Therefore, early responses in the recall process de facto predict latter recall. For example, if the item that occurred third in the sequence is erroneously allocated to the first serial position, it follows that when the third serial position is probed, an item will be incorrectly allocated to that position as the correct item has already been employed. In these paradigms responses are, therefore, highly reliant upon each other and consequently not independent.

Despite these violations, ANOVAs remain an accepted method in the literature by which to assess serial position effects. It is only with these reservations highlighted that ANOVAs are included within the present thesis as a method to assess serial position effects.

ANOVAs are computed comparing performance for each serial position within the sequence. Following a main effect of serial position, interaction between serial position and testing procedure, or interaction between serial position and modality, further analysis follow. In such an instance Newman Keuls analysis is employed in order to determine if significant differences exist between serial positions.

(2) Trend Analysis

The second analysis of serial position effects is trend analysis. This statistical test was employed by both Reed (2000) and Miles and Hodder (2005) following 2AFC recognition of odours. Trend analysis allows the functional relationship between serial position and recognition/recall accuracy to be explored. Thus, in contrast to comparisons between mean scores, trend analysis encompasses analysis of all the mean scores within a test procedure, focussing upon the overall shape or trend of the results (see, Keppel and Wickens, 2004, pp. 88-109). In essence, trend analysis provides the simplest mathematic description of the pattern (or trend) of the data.

Figure 0.1 provides an example of a linear trend. The line-of-best-fit is termed the linear function because the gradient of change remains consistent along all points of the independent variable (Keppel and Wickens, 2004). In the hypothetical example in Figure 0.1, recognition rates increase equally between each serial position. As serial position increases by one position, recognition (Y axis) rises, on average, by 1.7%. This is demonstrated in the equation of the line, $Y=1.7X + 51.73$. A subsequent *F*-test evaluates the extent to which the variation in the data conforms to the straight line. If the linear trend is found to be significant, an analysis is conducted to determine the extent to which the linear trend provides a complete summary of the relationship between the independent and the dependent variable. If the analysis is found to be non-significant, the researchers may investigate the extent to which the variance can be explained through a curved data trend (e.g. a quadratic trend).

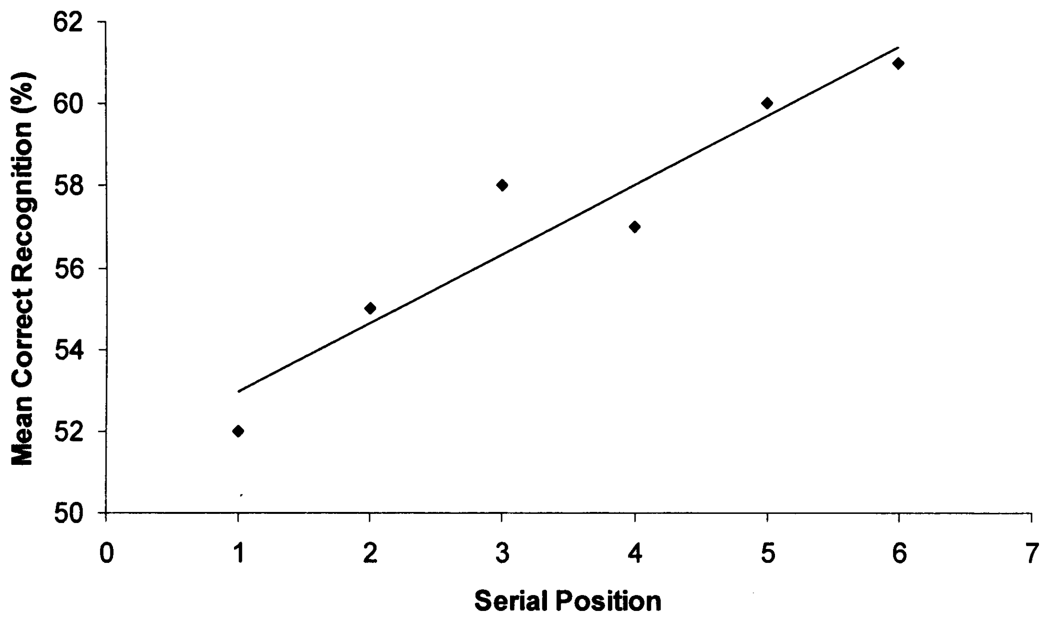


Figure 0.1: Mean percentage correct recognition as a function of serial position (hypothetical data). The line of best fit illustrates the linear trend.

Trends displaying a single concavity or bend are referred to as quadratic trends (Keppel and Wickens, 2004). Thus, rather than a straight line the data suggest a curve. In the most parsimonious form the trend would appear as a U (as depicted in the Figure 0.2 example) or an inverted U shaped curve.

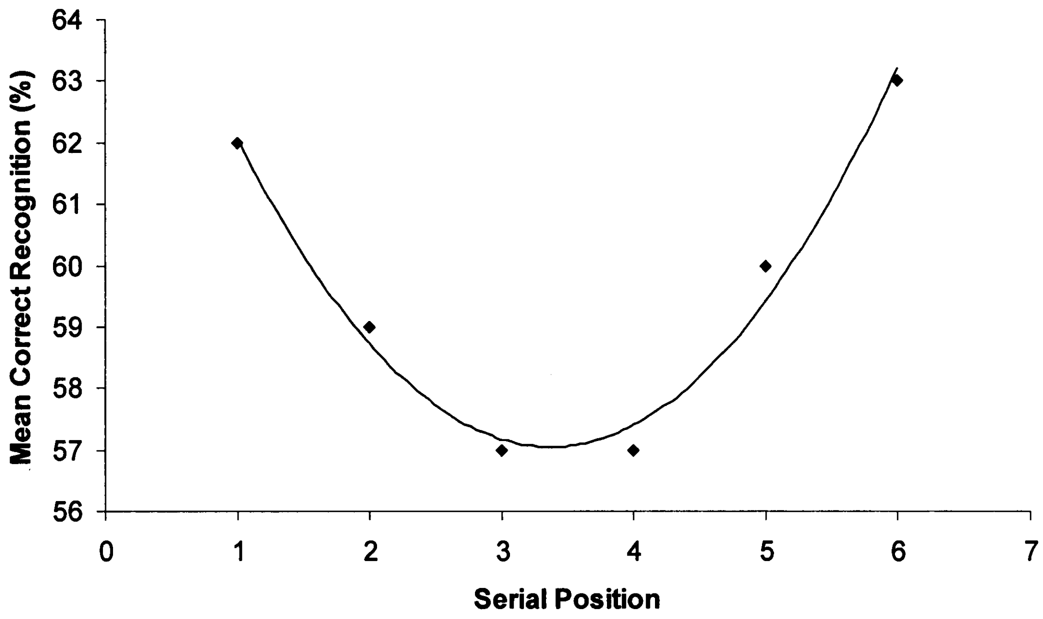


Figure 0.2: Mean percentage correct recognition as a function of serial position (hypothetical data). The line of best fit illustrates the quadratic trend.

The curve, demonstrated in Figure 0.2, can be described through the quadratic function $Y=67.2-6.02X+0.89X^2$. The function is similar to the equation of a straight line except the final function in the equation ($0.89X^2$) provides the quadratic (curved) element. A trend analysis may reveal a significant quadratic component in the absence of a linear component. If a straight line of best fit was presented through the data it would provide an inaccurate account of the data trend, as performance is high at both terminals of the sequence and low in the middle. A straight line of best fit could not reflect such a trend.

However, it is possible that residual variance following a significant linear component can be explained through a significant quadratic trend in the data. For example, both significant linear and quadratic trends may be found. One instance in which this may be observed is the single-item recency function displayed in Figure 0.3. In this function there is a flat serial position effect for early items in the sequence followed by enhanced recognition for the terminal item (recency). In such a pattern, a linear trend might accommodate the mean increase in performance induced by strong recency, whereas the shift from a flat function for pre-recency items to strong recency might produce a significant quadratic trend. These two trend components are demonstrated in Figure 0.3. The trend could be described through a linear equation of a line, whereby Y=52.53+1.23X, or through a quadratic function of the line describing the curvature, whereby Y=58.7-3.4X+0.66. It is argued, therefore, that a single-item recency function can be characterised by both a significant linear and quadratic component and that this is qualitatively different to that of an independent linear or independent quadratic component.

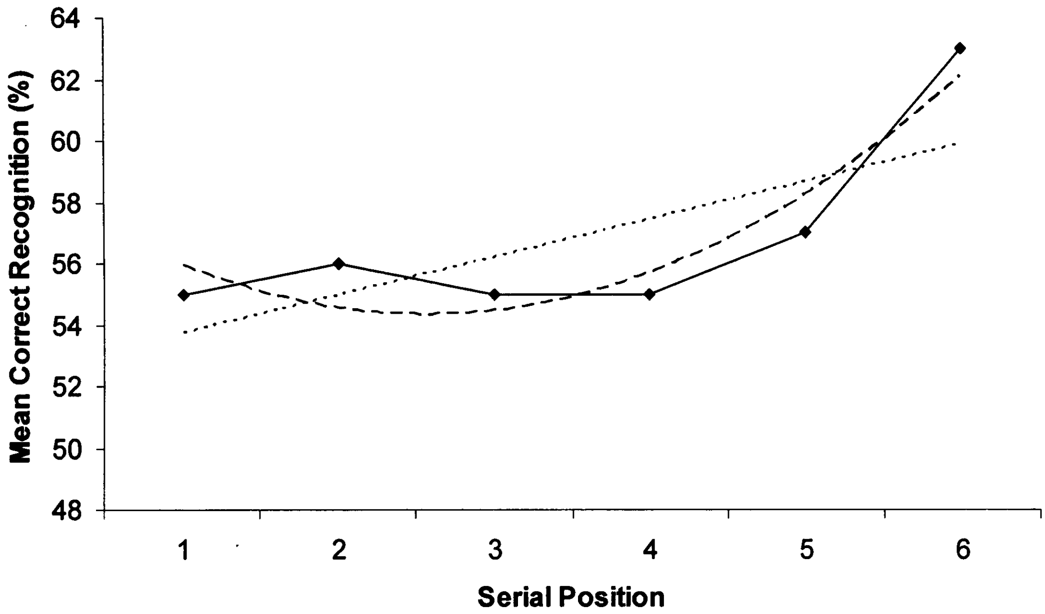


Figure 0.3: Mean percentage correct recognition as a function of serial position (hypothetical data). The dotted line-of-best-fit illustrates the linear trend and the dashed line-of-best-fit illustrates the quadratic trend.

With respect to primacy and recency, a significant linear trend, as depicted in Figure 0.1, might be used to indicate the presence of primacy but no recency or recency but no primacy (depending on a negative or positive gradient, respectively). A linear trend alone is unlikely to support the presence of both primacy and recency. In contrast, a quadratic trend alone as depicted in Figure 0.2 might indicate the presence of both primacy and recency. As previously described, the function produced following both a significant linear and quadratic is more complicated. For such a function it is possible that both primacy and recency may be present. However, it is equally possible that a significant linear and quadratic function might be characterised by recency without primacy or primacy without recency. The important point to emphasise, therefore, is that it is possible to report a quadratic function that does not reflect both primacy and recency. Therefore, since significant trend components do not provide unequivocal evidence of primacy and/or recency per se, it is important to not rely upon trend analyses alone to formulate conclusions. Rather, trend analyses are useful in conjunction with other analyses.

If the data are not fully accounted for through the linear and quadratic analysis, further polynomial equations can be investigated on the residual variance (e.g. cubic function, quartic functions). Keppel and Wickens (2004) stated that the more complicated polynomial trend analyses are rarely employed by behavioural researchers due to the difficulty of reconciling the complex nature of the trend with extant theory. In the present thesis, therefore, only linear and quadratic trends are reported, as there are no theoretical bases for the more complex trends.

In the reporting of trend analyses, when both linear and quadratic functions are present, it is stated in the text. However, only the statistics for the higher order trend (i.e. quadratic) will be reported.

(3) Primacy/Recency Analysis

The third analysis by which serial position effects are assessed is via a paired *t*-test comparison between the list boundary items and the mean of the non-terminal items (an analysis employed by Hanna and Loftus, 1992). Under this analysis, primacy is concluded to be present if recognition/recall for the first item in the sequence is significantly greater than the performance for the mean of the non-terminal items (termed the "middle"). Similarly, recency is concluded to be present if recognition/recall for the terminal/final item in the sequence is significantly greater than the performance for the mean of the middle items.

This additional analysis complements the trend analysis. As previously described, it is possible to obtain a significant quadratic or significant quadratic and linear components without the function demonstrating primacy and/or recency. This primacy/recency analysis assesses if a benefit is present for the first and/or terminal item in the sequence.

2.2 *Z*-Score Comparisons

A fundamental component of the present thesis is cross-stimuli comparisons. In these comparisons the serial position function produced for one type of stimuli is compared to that of another. The comparisons investigate the extent to which qualitatively different functions are produced for different stimuli types, i.e. does the shape of the serial position function change. Performance levels are found to differ across the stimuli types (e.g. odour performance is substantially lower than that for unfamiliar-faces). However, the analysis is not concerned with quantitative differences but only with qualitative differences. If memory for a particular stimuli type was more cognitively taxing, one might predict the serial position function to move down the y-axis. However, if qualitatively different serial position functions are produced, one might conclude that different memory systems/mnemonics are employed.

Since quantitative differences in the serial position functions are not of theoretical importance, cross-stimuli comparison scores are standardised to *Z*-scores. *Z*-scores indicate how far, and in what direction, each score deviates from the mean. The *z*-score is expressed in units of the standard deviation of its distribution and is calculated via the following equation:

$$Z_x = \frac{X - \mu_x}{\sigma_x}$$

Where X denotes the individual score provided by the participant, μ_x the mean score for that testing procedure and σ_x the standard deviation for that testing procedure.

This standardisation removes performance disparities and allows the shape of the serial position to be compared both graphically (i.e. the shape produced can be visually compared without the presentational confound of performance differences) and via an ANOVA (the main effect of stimuli type is now removed). Following cross-stimuli comparisons of standardised scores, one might predict a main effect of serial position, a null effect of stimuli type (due to the *Z*-score standardisation) and, if qualitatively different functions are produced, a significant interaction between serial position and stimuli type.

Z-score standardisations are the default method performed for all cross-stimuli comparisons. To limit unnecessary analyses, comparisons will not be performed on the non-standardised data since performance disparities will only complicate the investigation of functional equivalence.

2.3 Interference-Based Account

In the editorial process of a paper describing the 2AFC recognition task employed in Chapter 3, Lewandowsky (personal communication) suggested that recognition accuracy may be accommodated in terms of an interference–based account. Under this conceptualisation, the number of items intervening between presentation and test predicts recognition of an item. To conduct such an analysis, performance is collapsed across testing procedures and the serial position function re-plotted, with number of items intervening between presentation and test on the x-axis and recognition/recall accuracy on the y-axis. Correlation analyses between number of items intervening and recognition/recall accuracy can then be computed. If a significant correlation is reported, a regression analysis is computed to assess if the number of intervening items predicts recognition/recall accuracy.

In such an analysis it is unclear whether the effect of number of items intervening between presentation and test is due to interference from the intervening items or via time-based decay. However, with verbal recall, Lewandowsky, Duncan and Brown (2004) have found evidence against time qualitatively impacting the serial position function. On the basis of such a finding, this analysis will be tentatively referred to as an interference-based analysis' and employed as a supplementary analysis for both the item-based and order-based tasks.

2.4 Response Distributions

In a recent paper investigating the reconstruction of serial order for unfamiliar-faces, Smyth et al. (2005) reported the distribution of responses for each serial position to assess whether transposition errors were close to the correct serial position. Smyth et al. (2005) found that participants were more likely to allocate an incorrect response to an adjacent serial position. This analysis was conducted for single-probe serial position recall (Chapter 4) and modified-reconstruction (Chapter 5 and 6). This analysis allows one to investigate the extent to which participants encode serial positions in an absolute or relative code. If encoded in an absolute code (e.g. serial position 1) erroneous responses should be equally distributed across all other serial positions. However, if a serial position is coded along a relational spectrum of serial position (e.g. memory for serial position 1 is given a code that relates towards the beginning of the continuous spectrum of serial position) one might predict erroneous responses to be nearer to the correct probe.

The distribution of erroneous responses is determined through calculating the mean displacement distance for each incorrect serial position response. Mean displacement distance is calculated through dividing the number of displacements for a particular number of positions from the correct probe, by the number of opportunities by which that type of error can occur. For example, following a sequence of 4-items, a participant can make an erroneous response that is 1, 2 or 3 positions from the correct probe. However, there are only two opportunities in which a participant can make an erroneous response that is a 3-position displacement, i.e. (1) incorrectly allocating the position 1 probe to position 4 and (2) incorrectly allocating the serial position 4 probe to serial position 1. In contrast, a participant has six opportunities in which to make an erroneous response that comprises a single position displacement from the correct probe, i.e. (1) incorrectly allocating the position 1 probe to position 2, (2) incorrectly allocating the position 2 probe to position 1, (3) incorrectly allocating the position 2 probe to position 3, (4) incorrectly allocating the position 3 probe to position 2, (5) incorrectly allocating the position 3 probe to position 4 and (6) incorrectly allocating the position 4 probe to position 3. Therefore, the mean number of errors for each displacement distance has to be divided by the number of opportunities the participant has to make such an error.

Mean displacement distances for incorrect responses are then compared within a single-factor ANOVA, wherein any main effect of displacement distance is further probed through a Newman Keuls analysis.

2.5 Modified-Reconstruction

In Chapters 5 and 6 a modified-reconstruction paradigm is employed. In this task, participants receive each of the sequence items again at test. At test, these items are re-presented in the same order of original presentation (forward testing procedure), in the reverse order of presentation (backward testing procedure) or in an order that is neither forward nor backward (control testing procedure). The forward testing procedure is argued to be the closest replication of the serial order reconstruction task (e.g. Avons, 1998; Smyth et al., 2005) and is, therefore, of greatest theoretical importance. The backward testing procedure also has some theoretical importance as the terminal sequence item is tested first. This order allows any benefit underpinned from a short-term store (e.g. the duplex theory, Phillips and Christie, 1977) to be investigated. The control testing procedure is employed as a distracter condition, intended to prevent participants from learning the order of presentation. The control testing procedure is, therefore, of limited theoretical importance. In Experiment 3.2, the control testing procedure is discussed in detail but in subsequent experiments is omitted from the analysis. This is done for two reasons. First, graphical representations with only the forward and backward testing procedures are easier to interpret. Second, the ANOVA and the potential interaction between serial position and testing procedure is less complicated and easier to report/interpret following only the forward and backward testing procedure.

2.6 Additional Statistical Information

(1) For all statistics reported in this thesis, a rejection criterion of $p<.05$ was adopted. Statistics are also reported for borderline findings, $.05<p<.1$.

(2) All means are reported to 2 decimal places.

CHAPTER 3:
2-ALTERNATIVE FORCED CHOICE RECOGNITION

Introduction

Overview

Chapter 3 investigates recognition memory for olfactory, visual and auditory stimuli. The genesis of the chapter began with olfactory recognition studies and an intention to clarify the controversy within the literature regarding the presence of primacy for odours (e.g. Miles and Hodder, 2005; Reed, 2000). However, since the 2AFC recognition paradigm employed with odours differed to that conventionally applied to visual stimuli, visual stimuli were then applied to this adapted paradigm in order to ascertain any meaningful comparisons with olfactory memory. This adapted 2AFC recognition paradigm now enabled 2AFC recognition of auditory stimuli to be investigated, an examination not possible with the original Phillips and Christie (1977) paradigm. This adapted paradigm, therefore, enabled a cross-modal investigation that was not previously possible. Since the original Phillips and Christie (1977) 2AFC recognition paradigm cannot be employed cross-modally, the chapter begins with a brief description of other recognition paradigms in which cross-modal comparison is possible. The Phillips and Christie (1977) paradigm is then described and the findings of various studies applying visual stimuli to this paradigm are discussed.

Phillips and Christie (1977) propose a dual-store duplex theory to account for their pattern of results. The adapted 2AFC recognition paradigm employed in the experimental section of this chapter permits a direct empirical assessment of duplex. Consequently, the introduction for Chapter 3 contains a detailed description of the duplex theory followed by a review of the evidence in support of, and in contradiction to, duplex.

The remainder of the introduction for Chapter 3 focuses on the role of verbalisation. If participants re-code stimuli into a verbal code, observed serial position functions may be characteristic of verbal labels for the stimuli rather than memory for the stimuli percept per se. Furthermore, if verbal codes are employed across stimuli types, congruent findings observed cross-modally might disingenuously indicate amodal memory when, in fact, all were characteristic of verbal memory. The role of verbal labelling in olfactory memory is, therefore, discussed. One method by which verbal labelling can be prevented is through the use of non-human animal subjects. The final section in the introduction reviews such studies to assess the serial position functions produced for recognition memory following the removal of verbal contamination.

Human Recognition Studies

General Recognition Paradigms. A range of recognition paradigms have been employed regarding the recognition for hard-to-name stimuli. For example, Hines (1975) presented participants with a sequence of 4 random shapes. At test, an immediate forced-choice recognition task was employed in which the four sequence items were re-presented and intermixed amongst four novel distracter items. Participants were required to indicate which of the items were presented in the previous sequence, i.e. provide familiarity judgements. Hines (1975) reported flat serial position functions with the exception of the terminal item in the sequence, where enhanced recognition was observed (recency). There was no evidence of primacy for these non-verbal stimuli.

In another series of studies, Wright and colleagues (e.g. Wright, Santiago, Sands, Kendrick, and Cook, 1985) employed a single yes/no recognition probe paradigm. Participants received a sequence of visual representations (kaleidoscopic patterns) followed at test by a single probe that was either in the previous sequence or novel. When the test probe immediately followed the sequence, i.e. retention interval of 1000 ms, only recency was observed (e.g. Wright, Cook, Rivera, Shyan, Neiworth, and Jitsumori, 1990, Experiment 1; Wright et al., 1985). The finding further indicates that the function produced for recognition of non-verbal stimuli is characterised by recency but not primacy. However, in a recent study employing a similar single-probe recognition paradigm to that described by Wright et al. (1985), Mondor and Morin (2004) reported both primacy and recency for the recognition of pure tones within a 3-item sequence. The authors argued that primacy was not due to a verbal coding strategy as (1) a performance improvement might have been predicted once participants had learnt to adopt the verbal coding strategy; no performance differences were observed between the first and second half of the experiment, and (2) obtaining a suffix effect dependent on acoustic similarity suggested that items were coded perceptually rather than verbally. This latter argument is relevant only to storage of the terminal item and does not demonstrate, per se, that pre-recency items, particularly the primacy component, were not being coded verbally. In this study the retention interval (including suffix) was relatively long (5000 ms) and equivalent in length to the sequence presentation duration. The pattern may, therefore, be indicative of the transient shift in function shape following increased retention intervals (as proposed by Wright and colleagues). However, since a constant retention interval was employed the extent to which this function is robust over shorter/longer intervals is unclear. For instance, if earlier list items are being coded verbally, a longer retention interval provides greater rehearsal opportunities, thereby facilitating primacy. It remains to be empirically investigated the extent to which primacy remains following shorter retention intervals with fewer rehearsal opportunities.

A further recognition paradigm is known as the oddity task (e.g. McFarland and Cacace, 1995). In this task the participants were presented with three 8-item sequences. Two of the sequences presented were identical and the other sequence differed only by the transposition of two adjacent list items. The participant had to select which sequence was different. The positions of the transposed items varied within the sequence, thereby allowing production of a serial position function. The task necessitates a familiarity judgment and gave rise to both primacy and recency. Primacy and recency components were found for both auditory stimuli and abstract visual patterns. However, the results should not be taken as prima facie evidence of primacy in item recognition as the paradigm is qualitatively different to that employed in the aforementioned recognition tasks. In traditional recognition tasks, the participant is required to make a familiarity judgement based upon whether the test-item is perceived in the previous sequence. In the oddity task, the participant is required to recognise temporal context; that is, not only recognise the item but recognise the position in which the item was situated. (The paradigm is, therefore, an order-based task and not necessarily indicative of non-verbal item recognition.)

In summary, this brief review of recognition studies demonstrates some conflict with respect to the functions produced. That is, evidence for the presence of recency and/or primacy is mixed. Different recognition tasks inherently possess different task constraints and these constraints can themselves determine the serial position function. In the present thesis the 2-alternative-forced-choice (2AFC) recognition paradigm will be employed. However, 2AFC recognition is employed with the caveat, demonstrated by the aforementioned brief review, that any findings can only be generalised to that particular paradigm and not all recognition tasks.

2AFC Recognition. Despite the range of recognition paradigms available, the present thesis will focus upon the 2AFC recognition task. In the 2AFC recognition paradigm, a sequence of items is presented to the participant followed by a test-pair comprising one item from the previous sequence paired with a novel item. The participant is required to make a binary judgment as to which of the two items was presented in the previous sequence. This recognition task was originally established by Phillips and Christie (1977) who presented participants with a sequence of visual hard-to-name patterns constructed within a 4x4 visual matrix. The sequence was followed by a series of 2AFC recognition test-pairs and testing was conducted in the reverse order of original presentation. This produced enhanced recognition for the terminal item in the sequence (single item recency); with equivalent, but reduced performance of pre-recency items. This pattern of recognition was found for sequences of 2, 4 and 8-item sequences. Phillips and Christie (1977) failed to find any evidence of primacy.

Attempts to replicate single-item recency following 2AFC recognition for hard-to-name stimuli have produced mixed results (e.g. see Avons and Daley, 1990; Avons, Ward, and Melling, 2004; Ward et al., 2005). Avons and Daley (1990) presented a series of coloured patches to the participants and employed a series of single yes/no recognition probes presented in the reversed order to original encoding. Single-item recency with no evidence of primacy was found for 3-item sequences of coloured patches (Experiment 1). Employing 4-item sequences (Experiment 2), single-item recency was again observed but with some evidence (although not significant) of primacy. However, when Avons and Daley (1990) employed a single 2AFC recognition task following each trial a flat serial position function was produced (although significantly shorter reaction times were observed for the terminal item compared to positions 1-3). Although the function is, therefore, inconsistent with the single-item recency reported by Phillips and Christie (1977), the terminal item benefit, found for reaction times, suggests some enhanced/superior memory for that terminal item.

The Phillips and Christie (1977) function was also not replicated follwing a single test-pair employing pictorial scenes. Weaver and Stanny (1978) presented participants with sequences of five pictures of similar outdoor scenes. Following a 2000 ms retention interval, a 2AFC recognition task was employed with only the first, middle and terminal pictures used as critical slides within the recognition task. An absence of serial position effects was reported when the duration of stimuli presentation varied across trials (Experiment 1), when stimuli high or low in similarity were employed (Experiment 2) and when the sequence was extended to nine images (Experiment 3). The absence of serial position effects was not governed through performance level (i.e. floor or ceiling effects), since recognition rates neither exceeded 83% nor approached chance (50%). Taken together, these findings suggest that the single-item recency reported by Phillips and Christie (1977) may be an artefact of the backward testing procedure they employed. In the Phillips and Christie (1977) study, recognition for pre-recency items was disadvantaged by (1) being subjected to a greater number of items intervening during the test phase and/or (2) increased susceptibility to decay, as the series of 2AFC test probes intervening between presentation and test increased the retention interval.

In contrast to the Avons and Daley (1990) finding, Avons et al. (2004) reported a large advantage for the terminal list position following a single 2AFC test-pair. In Experiment 1, participants were presented with a sequence of 6 matrix patterns, each for 1500 ms followed by a 500 ms ISI. Two patterns were simultaneously presented at test; one from the previous sequence and one novel. Consistent with Phillips and Christie (1977), orthogonal contrasts revealed that recognition for serial position 6 was significantly superior to that for the mean of positions 1-5. However, contrary to the Phillips and Christie (1977) data, some evidence of negative primacy was found, i.e. the pre-recency function was not statistically flat. In Experiment 3, the procedure was replicated with sequences of 4, 5 and 6 matrix patterns. Sequences of 4 and 5 matrices produced single-item recency consistent with Phillips and Christie (1977), whereas sequences of 6-items replicated the finding in Experiment 1, wherein recency was found in addition to some negative primacy. Similarly, Kerr, Avons, and Ward (1999, Experiment 1a) presented participants with a sequence of 4-matrix patterns (1000 ms on time and 1000 ms ISI) and, following a single 2AFC recognition test, reported single-item recency at immediate testing. Significantly, these findings suggest that recency in the 2AFC paradigm (e.g. Phillips and Christie, 1977) is not an artefact of item interference or item decay due to the presentation of the series of test probes in the backward testing procedure. Expressly, a single test-pair produced a qualitatively equivalent function as a series of test-pairs in the reverse order of presentation.

The aforementioned studies (e.g. Avons and Daley, 1990; Kerr et al., 1999) employed only a single 2AFC test-pair following each sequence. This differs from the original Phillips and Christie (1977) study whereby a series of 2AFC test-pairs are presented in the reverse order of original presentation. Avons and colleagues reproduced this methodology and have replicated the single-item recency function following a series of 2AFC recognition tests presented in the reverse order of presentation. For example, Ward et al. (2005) presented participants with sequences of 5-unfamiliar faces (Experiment 2) and 5-single syllable nonwords (Experiment 4), wherein each item was presented for 1500 ms and followed by a 500 ms ISI. A series of 2AFC test-pairs was presented in the reverse order of original presentation. For both unfamiliar-faces and non-word sequences, the only significant difference between serial positions was superior recognition for the terminal item compared to positions 1-4. Ward et al. (2005) describe the functions as "typical of 2AFC recognition memory, showing no primacy, stable and above chance pre-recency, and limited recency" (pg. 315).

However, recency and no primacy characterising 2AFC recognition (Ward et al., 2005) appears to be an over-generalisation, as the order of test is an important variable in determining the 2AFC function. Specifically, in a series of further studies, Avons and colleagues (e.g. Avons, 1998; Avons and Mason, 1999) gave participants a series of 2AFC test-pairs in the same order as original presentation and repeatedly observed an above chance, yet flat, serial position function, i.e. no recency was observed. Both Avons (1998, Experiment 4) and Avons and Mason (1999, Experiment 2) presented participants with a sequence of 5 6x6 matrix patterns (each presented for 1550 ms and followed by a 460 ms ISI). These patterns differed with respect to whether the squares in the matrix were blank or filled black. At test, a series of 2AFC recognition test probes followed in the original order of presentation; the function produced no main effect of serial position. Furthermore, this serial position function was not qualitatively affected by the degree of similarity between matrix patterns. The flat serial position function was not an artefact of floor or ceiling effects as performance ranged between 71% and 81%. Similarly, Avons and Mason (1999) reported no main effect of serial position. Again, the function was not qualitatively altered by the employment of novel, repeated-similar or repeated-dissimilar matrices. These findings indicate that the order of presentation in which the test-pairs are presented is influential in determining the shape of the serial position function. When the terminal item in the sequence is tested first, a recency component is evident. However, when the items are presented in the same order as original presentation, an absence of serial position effects is found. However, it is important to emphasise that this flat function for forward testing is not due to floor effects as performance is substantially above chance.

In summary, a series of 2AFC recognition test-pairs presented in the reverse order of original presentation (i.e. the Phillips and Christie, 1977, paradigm) consistently produces recency but not primacy. However, when the series of 2AFC recognition test-pairs are presented in the same order of original presentation, an absence of serial position effects are found. Findings are less consistent following a single 2AFC test-pair and this is further evidenced in respect to olfactory memory.

Olfactory 2AFC Recognition. Although in relative infancy, application of the 2AFC paradigm to olfactory stimuli has proven controversial. Reed (2000), using a restricted set of 7 odours, reported evidence of primacy and recency following a single 2AFC recognition paradigm. Primacy and recency was observed following presentation of a 7-odour sequence (each odour was presented for 3000 ms and followed by a 2000 ms ISI) employing a 3000 ms retention interval (Experiment 1). However, Reed (2000) did not provide serial position recognition accuracy comparisons, i.e. post-hoc comparisons, on the basis of (1) a main effect of serial position and (2) a significant quadratic trend analysis. The positions in the sequence that differ statistically are, therefore, not known, i.e. is the main effect of serial position driven by the primacy and recency accentuation? For example, the quadratic function and main effect of serial position might be underpinned via poor serial position 4 recognition rates alone, a finding not necessarily demonstrating primacy and recency in the olfactory domain. Further post-hoc comparisons can serve to eliminate such propositions.

Reed (2000) found the serial position function to be immune to extended retention intervals utilising 6-item sequences; both primacy and recency was evident at both 3 and 60 s delays with no apparent drop in accuracy (Experiment 3). The near identical serial position curves across delays is congruent with earlier research proposing a single unitary memorial system for olfaction unaffected by retention interval (e.g. Engen et al., 1973). However, on closer inspection, the serial position curves of Experiment 3 appear more erratic than the bowed curve described by Reed (2000). Reed (2000) acknowledged that the 60 s retention interval does appear to produce "a rather flat function of serial position" (pg. 415), yet justifies the existence of primacy and recency based upon "greater numbers of participants than would be expected by chance correctly identified the odours from Serial Positions 1, 3, and 6" (pg. 415). This argument is voiced despite recognition rates of serial position 4 and serial position 5 at 70% and 65% respectively (with chance at 50%). In addition, Reed (2000) does not report a trend analysis on the recognition data (despite doing so for the confidence data). For the recognition data, heightened performance for serial position 3 illustrated more of a cubic than quadratic trend for the confidence data. Reed (2000) accepted that "it is unclear what is implied by the greater recognition of the odour at Serial Position 3" (pg. 415). Reed (2000) similarly justified the bowed serial position curve for the 3 s delay, stating that positions 1, 5, and 6 were significantly above chance despite again failing to find a significant main effect of serial position. In the 3 s delay condition, two-item recency is apparent, wherein recognition for serial position 5 is superior to position 6.

In addition, for Experiment 3 of Reed (2000) participants (n=10) were tested only once at each serial position for each delay interval (total of 12 trials) in order to limit olfactory fatigue (which was cited to explain flat performance in Experiment 2). Therefore, each serial position is a product of only 10 between-participant trials. This restriction of trials is introduced despite the quadratic trend and main effect of serial position in Experiment 1 found following 20 trials per participant. It is, therefore, questionable if (1) olfactory fatigue is an issue and (2) if such a significant reduction in the number of trials is justified.

Miles and Hodder (2005) attempted to replicate the findings of Reed (2000) but failed to demonstrate evidence of primacy within the serial position function. In Experiment

1, Miles and Hodder found recency but no primacy following 2AFC recognition for a 5-odour sequence. Odour presentation was reduced from 3000 to 1000 ms in Experiment 2 to investigate if trace decay might account for the absence of primacy. However, decreasing sequence presentation time in the presentation phase (from 25 s in Experiment 1 to 16 s in Experiment 2) resulted in a statistically flat serial position function. The absence of serial position effects was not an artefact of performance reaching ceiling, as recognition accuracy was at approximately 70%.

In Experiment 3, Miles and Hodder (2005) employed sequences of 7-odours in an attempt to replicate Reed (2000, Experiment 2). Miles and Hodder (2005) argued that primacy was present due to trend analysis yielding both significant linear and quadratic components. However, the function produced by significant linear and quadratic functions is qualitatively different to that of a solitary quadratic function. Reported exclusively, a quadratic trend is characteristic of a U-shaped function, indicative of both primacy and recency. In combination, a linear and quadratic trend suggests a function different to that of the U-shaped curve, indicating a linear decline/increase in performance and some curvature in the function (see Chapter 2: Statistical Methodology and also Keppel and Wickens, 2004). In fact, a linear and quadratic function might be more symptomatic of a single-item recency function; flat sub-recency performance and some upturn at the recency component. Furthermore, this conclusion of primacy appears contradictory to the data presented. Recognition rates for the first serial position odour was approximately 67%, marginally less than recognition for the fifth odour (approximately 69%) but superior to positions 2-4 (that vary approximately between 59% and 64%). However, first item recognition is substantially lower than that for positions 6 and 7 (80% and 90%, respectively). In view of the serial position curve, performance appears relatively flat for the first five odours in the sequence with two-item recency.

In Miles and Hodder (2005) it could, therefore, be argued that the significant linear component represents a slight general increment in performance throughout the sequence. In contrast, the significant quadratic component is illustrative of the sharp increase in recognition rates for the last two items in the sequence (80% and 90% for the sixth and seventh position respectively). Unfortunately Miles and Hodder do not provide post-hoc comparisons between the positions; therefore, it is unclear if serial position 1 differs significantly from other sequence items. If the serial position function demonstrated a bowed serial position curve (clearly demonstrating primacy and recency) one might have expected a significant quadratic function but a non-significant linear component. The limited primacy becomes more apparent when compared to Reed (2000, Experiment 1), in which recognition for the first item was at approximately 78% accuracy compared to that of Miles and Hodder at 67%. This was found despite overall recognition rates at 51% and 59% respectively. These studies suggest that the primacy effect following 2AFC recognition for odours is unreliable and difficult to replicate.

Additional Olfactory Recognition Studies. Although not employing the 2AFC recognition paradigm, studies by White and colleagues necessitate discussion. These experiments provide additional insight into recognition for olfactory stimuli, a domain containing relatively few studies. White (1992) gave participants a sequence of 10-odours (each odour was presented for 500 ms and followed by a 2750 ms ISI) followed by 3 single yes/no recognition probes. Employing a sequence of 10-odours, White (1992) reported recency and an absence of primacy[3]. White (1992) found analogous serial position functions (qualitatively but not quantitatively similar) for verbal materials (consonants in Experiment 3 and odour names in Experiments 4-6) presented visually, suggesting that similar mechanisms or strategies may underpin memory for olfactory and verbal stimuli. White (1992) proposed that the difference in performance levels across modalities might be accounted for by verbal material being encoded with greater efficiency.

White and Treisman (1997) replicated the original experiments described by White (1992). In a pilot study, the authors selected a sub-set of odours exhibiting low correct identification rates and fewer generated verbal labels. The findings of White (1992) were replicated, with serial position effects for both verbal stimuli and odours (using 5-item lists). White and Treisman (1997) concluded that "the serial position effects for content and order memory are sufficiently similar in patterns to support the conclusion that STM processing of olfactory and verbal memory is conducted by analogous memory mechanisms" (pg. 459). White and Treisman (1997) argued that

[3]In White (1992) the presence of primacy and recency appear to be defined via observation of the shape of the functions accompanied with a main effect of serial position.

the absence of primacy might be explicable by an inability to rehearse odours as one might with verbal stimuli. However, an absence of primacy is also found for the verbal material and it is conceded that the probed response paradigm may reduce primacy (see Avons, Wright, and Pammer, 1994). The presence of recency is argued to be clear evidence of the existence of olfactory STM.

Evidence for a Duplex Account of STM

The Duplex Theory. As previously described, Phillips and Christie (1977) reported single-item recency following a series of 2AFC recognition pairs presented in the reverse order of original presentation. Contrary to Wickelgren's (1974) theory of a temporally-based, single, smooth decaying memory trace, Phillips and Christie (1977) conceptualised single-item recency via the two-component duplex theory. The theory proposes that attention is allocated to each item when presented serially within a sequence. When a new item in the sequence is presented, attention is shifted from the previous item to the encoding of the new item. The previous item is then displaced from this highly accurate, yet fragile, attentional short-term store (STS) and enters a more durable, but less accurate, long-term store (LTS). Phillips and Christie (1977) suggested that recency reflects the immediate testing of the terminal item in the sequence whilst this item is held within the highly accurate STS. Following reverse testing, intervening items separate presentation and test of all pre-recency items; this causes displacement from the STS into the LTS producing reduced, but consistent, recognition rates for pre-recency items.

The fragility of this attentional store was demonstrated by Phillips and Christie (1977, Experiment 2) following the introduction of a 10 s retention interval. Following the employment of an extended interval between presentation and test, the authors found an interaction between serial position and interval length, i.e. the retention interval, either 0 s or 10 s, qualitatively changed how the serial position function (despite no main effect of interval length). This finding has been replicated by Kerr et al. (1999) employing a single 2AFC recognition pair. Following a sequence of 4-abstract matrices, single-item recency was found for immediate testing. However, after a 5000 ms retention interval recency was attenuated and recognition across positions 1-4 was equivalent. The reduction in terminal item recognition is consistent with displacement of the terminal item from an attentional store into a less accurate LTS.

In their sixth experiment, Phillips and Christie (1977) manipulated both retention interval and presentation time. Although the interaction between presentation rate and serial position failed to reach significance (F=2.17), a comparison was made between the effect of presentation time on position 5 and the effect of presentation time on the mean of positions 1-4. A significant difference was found indicating that the presentation rate affects the long-term stable component of recognition performance but not the recency component. In summary, therefore, a double dissociation between STS and LTS is demonstrated, whereby the increased retention interval failed to affect pre-recency recognition (Experiment 2), whereas manipulation (increase/decrease) of presentation rate affected pre-recency performance independently of terminal item recognition.

Experimental Support for a Duplex Account. As previously described, the testing procedure in the 2AFC recognition paradigm qualitatively modifies the serial position function. A series of 2AFC recognition pairs probing items in the original order of presentation yields an absence of serial position effects, i.e. statistically, a flat serial position function (e.g. Avons and Mason, 1999; Avons 1998). Such a finding is consistent with a duplex account of STM. The terminal item is displaced from the attentional store by a series of intervening test items separating presentation and test of that terminal list item. This displacement eradicates recency. Since all sequence items are then held within the more durable LTS, recognition levels are consistent across positions.

Neurological Support for a Duplex Account. The duplex theory produces strong predictions following imaging. Specifically, recency and primacy should activate different neurological areas. In contrast, it has been suggested (Dwyer and Killcross, personal communication) that the single-item recency function might be explained in terms of an exponential rate of decay in memory trace strength. By such an account, recency should be apparent only when the terminal item in the sequence is tested immediately. Following an increase in delay between presentation and test, evidence for recency should be greatly attenuated due to the rapid decay in the memory trace of the terminal item. An account such as this requires a unitary store in which memory traces decay exponentially. Such an alternative account would not predict that separate neurological areas should be activated following primacy and recency. However, difficulty for this unitary store account can be found in the neurological literature, where a neurological dissociation between recency and primacy was observed. For example, Lee, Jerman, and Kesner (2005) performed axon-sparing neurotoxic lesions of the CA1 and CA3 regions within the rat hippocampus and demonstrated dissociated effects on the serial position curve. Probing of four sequentially presented sections of a maze, it was shown that CA3 lesions in rats disrupted performance of the terminal item in the sequence (recency) only. In contrast, CA1 lesions disrupted performance across all serial positions. Lee et al. (2005) proposed that the CA3 region provides the neurological basis of recency, whereas the CA1 region provides the neurological basis of the pre-recency component of the serial position function. It is further argued that the lack of recency in the CA1 lesion might be explicable via the detachment of the connection between the hippocampus and the prefrontal cortex via CA1.

Similarly, Golob and Starr (2004) found, following a single-item yes/no recognition probe for 5-item auditory sequences, that the peak of auditory cortical N100 wave amplitude was significantly higher for recognition at position 1 (compared to positions 2-5). In contrast, linear increases were observed in late positive waves towards the end of the sequence (i.e. greatest amplitude observed for position 5). Following the neurological dissociation between the primacy and recency components, Golob and Starr (2004) conclude different neurological areas may mediate primacy and recency.

Further evidence for such a recency-primacy dissociation has also been found in fMRI studies. Talmi, Grady, Goshen-Gottstein, and Moscovitch (2005) presented participants with sequences of 12 words, each consisting of 4-8 letters. The sequence was followed by a single yes/no recognition probe word. Unitary recency was reported, demonstrating a memorial benefit when the terminal item was tested first; a finding consistent with much of the aforementioned 2AFC literature. Employing fMRI, Talmi et al. (2005) found medial temporal lobe areas to be more active for earlier probes than for later and control probes. Relative to later probes, earlier probes also demonstrated greater activation, in particular for prefrontal cortex areas. The right inferior parietal lobe was the only area that demonstrated greater activation for later compared to earlier probes. The findings again suggest a double-dissociation in neural activity between the primacy and recency components of the recognition function; an observation that is consistent with the proposed dual-store account of short-term recognition memory. Nevertheless, it is important to emphasise[4] that imaging studies are not definitive as they might simply reflect spectator processes that do not necessarily underpin the operation. However, they do appear consistent with a multiple store architecture.

Problems for a Duplex Account: Extended Recency and the Suffix Effect. The results of a number of experimental studies are difficult to accommodate within a duplex framework. For instance, employing a single 2AFC recognition test for sequences of 5-visual matrices, Avons et al (2004, Experiment 1) demonstrated evidence of a linear function with orthogonal contrasts showing extended recency. Under a strict duplex interpretation e.g. that defined by Phillips and Christie (1977), recency should be confined to the terminal item.

More problematic are studies in which a de facto suffix fails to eliminate the terminal item benefit. In the previously described experiments by White and colleagues (White, 1992; White and Treisman, 1997), presentation of the olfactory and visual sequences was followed by 3 yes/no recognition probes. In these studies the order of positions tested within the 3 test probes was counterbalanced. The findings produce two clear problems for a duplex account. First, similar to Avons et al. (2004) extended recency was found for both verbal and olfactory stimuli. This is contrary to a duplex account as pre-recency items have additional items intervening between presentation and test. These intervening items should displace these pre-recency items from the STS and, therefore, negate any recognition benefit of these items. However, a recognition benefit of pre-recency items was still observed. Second, and potentially more damaging for a duplex account, was the finding of a null effect of order of recognition test probes (White, 1992; White and Treisman, 1997). Under the duplex account, one might predict that recency should only be observed when the terminal

[4] As stated by an anonymous reviewer during the submission process of Experiments 1.1a and 1.1b

item is tested first in the test trio. When the terminal item is probed either second or third in the test phase, the preceding test item(s) should operate as a de facto suffix, displacing that item from the temporary fragile store. Such displacement should result in a recognition performance reduction to a level comparable with that of the pre-recency items. This was not found.

These findings are more consistent with a process account of STM such as temporal distinctiveness (e.g. Neath, 1993). In this model, stores are not delineated but memory is determined via a measure along a single dimension of distinctiveness. Under this account, the distinctiveness of an item (d) dictates how accurately an item is recalled relative to other sequence items. Distinctiveness is determined via a combination of: number of intervening items, ISI and retention interval. Neath provides the analogy of a line of uniformly spaced telegraph poles, whereby the nearest telegraph pole to the observer appears most distinct. However, due to perspective, as the sequence progresses the poles appear less visually distinct. Under such an account, the ratio between ISI and retention interval is important. For example, following immediate testing (where the retention interval and ISI are broadly consistent), a distinctiveness account accurately predicts recency. To use the telegraph pole analogy again, the terminal pole appears close to the observer relative to the other poles. This distinctiveness model can also account for the effect of extended retention interval (e.g. Phillips and Christie, 1977), i.e. the reduction in recency magnitude. Following longer retention intervals, the ratio between the retention interval and ISI is altered. Defaulting to the telegraph pole analogy, the observer now perceives a greater visual distance between themselves and the terminal telegraph pole. Consequently, the terminal pole is less visually distinctive from the preceding row. However, when a longer retention interval is introduced, but the ISI is also lengthened to an equivalent duration, the ratio between retention interval and ISI remains constant. Since the ISI-retention interval ratio is constant, the distinctiveness model predicts that the terminal item retains its enhanced distinctiveness over preceding items. It is under these conditions in which distinctiveness and duplex accounts generate obviously differing predictions. Since the ratio between ISI and RI is unaltered, distinctiveness accounts predict that recency remains. In contrast, a duplex interpretation predicts attenuation of recency since increased retention intervals allows storage of the terminal item in the fragile STS to decay.

One example of this prediction being tested can be found in Miles and Hodder (2005, Experiment 7). A sequence of five odours was presented whilst an interleaving to-be-ignored odour was presented during each 5000 ms ISI. In the control condition, participants did not perform articulatory suppression throughout the 5000 ms ISI. Miles and Hodder (2005) reported a null effect of experimental condition and no interaction with serial positions. Despite no effect of serial position, it is clear from the figure provided that performance is superior for the terminal item in both conditions. Recognition rates of the terminal item (approximately 88%) is equivalent across the interleaving odour and non-distractor conditions and higher than pre-recency recognition levels (<80%). The finding is consistent with a distinctiveness account which predicts that since the ratio between retention interval and ISI remains constant (as an interleaving odour follows presentation of each item), a benefit for the terminal item should still be found. The finding is inconsistent with a duplex account which predicts that the recency component should be attenuated since the interleaving item presented within the retention interval should replace the terminal sequence item within the STS.

Miles and Hodder (2005) argued that their findings in Experiment 7 contradict Walk and Johns (1984) who, using a 4AFC recognition paradigm, interpolated a single odour between presentation and test (but not within each ISI). The interpolated odour impaired recognition memory. However, the Miles and Hodder (2005) and Walk and Johns (1984) paradigms differ qualitatively and generate two distinctly disparate predictions with respect to the duplex and distinctiveness accounts. In Miles and Hodder (2005), the interpolated odour followed each odour in the sequence. Under a duplex account, one might predict that the terminal interpolating odour (following the terminal sequence item) will act as a de facto suffix and thereby remove storage of the terminal sequence item from the fragile STS. This item displacement would result in the terminal item benefit (i.e. recency) being eradicated. However, following equal intervals between each item (in this instance that interval is in the form of an interleaving odour), a distinctiveness account predicts an unchanged level of distinctiveness since the ratio between ISI and retention interval is constant.

In Walk and Johns (1984), both duplex and distinctiveness accounts predict the single suffix item to attenuate recency. Applying duplex, the suffix replaced the terminal list item in the STS and thus removes any benefit enjoyed by the terminal item. Under distinctiveness, the ratio between ISI and retention interval will have altered (due to the suffix extending the interval between presentation and test). Employing the telegraph pole analogy, the terminal pole in the list now appears less distinct in relation to the pre-recency poles. The findings in both Walk and Johns (1984) and Miles and Hodder (2005) are consistent with the distinctiveness account.

Bjork and Whitten (1974) investigated immediate free recall of 10-word lists. Similar to Miles and Hodder (2005, Experiment 7), Bjork and Whitten (1974) added a distracter task following each sequential item, including the terminal item, and found recency remained. Under a duplex framework, the distracter task should have usurped the terminal list item from the limited short-term component. Congruent with the distinctiveness account previously described, Bjork and Whitten (1974) proposed that "long-term recall of a series of inputs to memory will exhibit an effect of recency only if those inputs, from the standpoint of the subject at the time of recall, constitute a well-ordered series" (pg. 188). Therefore, if a list of words is presented to participants at the rate of one word per day for seven days, recall will produce recency if the retention interval is 1 day but not if recall occurs 1 month later. In Neath and Crowder's (1990) ratio rule of temporal distinctiveness, the magnitude of recency is equated to the spacing between items. That is, if the retention interval is held constant, recency will increase following longer ISIs and correspondingly attenuate following shorter ISIs. In the context of Bjork and Whitten (1974), the ratio between the ISI and retention interval remained the same since a distracter task of similar length followed each item, including the terminal item.

Problems for a Duplex Account: The Recency-to-Primacy Shift. A further difficulty for a duplex interpretation comes from those studies demonstrating a shift from recency to primacy over extended retention intervals, as initially reported by Wright et al. (1985). They presented both monkeys and pigeons with a 4-item sequence of travel slides and presented humans with 4-item sequences of kaleidoscopic patterns. Participants were tested via a simple yes/no recognition probe. At immediate testing, unitary recency was reported across species; a finding consistent with the duplex theory. However, as the retention interval was increased (humans to 10 s, pigeons to 1 s and monkeys to 2 s) there was evidence of attenuation in recency and an increase in primacy for all species. Following extended retention intervals (humans to 100 s, pigeons to 10 s and monkeys 30 s), recency was absent but strong primacy was evident for all species. This recency to primacy shift has been replicated following delays of up to 100 s with human participants in a yes/no recognition paradigm for 4-item sequences of abstract pictures (Korsnes and Glisky, 1993) and in a 4AFC serial recall task employing abstract patterns (Korsnes, Magnussen, and Reinvang, 1996). Such studies, suggesting a dynamic primacy component of the serial position curves, are clearly problematic for the duplex theory. Specifically, duplex predicts an absence of serial position effects following extended retention intervals as all list items are held within the LTS.

Wright, Santiago, and Sands (1984) argued that the unitary recency observed for immediate testing is just one stage in the transient serial position function that is governed via both retroactive and proactive interference processes. They suggested that at immediate testing only retroactive interference is present, such that the terminal list item is the only stimulus not subject to interference. They suggested further that an absence of interference for the terminal item results in the development of recency. As the retention interval increases, retroactive interference gradually dissipates and proactive interference develops. These processes together result in a bowed serial position function as the first and terminal positions are the only items subjected to only one form of interference. When the retention interval is lengthened further, retroactive interference completely dissipates such that only proactive interference remains, thereby producing primacy but not recency.

A further challenge for a duplex account is the finding that auditory stimuli produce a primacy-to-recency shift following increased retention intervals (Wright, 1998a, 1998b, 1999a, 1999b, 2002; Wright and Roediger, 2003). This finding further contradicts the duplex account. Under a duplex account, recency is due to storage of the terminal sequence item within the STS. However, following an increased retention interval the item held within the STS fades and performance levels for that item decreases. Contrary to the duplex account, in the aforementioned studies, recency is initially absent but develops over time.

However, the recency-to-primacy shift has received criticism. One might argue that the development of primacy at extended retention intervals may be explained via increased rehearsal opportunities (see Rundus, 1971). In response, Wright and colleagues (Wright et al, 1985; Wright, Cook, Rivera, Shyan, Neiworth, and Jitsumori, 1990) argued that in order for the item to be rehearsed within the lengthened retention interval, a representation of the item must be stored at the beginning of the interval. If such a representation is held, it follows that recognition for that item at immediate testing should correspond with recognition at extended intervals, since the rehearsed representation is the item held at immediate testing. Furthermore, Wright (1998b) argues that non-human participants do not to engage in explicit verbal rehearsal of the items during the retention interval. Nevertheless, the possibility of non-human rehearsal still remained. This possibility was investigated in Wright et al. (1990) utilising the ISI effect; the effect of increased performance following lengthened ISIs due to greater rehearsal opportunities. Following manipulation of ISI duration, Wright et al. (1990) found that increasing the ISI did not significantly increase performance levels in rhesus monkeys yet primacy remained. The finding suggested, therefore, that non-human primacy was not due to rehearsal.

Gaffan (1992) has criticised the work of Wright and colleagues arguing that the first item benefit was an artefact of list initiation by the animals. She argued that sequence initiation heightened the animal's attention to the first item and, therefore, facilitated later recognition for that item. Wright (1994) countered the claim arguing that if list initiation produced primacy then enhanced memory of the first item should have been present at all delays since list initiation was constant for all sequences. However, primacy was observable following increased retention intervals only. Furthermore, Castro and Larsen (1992) did not use an initiating response by rhesus monkeys to commence the presentation of a visual list of miscellaneous objects and, nevertheless, observed both primacy and recency following a 30 s retention interval.

The proposed recency-to-primacy shift does not appear to be a reliable phenomenon. Kerr et al. (1999) failed to demonstrate the recency to primacy shift following a 5 s retention interval prior to 2AFC recognition or a single probe yes/no recognition methodology. The shift was not found for block matrices (Experiment 1A and 1B), for randomised matrices (Experiment 1C), for faces in a randomised design or faces in a mixed (blocked and randomised) design (Experiment 1G). In a sequence recognition paradigm, recency attenuation but not primacy development was found following increased retention intervals for face (Cornell and Bergstrom, 1983) and tactile stimuli (Mahrer and Miles, 1999).

In summary therefore, mixed evidence has been found with respect to the extent to which a duplex account of STM can accommodate the recency observed for 2AFC recognition in the backward testing procedure.

The Role of Verbal Labelling

Olfaction Underpinned by Verbalisation. A further controversy within the domain of short-term recognition concerns the extent to which performance is an accurate reflection of recognition for that modality, or if performance is underpinned via verbal labelling. The problem is recurrent throughout the short-term recognition literature and has already been noted in this thesis with respect to both the development of primacy in the recency-to-primacy shift and the observation of primacy by Reed (2000) in 2AFC olfactory recognition. This issue of verbal labelling is particularly important when investigating olfactory memory, as White (1998) argues; "a classic problem surrounding olfactory theory is the degree to which verbal or visual mediation of olfactory information may have influenced memory performance" (pg. 434).

Schab (1991) provided the example of a cognitively Machiavellian subject who will use any strategy that aids performance; specifically, participants will, whenever possible, generate verbal labels to facilitate memory. Elaboration of the stimulus via a non-olfactory modality may result in a misleading pattern of recognition, reflecting the verbal/visual serial position function rather than a pure olfactory measure. Indeed, if performance is underpinned via verbalisation, qualitative cross-modal similarities will be found in item recognition trends, erroneously indicating analogous cross-modal memory mechanisms. Therefore, due to the confounding influence of verbal semantic elaboration, it is proposed that researchers should be especially interested in the retrieval of hard-to-name odours (Crowder and Schab, 1995).

Mixed evidence exists with respect to the role of verbalisation in olfactory coding. Traditionally, the relationship between odours and verbal labels has been demonstrated as weak. Correct identification of familiar odours has consistently reported an accuracy rate of 50% or less (Cain, 1979; Summer, 1962) even when invoking a liberal scoring system (Lawless and Engen, 1977). In an assessment of the verbal labelling of odours by participants, Engen (1987) claimed that errors in the verbal labelling of odours are inconsistent with a mechanism underpinned by verbal labelling. The results indicate that participants do not categorise in a semantically cohesive manner but in terms of perceptual similarity and similarity to the context in which the odour may be perceived.

This finding of errors being inconsistent with verbal labelling is supported by White, Hornung, Kurtz, Treisman, and Sheehe (1998) who investigated the extent of perceptual/verbal substitution errors in recall. The study was founded upon the assumption that "different memorial representations favour different types of substitutions when an error is made in retrieving a stimulus" (pg. 411). That is, for verbal errors, erroneously substituted items should be phonologically similar (e.g. beef and leaf), whereas if stored in olfactory code, erroneously substituted items should be similar in terms of olfaction (e.g. beef and lamb). Participants learnt to associate odours with non-veridical names and were then given a free recall test following presentation of a test sequence. Substitution errors made in attempting to recall the test odorants were classed as verbal (foils that were verbally similar to the test odour label but not perceptually similar) or olfactory (foils that were perceptually similar to the test odour but not verbally similar to the test odour label). A significant percentage of the errors were perceptual rather than verbal in origin. The authors, therefore, concluded that short-term perceptual encoding, rather than verbal encoding, was employed for olfactory perceptions.

This finding supports clinical studies by Lerner and colleagues who reported a dissociation between odour memory and verbal labelling of odours. Parkinson's disease patients were found to have intact odour recognition (employing an old/new recognition paradigm) but poor odour identification (Lehrner, Brücke, Dal-Bianco, Gatterer, and Kryspin-Exner, 1996). Similarly, no differences in olfactory recognition were found between two HIV infected groups (severely immuno-compromised and

HIV infected patients) and a seronegative control group. However, the severely immuno-compromised group was significantly impaired in odour identification (Lehrner, Kryspin-Exner, and Vetter, 1995). Lehrner et al. (1996) argued that both studies support the proposition that olfactory memory processes can operate without verbal labelling. These findings indicate that olfactory recognition is independent of verbal identification ability.

De Wijk and Schab (1995) have argued that the deficient link between odours and verbal labels results from differing learning strategies for odours compared to other modalities. "In our society, learning to name objects by smell is not as formalised as is visual identification: school children are not taught that this smell is called "apple" and that smell "leather". We usually learn gradually (and usually incidentally, following numerous pairings) that a given object, say ketchup, has a particular smell, rather than that a particular smell identifies the object" (pg. 22).

Engen (1987) proposed that the perceptual nature of olfaction limits the ability to verbalise. For instance, for visual items the individual can recall the colour or shape, but one is unable to recall the sensation of an odour. This is evidenced by the tip-of-the-nose phenomenon (analogous to tip-of-the-tongue) described by Lawless and Engen (1973). They found that unlike the verbal-based impasse, tip-of-the-nose is not alleviated by presentation of a dictionary definition of the item (Jönsson and Olsson, 2005).[5]

Moreover, any evidence for verbal labelling has been found to be idiosyncratic and inconsistent. Cain et al. (1994) reported that the same participants assigned different labels to the same odours when presented on different days. In some instances, different labels were even assigned to the same odours across trials within the same testing procedure. Due to this impoverished linguistic coding of odours, it is argued that linguistic factors play a limited role and, instead, participants employ hedonic factors (Richardson and Zucco, 1989). This is consistent with Jones, Roberts, and Holman (1978) who found a single underlying dimension of pleasantness in recognition for spice odours.

[5] Interestingly, a tip-of-the-finger phenomenon has been recently reported for sign language use with deaf signers, Thompson, Emmorey, and Gollan, 2005.

As an alternative, one might argue that inefficient encoding may explain the apparent poor association between odours and verbalisation. Idiosyncratic perception might, therefore, be responsible for verbal misidentification. Successful verbal identification of an odour is reliant upon unambiguously perceiving the stimulus, successfully recognising that the odour had been presented previously and recalling the verbal label of that percept (Cain, 1977). On this basis it has been argued that odour identification is not as deficient as first claimed. During discrimination, perception of the odour can be distorted by 'noise' and subsequent identification can be further compromised by recognition failures (Cain, 1977). Using a 2-day retention interval, Cain and Potts (1996) switched items and presented for recognition the item that the previously presented odour had been misidentified as. Participants commonly failed to notice the switch and actually identified the switched item correctly. An inefficient coding explanation is consistent with the finding that participants can fail to identify an odour on one occasion yet succeed on another (Cain et al., 1998).

Goodglass, Barton, and Kaplan (1968) presented 27 aphasics with 16 objects for tactile naming, 16 for auditory naming and 16 for olfactory naming. The authors reported that aphasics' naming was generally less than one standard deviation unit apart in all modalities. Goodglass et al. (1968) concluded that a modality non-specific mechanism operates in item identification. This view is contrary to the notion that the olfactory naming process is, in some respect, ineffective compared to the systems operating for other modalities. Inefficient encoding therefore reduces the amount of necessary information reaching the cross modal (or cross-modally analogous) identification mechanism.

In summary, the aforementioned set of findings indicates the olfactory recognition is not reliant upon verbalisation and that olfactory recognition is memory for an olfactory percept rather than a label for the percept.

Effects of Olfactory Verbal Elaboration. The findings regarding verbal elaboration of olfactory stimuli are mixed. Early studies suggested that providing participants with verbal labels at encoding did not aid odour recognition (e.g. Engen and Ross, 1973; see also more recently Ayabe-Kanamura, Kikuchi and Saito, 1997; Zucco, 2003). Lawless and Cain (1975) presented participants with 11 odours and instructed them to either think about the pleasantness of the odour or generate a meaningful verbal label. Following a retention interval of 10-minutes, 1-day, 7-days or 28-days, recognition was not influenced by either duration of interval or method of encoding. Lawless and Cain (1975) concluded, therefore, that odours are stored in a "raw, unencoded form" (pg.335) and differ greatly from the verbal memory system.

Consistent with the Lawless and Cain (1975) finding, Herz (2000) found that switching from the odour to the verbal code at test significantly compromised recall performance. In contrast, switching visual cues to word form produced no decrement in memory. The finding indicates a dissociating effect of verbalisation across the olfactory and visual domain. Furthermore, there is evidence of the perceptual dominance of the olfactory memory trace over verbal elaboration. Miles and Jenkins (2000) trained participants to label and identify a set of odours. At test, participants were instructed to serially recall the odour labels. The authors found both primacy and recency. However, recency was only attenuated following the employment of an olfactory suffix. The finding suggests that items were stored in an olfactory sensory code as only an olfactory suffix, but not a verbal suffix, interfered with terminal item recall.

However, numerous studies have demonstrated that verbal labelling can facilitate odour memory. The ability to label odours has been shown to positively correlate with subsequent recognition (Murphy, Cain, Gilmore, and Skinner, 1991). Indeed, recognition facilitation has been shown to be particularly apparent when the participant free associated a label with the target odour (Walk and John, 1984). Rabin and Cain (1984) found, following retention intervals varying between 10 mins and 7 days, that odour recognition was superior for odours labelled during learning. Furthermore, Larsson and Backman (1997) found that age and odour naming was the best predictor of subsequent odour recognition, demonstrating the assistive role of language in odour memory. It was also reported that controlling for odour naming eliminated the effect of age, indicating that the basis for olfactory recognition deficits in old age may be attributed to verbal-cognitive deterioration.

Verbal elaboration has been found to facilitate odour memory to a greater extent than visual elaboration. Lyman and McDaniel (1986) found that participants instructed to name odours and provide definition for the odour source, demonstrated superior recognition for odours (1 week later) compared to both participants instructed to visually image the odour and control participants who received no elaboration instruction. The finding is argued to be consistent with the dual-coding theory of Paivio (1986), wherein odours are stored in the non-verbal component of memory and odour names held within the verbal store. Since olfactory and visual coding both engage the non-verbal component, the supplementary visual elaboration does not facilitate memory.

Similarly, Jehl et al. (1997) found that odours encoded in association with the name of the odour source (veridical names) and with names generated by the participant facilitated recognition. However, when odours were encoded with the chemical name, no facilitative dual-coding benefit was observed. Jehl et al. (1997) argued that the potential benefit of verbal dual-coding is sensitive to semantic content. Veridical and generated verbal labels are argued to be more likely to stimulate additional representations consistent with the odours, such as visualisations of the odour source and autobiographical memories related to that odour. The finding suggests that the verbal labelling facilitation is not just a product of verbalisation per se but is driven by meaning; indicating a verbal/semantic association with the encoded odour.

These studies indicate that olfactory memory can be facilitated via verbal elaboration. However, this does not demonstrate that olfactory memory is reliant on verbal coding, merely that when an additional stimulus is presented alongside the odour (i.e. the odour label) memory is improved. Such a finding is consistent with a dual-coding conceptualisation (e.g. Paivio, 1986).

Effects of Restricting Odour Verbalisation. An empirical methodology by which odour memory can be assessed with verbalisation restricted, is via the technique of articulatory suppression. Engen, Kuisma, and Eimas (1973) found backward counting (articulatory suppression) during odour presentation to have no detrimental effect on odour recognition. In contrast, Annett and Leslie (1996) and Perkins and McLaughlin Cook (1990) found both recognition for odours and recall of odour names to be impaired by both visual and articulatory suppression. The impact of interference suggests some involvement/connectivity between verbal/visual processing and olfactory memory. If one employs a Working Memory interpretation of this dual-task finding (e.g. Baddeley and Hitch, 1973), it suggests that olfactory memory is not separate to that of verbal/visual memory. Under such a Working Memory conceptualisation, olfactory memory should not be impaired by an additional task employing verbal (phonological loop) or visual stimuli (visuo-spatial sketchpad).

However, an alternative explanation for the detrimental effect of visual/verbal interference in Annett and Leslie (1996) and Perkins and McLaughlin Cook (1990) might be via division of resources. One might argue that the additional task of articulatory suppression reduces cognitive resources (if one assumes it to be a finite resource) available for odour encoding. One method in which to investigate this proposition is to assess the effect of articulatory suppression on the serial position function. If the act of articulatory suppression reduces overall performance, the function will not change qualitatively but merely quantitatively; moving down the y-axis. However, if the function is altered qualitatively, it indicates that articulatory suppression impacts more than just cognitive resources, disrupting a fundamental process by which odours are encoded. This was investigated in two previously described studies of olfactory short-term recognition (Reed, 2000; Miles and Hodder, 2005).

Reed (2000) reported both primacy and recency following 2AFC recognition for odours. Since only 31% of the stimulus set were found to be nameable, Reed (2000) therefore argued that the emergence of primacy was not verbal based (i.e. induced by verbal rehearsal of early list items). Reed (2000) claimed that this argument was supported by the resistance of both the primacy and recency components to articulatory suppression, despite an overall decrement in performance. That is, a non-significant interaction between quiet/articulatory suppression and serial position (Experiments 4 and 5, both Fs<1) was observed. Reed (2000) argued that the U-shaped serial position function was, therefore, characteristic of olfactory, rather than verbal, short term memory. However, although non-significant interactions were observed in both experiments, a dissociation is apparent between the detrimental effect of articulatory suppression on the primacy and recency components.

In Experiment 4, Reed (2000) presented sequences of 5 odours and found that following articulatory suppression recognition for position 5 fell by approximately 5%. In contrast, following articulatory suppression the primacy component decreased by over 15%. This trend is magnified for sequences of 4-odours in Experiment 5, wherein terminal item recognition again decreased by approximately 5%, whereas first item recognition decreased by over 20%. These trends suggest that primacy is compromised to a far greater extent by articulatory suppression than is recency. This dissociation indicates that the primacy component reported is underpinned, to some extent, by verbalisation.

Consistent with Reed (2000), Miles and Hodder (2005) found only a limited detrimental effect of articulatory suppression on recognition rates (Experiment 6). Since participants are unable to suppress whilst perceiving the odours, the authors increased the ISI so that presentation of each of the 5-sequential odours was punctuated by a 5000 ms interval. During these intervals the participant was either required to sit in silence (quiet condition) or repeat the word "the" throughout (articulatory suppression condition). Unlike Reed (2000), where participants were only given 2000 ms in which to suppress, Miles and Hodder (2005) provided increased articulatory suppression time in order to maximise the elimination of verbal rehearsal.

Although Miles and Hodder (2005) reported a main effect of articulatory suppression, importantly, there was a non-significant interaction between serial position and articulatory suppression condition. Both conditions demonstrated a flat serial position function with one item recency, and, arguably evidence of negative primacy in the articulatory suppression condition. Importantly though, Miles and Hodder (2005) again fail to demonstrate any evidence of primacy. Consistent with Reed (2000), articulatory suppression appears to impair the primacy component of the function to a greater extent than the recency component. In fact, Miles and Hodder (2005) acknowledged that although the interaction between articulatory suppression/quiet and serial position was non-significant, there is evidence that the effect of articulatory suppression was not equivalent across serial positions. Recognition for serial position 5 following articulatory suppression is approximately 2% higher compared to the quiet condition. However, the primacy component is reduced by approximately 11% following articulatory suppression. Although the interaction between serial position and articulatory suppression is non-significant, the decrease in the primacy component is suggestive that separate processes may underpin the primacy and recency components in olfactory STM.

The Miles and Hodder (2005) study, therefore, suggests the olfactory recognition serial position function is not qualitatively altered following articulatory suppression. Miles and Hodder (2005) did not observe primacy, however, when primacy has been reported (Reed, 2000) it appears to be differentially impaired by articulatory suppression. The finding suggests that primacy following odour recognition is dependent upon verbalisation, whereas the remainder of the function is not qualitatively changed.

Neuropsychological Evidence of Odour Verbalisation. If olfactory memory is dependent upon verbalisation, one might predict that the left hemisphere – associated with verbalisation – would be activated during olfactory memory tasks. However, neuropsychological evidence of olfactory independence from speech is contradictory. Rausch, Serafetinides, and Crandall (1977) and Abraham and Mathai (1983) both found an impairment of immediate olfactory memory in patients who exhibited damage to the right temporal lobe. The finding indicates that the right non-speech hemisphere is important is olfactory memory. Rausch et al. (1977) found that patients with a left or a right temporal lobectomy performed at a lower rate than controls in odour recognition, implicating the temporal lobe in olfactory memory. However, recognition rates were significantly lower for the right temporal lobe lobectomy group. The dissociation implies olfactory memory is localised in the right cerebral hemisphere and is functionally separate from language areas of the left cerebral hemisphere. If olfactory memory was dependent upon verbal memorial mechanisms, one might predict a greater impairment following the left temporal lobe lobectomy. In contrast, Eskenazi et al. (1986) and Eskenazi, Cain, Novelly, and Friend (1983) reported no difference in performance between the differing hemisphere that had undergone an epilepsy induced temporal lobectomy.

Olfactory Memory in Non-Human Participants. One method by which verbal labelling can be eliminated is via the use of non-human participants. White and Treisman (1997) argued that the existence of a separate olfactory memory for humans (or at least a system not governed linguistically) is consistent with the non-human animals. Many species must employ olfactory memory in the absence of a verbal facility, therefore, White and Treisman argued that "there is no a priori reason why humans alone should lack an olfactory memory" (pg. 469). Indeed, two non-human olfactory memory studies suggest that recency without primacy is evident for both insect and rodent participants. Kaiser and De Jong (1993) exposed Leptopilina boulardi (a parasitic wasp of the Drosophila Larvae) to odours using an olfactometer. By observing behavioural responses, it was concluded that the insects could memorise three different odours presented in a series. When these odours were presented in competition, a preference was observed for the last learned odour. Although this finding does not demonstrate better memory of the terminal sequence item per se (as the insects may remember each odour equally and simply prefer the most recent odour), the finding does at least indicate accurate non-verbal memory of the terminal sequence item.

Another interesting finding regarding the non-human olfactory serial position functions is reported by Fortin, Agster, and Eichenbaum (2002). They reported evidence of recency (in the absence of primacy) in normal rats for both recognition and order judgments of 5-item olfactory judgements. In relative recency judgments the rats were required to indicate which of the two test odours had appeared earliest in the sequence. Rats were superior at decisions that involved the terminal sequence item; demonstrating a linear decrement in performance when pairs of items earlier in the sequence were tested.

In the recognition task, Fortin et al. (2002) gave rats a 2AFC recognition test analogous to Miles and Hodder (2005) and Reed (2000) experiments. Rats were presented with a sequence of 5-odours (exposure of each odour 2.5 mins followed by a 2.5 mins ISI). At test, following a 3 min retention interval, a novel odour and an odour from the previous sequence was presented for a binary judgment. Rats were required to indicate the novel odour in the 2AFC test pair. Rats demonstrated superior recognition for later sequence items and importantly failed to display primacy.

However, there are obviously problems in comparing the absence of primacy in the Fortin et al. (2002) study to that of Reed's (2000) finding. Although the ratios between presentation time and ISI are comparable across studies, in absolute terms, the interval between presentation of the first item and test is far greater in the Fortin et al. study (approximately 23 mins compared to <1min in Reed, 2000) allowing more opportunity for trace decay.

These findings generally suggest that human participants can perform olfactory memory tasks without verbalisation. However, when the opportunity to verbally encode arises participants will seek to facilitate memory via dual olfactory-verbal coding. Due to this propensity, it is important for researchers to limit labelling opportunities to ensure that functions are characteristic of olfactory rather than verbal memory.

Animal Recognition Studies. The employment of non-human animal subjects can also provide insight into the serial position functions produced for other stimuli when verbalisation is removed. In the animal domain, there exists mixed evidence as to the existence of primacy in recognition memory. Employment of the 2AFC recognition task has produced findings broadly consistent with backward (e.g. Phillips and Christie, 1977) and forward 2AFC (e.g. Avons, 1998) in the human domain. Gaffan and Weiskrantz (1980) presented rhesus monkeys (*Macaca mulatta*) with a sequence of 5 3-dimensional junk objects. At test the monkeys were presented with a series of 2AFC recognition pairs testing each sequence item alongside a novel foil in the reverse order of original presentation (analogous to Phillips and Christie, 1977). Gaffan and Weiskrantz (1980) observed a decline in recognition accuracy as distance increased between the acquisition trial and the retention test. Consistent with Phillips and Christie (1977), the recency component was shown to diminish by adding an additional 60 s retention interval. Overman, McLain, Ormsby, and Brooks (1983) presented squirrel monkeys with sequences of 3, 5 or 10 visual items. At test a series of 2AFC recognition pairs were presented testing items in the same order of original presentation (as in Avons, 1998). Consistent with forward 2AFC testing of hard-to-name stimuli by humans (Avons, 1998), Overmans et al. (1983) demonstrated an absence of serial position effects.

In recognition paradigms other than the 2AFC recognition task, differing findings were reported with respect to the presence of primacy. Thompson and Herman (1977) studied the auditory STM of dolphins. The authors employed a same/different response paradigm whereby the animal swam to different locations to indicate familiarity or novelty. Reporting a span of four items, Thompson and Herman (1977) found pronounced recency and a linear decrement in performance as distance increased from the terminal item. In contrast, Sands and Wright (1980a) reported that employing 10-item sequences of coloured pictures (each item was presented for 1000 ms and followed by a 800 ms ISI) and using a single probe same/different recognition paradigm, rhesus monkeys displayed both primacy and recency at immediate testing (retention interval of 1000 ms). However, in this study the recency component was far larger than the primacy component. This trend has since been replicated by Sands and Wright (1980b) employing 20-item sequences, using both a single human and primate subject.

Primate recognition primacy was replicated by Castro (1997) using the same single probe same/different recognition paradigm employed by Sands and Wright (1980a and b). Castro (1997) argued that primacy and recency were present in the baseline condition. However, on closer inspection, performance appears at asymptote for positions 1, 2, 3, and 6 (at approximately 95% accuracy) with a slight drop in accuracy for positions 4 and 5 (to slightly below 90%). Castro (1997) reported that post hoc analysis revealed significantly inferior accuracy for positions 4 and 5, this indicates "the presence of both primacy and recency memory effects" (pg. 679). However, the task appears straightforward for the animals, such that performance is observed at asymptote for all but 2 (out of 6) of the serial positions. The disparate findings between primate 2AFC recognition (e.g. Gaffan and Weiskrantz, 1980) and single probe recognition (e.g. Castro, 1997) indicates that the presence of primacy for primate recognition may be influenced by the paradigm and not generalised across recognition tasks.

The rat recognition data are also contradictory. Roberts and Smythe (1979) employed a 2AFC spatial recognition task in which rats were required to choose between a novel and familiar arm. Rats displayed extended recency for sequences of 3 (Experiment 1) and 6 (Experiment 2) maze arms and importantly demonstrated no benefit for the first list item. However, consistent with the previously described recency-to-primacy shift data, primacy has been shown to develop over lengthened retention intervals following recognition for visual slides by rhesus monkeys (Wright et al., 1984), pigeons (Wright et al, 1985) and capuchin monkeys (Wright, 1999), rat sensory preconditioning (Urushihara, Wheeler and Miller, 2004) and for rat spatial memory (Bolhuis and Kampen, 1988). As previously detailed this effect was not an artefact of list initiation (Castro and Larsen, 1992). At immediate testing these studies produced recency and an absence of primacy, with primacy developing over extended intervals.

Much controversy has surrounded replication of a bowed serial position function, specifically the presence of primacy, for 2AFC recognition (non-matching to sample) by hungry rats (Reed, Chih-Ta, Aggleton, and Rawlins, 1991). Rats visited five goal-boxes and, following a 20 s retention interval, were presented an identical goal box to one in the series (although, to eliminate olfactory cues, not the same item) or a novel goal box. Reed et al. (1991) reported that 8 out of the 11 rats tested displayed both primacy and recency.

However, Gaffan and Gaffan (1992) argued that the variability reported by Reed et al. (1991) was below the variance baseline expected from a binomial model (employing a 2AFC recognition paradigm) and this, therefore, implies potential violations of statistical assumptions. Gaffan and Gaffan (1992) highlight the variability of 0.16 reported for the third serial position. Even though the mean of the position was 3.18 (out of 6), Reed et al. argued that none of the 11 animals performed below chance (3.0). Gaffan and Gaffan (1992) argued that to achieve such low variability (especially with the mean so close to chance) there may have been a methodological flaw that may have included either stimulus preference (in which rats followed the scent of their predecessors), some kind of stimulus preference elicited by all the animals, or some experimental bias (albeit unintentionally).

Rawlins, Deacon, Chih-Ta, and Aggleton (1992) cast further concerns upon the Reed et al. data following a failure to replicate the study. They reported an absence of primacy but clear recency. However, in response, Reed (1992) countered the findings of Rawlins et al. (1992) and argued that they produced a relative reduction in retention intervals and this reduction has been shown to promote recency at the expense of primacy. However, Deacon and Rawlins (1995) again failed to replicate primacy employing the identical 2AFC non-matching-to-sample paradigm reported by Reed et al. (1991). Furthermore, contrary to Wright and colleagues, an increase of retention interval (up to 30 mins for a single probe and 120 mins for multiple probes) by Deacons and Rawlins (1995) failed to produce primacy but did produce attenuation of recency resulting in a flat serial position function.

Reed has since replicated the presence of primacy in rodent memory of flavour sequences. Based upon neophobia, the finding that rats have a reluctance to consume novel flavours, Reed, Croft, and Yeomans (1996) employed consumption volume as an index of familiarity. Reed et al. (1996) reported recency and primacy following extended retention intervals (30 mins to 24 h). However, it should be noted though that an absence of serial position effects, i.e. a statistically flat line, were found at immediate testing.

In summary, when verbalisation capabilities are removed from recognition, i.e. via the use of non-human participants, the presence of primacy is controversial. Congruency with the human domain is most evident in the 2AFC recognition paradigm, such that recency but not primacy is observed when the terminal item from the sequence is tested first. However, the finding of extended recency in these studies is contrary to a duplex account that predicts single-item recency. Nevertheless, these experiments do highlight two important findings; first, recognition memory can produce serial position effects without verbal coding and, second, olfactory recognition memory can operate without verbal labelling/verbal elaboration.

Experiment 1.1a

The present study is designed to further our understanding of the serial position function for olfactory recognition. Notwithstanding the differences in the pattern of findings following Reed (2000) and Miles and Hodder (2005), it is argued that neither study represents a fair test of the duplex theory.

At least two important methodological points differentiate the Phillips and Christie (1977) paradigm from that employed by Reed (2000) and Miles and Hodder (2005). First, unlike Phillips and Christie (1977), both presented participants with a series of odours followed by a single 2AFC recognition test-pair. The single 2AFC test-pair probed recognition only for one of the sequence items per trial, with the order of testing for each position randomised across the experiment. This contrasts with Phillips and Christie (1977), wherein each item in the sequence was tested within every trial alongside a novel item and items were tested in the reverse order to original presentation. Second, in Reed (2000) and Miles and Hodder (2005) the same 8 odours were employed throughout the experiment and their position within the sequence was counterbalanced. Therefore, the participants experienced high familiarity with each item but were required to differentiate familiarity of the previous sequence from general familiarity arising from repeated exposure to the items. In Phillips and Christie (1977), a 4x4 square matrix was employed and a selection of cells within the matrix lighted to create each novel pattern. Novel patterns were, therefore, formed for each trial, such that recognition was based solely upon familiarity of the item within the preceding sequence. The following experiment will seek to address these differences by employing the series of 2AFC test pairs described by Phillips and Christie (1977) and by limiting familiarity through employing a large stimulus set of odours.

In a further test of the duplex account, a second condition was included whereby each sequence item was tested alongside a novel item and these items were tested in the order of original presentation (forward testing procedure as employed by Avons, 1998; Avons and Mason, 1999; Overman et al., 1983). Duplex theory predicts a finding of recency following the backward testing procedure only. This is because the terminal list item is the only item present in the STS at test. For the forward testing procedure duplex predicts a flat serial position function, wherein all sequence items are displaced into the LTS. Therefore, an interaction is predicted between testing procedure (forward and backward) and serial position. Under a duplex conceptualisation, the interaction should be driven by increased terminal item recognition in the backward testing procedure.

It is important to note that this methodology does differ fundamentally to that of Phillips and Christie (1977) at the test phase. In the original Phillips and Christie (1977) study participants received the test pair items simultaneously and the participant was then required to make a familiarity judgment based upon comparisons between these items. However, odours cannot be perceived simultaneously and, therefore, the items in the test pair have to be presented individually. The participant must then compare the test items by storing the first test item in working memory in order to contrast familiarity with the second test odour.

Although Reed (2000) and Miles and Hodder (2005) argued for a limited strategic role of verbal labelling in odour recognition, it is conceivable that verbal elaboration of olfactory traces may be employed to facilitate learning, (e.g. Jehl, Royet and Holley, 1997; Lyman and McDaniel, 1986, 1990). In the present experiment therefore, 120 non-food odours were selected (e.g. gun smoke, lavender, leather) in order to reduce familiarity with the odours and thus limit their ability to ascribe verbal labels to the odours.

Method.

Participants. Twenty-four (12 males, 11 females, 1 transsexual: mean age = 23 years 9 months, 18 non smokers) Cardiff University volunteer undergraduates from a variety of disciplines participated and each received a £5.00 honorarium upon completion of the study. Participants suffering from a blocked nose or cold were excluded.

Materials. One hundred and twenty non-food related odour pots supplied by Dale Air Limited, UK were utilised (see Appendix 1 for a complete list of the odours employed). Each odour was presented as a liquid soaked in cotton wool contained in a vortex cube. Each cube was blue in appearance with identical dimensions of 50mm by 50mm by 50mm. An odour name label was situated on the base of each pot. One face of the cube contained six perforations from which the odour was inhaled. The integrity of the odour within in each pot was maintained by a protective sticker placed over the perforations.

Design. A 2x6 within-subjects factorial design was adopted in a two-alternative forced-choice (2AFC) recognition paradigm. The first factor represents testing procedure (forward versus backward) and the second factor represents serial position (1-6). Testing procedure (forward versus backward) was blocked and each block comprised 10 trials. Order of block presentation was counterbalanced across participants. Each of the 120 odours was presented twice: once in the forward testing procedure and once in the backward testing procedure. The order of odour presentation was randomised for each participant.

Procedure. The odour presentation procedure followed closely that reported by both Reed (2000) and Miles and Hodder (2005) and the testing procedure reflected that described for visual stimuli by both Phillips and Christie (1977) and Avons et al (2004, Experiment 1). Participants were tested individually in a well-ventilated, soundproofed laboratory and sat facing the experimenter with a fan blowing across their face. In order to minimise visual cues, the participant was instructed to fixate on a red spot located on the table 30cm in front of them throughout the trials. For each trial the participant was presented with a sequence of 6 odours. Each odour was presented over a wooden screen located 40cm in front of the participant and held under the nose of the participant for a period of 3000 ms. The participant was instructed to inhale deeply through both nostrils for the duration of each odour presentation. The odour was then replaced behind the screen during which time the participant exhaled. There was an ISI of approximately 2000 ms after which the next odour was presented. This procedure continued to the presentation of the sixth odour.

A retention interval of approximately 3000 ms followed sequential presentation of the 6-odours. For the test phase the participant was presented with a series of 2AFC recognition tests, where one of the test odours was the target-probe odour taken from the previous sequence and the other was a novel odour. Both the rate of presentation of the test odours and the ISI between test-pairs were the same as those employed in the presentation phase. The participant was required to state verbally if the first or the second odour in the test pair was familiar from the previous sequence by responding "first" or "second".

In the forward testing procedure the target odour in the first test-pair presented was the odour presented first in the previous sequence. This procedure was repeated with the second test-pair which comprised the odour presented second in the previous sequence and a novel odour. This pattern of testing continued until each odour in the sequence had been tested against a novel odour. The order of testing was, therefore, identical to the order of presentation. The backward testing procedure followed that described for the forward testing procedure and included the exception that the sequence of test pairs tracked backwards through the sequence previously presented. Thus, the first test pair presented comprised the odour presented last in the preceding sequence paired with a novel odour. The position of the target odour (first or second) within test pairs was randomly assigned with the proviso that it occurred an equal number of times in each position and that there was a maximum of two consecutive trials in which the position of the target odour was unchanged. Each trial was followed by an interval of approximately 12 s and the participant was given the option of a 120 s rest after every 5 trials. The complete experiment lasted approximately 1 h.

Results and Discussion.

Serial Position Analysis

Figure 1.1 shows the mean percentage correct recognition at each serial position for both the forward and the backward testing procedures. A 2-factor (2x6) within-subjects Analysis of Variance (ANOVA) was computed on the correct recognition scores where the first factor represents test procedure (forward versus backward) and the second factor represents serial position (1-6). A null effect of test procedure was found, $F<1$ (forward mean correct recognition = 71.73%; backward mean correct recognition = 71.46%), a main effect of serial position, $F(5,23)=2.88$, $MSe=2.07$, and, more importantly in the present context, the predicted interaction between test procedure and serial position, $F(5,115)=2.53$, $Mse=2.37$.

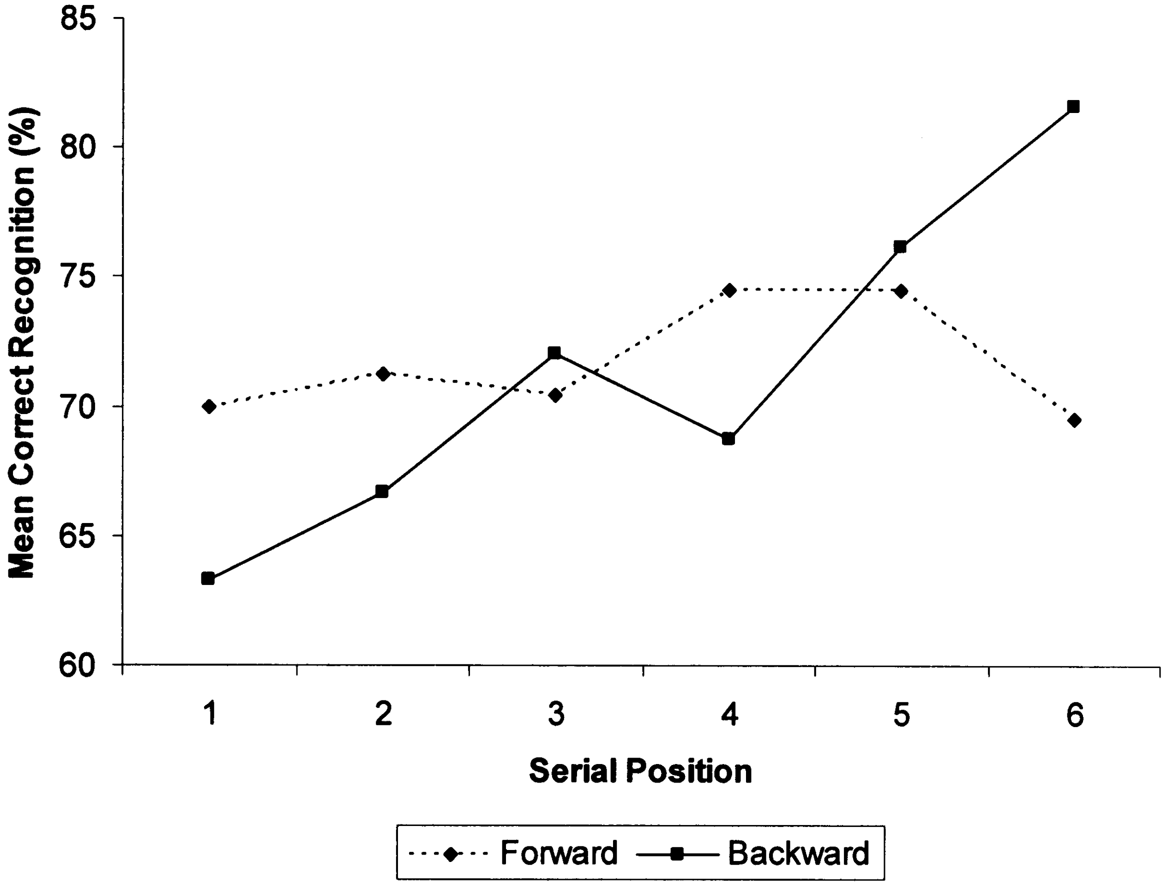


Figure 1.1: Mean percentage correct recognition for the forward and backward testing procedures as a function of serial position.

Further analysis of the interaction (Newman Keuls) showed that for the forward testing procedure there were no significant differences between serial positions. In contrast, for the backward testing procedure, recognition at serial position six was significantly greater than that at serial positions one, two and four. In addition, recognition at serial position five was significantly greater than that at serial position one; indicating extended recency. Pairwise comparisons between the two testing procedures at each serial position revealed a significant difference only at serial position six.

Trend Analysis

Following both Reed (2000) and Miles and Hodder (2005), trend analyses were computed. Trend analysis allows the functional relationship between serial position and correct recognition rates to be assessed. Trend analysis for the forward testing procedure showed both the linear and quadratic components to be absent, both $Fs<1$. In contrast, trend analysis for the backward testing procedure revealed a significant linear component, $F(1,23)=17.28$, $Mse=2.72$ but a non-significant quadratic component, $F<1$. The linear trend and extended recency produced following the backward testing procedure is contrary to the single-item recency predicted by duplex.

Order of Test-Pair Analysis

Further evidence against the duplex account can be found when the position of the probe item in the test pair is analysed. Under a strict duplex interpretation, benefit from storage within the STS should only be observed when (1) the terminal item in the sequence is tested first and (2) when that terminal item is tested first within the test pair. If the terminal item in the sequence is presented second within the test pair, the novel item in the pair would operate as a de facto suffix displacing that item from the STS. Recency, therefore, should only be observed when the terminal item is tested first in the test pair following the backward testing procedure; as this terminal item, held in the STS, will be immediately matched with test item. In the 2AFC recognition paradigm described by Phillips and Christie (1977) the test pair order cannot be assessed as the test pair is presented simultaneously. However, the present methodology permits this additional test of duplex. A paired *t*-test was employed comparing terminal item recognition accuracy following the backward testing procedure when the probe odour was first (recognition accuracy = 80.83%) and when second in the test pair (recognition = 81.67%) and revealed no significant difference, $t(23)=0.14$, $p=.89$. The finding contradicts the difference predicted by duplex.

Olfactory Fatigue Analysis

Following the work of Reed (2000) and Miles and Hodder (2005) the possibility of olfactory fatigue was investigated. Reed (2000) described olfactory fatigue as "the process whereby the participant, due to excessive exposure to olfactory stimuli, becomes insensitive to any further olfactory stimulation and cannot smell any new odours" (p. 414). In the present experiment, recognition for both the first quartile (trials 1-5; mean recognition accuracy = 71%) and for the final quartile (trials 16-20; mean recognition accuracy = 71.4%) was compared and was found to be comparable, $t<1$, failing to provide support for the emergence of olfactory fatigue as the experiment progresses; a finding consistent with Miles and Hodder (2005) but inconsistent with Reed (2000).

Analysis of Blocked Testing Procedure

In the present experiment a blocked testing procedure was employed, whereby participants received blocks of both forward and backward testing procedure trials. It is possible that in the backward testing procedure, participants learned that the latter sequence items were always tested first. To test this hypothesis, an analysis within the blocked backward testing procedure compared recognition accuracy of the last sequence items in the first half of the block (mean recognition accuracy = 81.7%) and the second half of the backward testing block (mean recognition accuracy = 81.7%). The analysis indicated no evidence of learning, $t<1$.

Experiment 1.1b

In order to rule out learning directly, Experiment 1.1b replicated the previous experiment but employed a mixed order design. Throughout the experiment participants received both forward and backward trials at random with the proviso that the same testing procedure was employed on no more than two consecutive trials. Such a design was devised to limit the development of encoding strategies based upon predicting the testing procedure. If the blocking testing procedure has not artificially induced recency in the backward testing procedure, an interaction between testing procedure (forward and backward) and serial position should again be observed.

Method.

Participants. Twenty-four (10 males, 14 females: mean age = 19 years and 11 months, 20 non-smokers) Cardiff University volunteer undergraduates from a variety of disciplines participated and each received a £5.00 honorarium upon completion of the study. None had participated in Experiment 1.1a. Participants suffering from a blocked nose or cold were excluded.

Materials. The materials were as those described for Experiment 1.1a.

Design. The design was as that described for Experiment 1.1a with the exception that the forward and backward testing procedures were mixed within blocks, with the proviso that trials in the same testing procedure did not exceed two in succession. Two orders of trial presentation were employed and counterbalanced across participants.

Procedure. The procedure was as described for Experiment 1.1a.

Results and Discussion.

Serial Position Analysis

Figure 1.2 shows the mean percentage correct recognition at each serial position for both the forward and the backward testing procedures. A 2-factor (2x6) within-subjects ANOVA was computed on the correct recognition scores where the first factor represents test procedure (forward versus backward) and the second factor represents serial position (1-6). A null effect of test procedure was found, $F<1$ (forward mean correct recognition = 68.13%; backward mean correct recognition= 68.96%), and a main effect of serial position, $F(5,23)=2.34$, $MSe=1.62$.

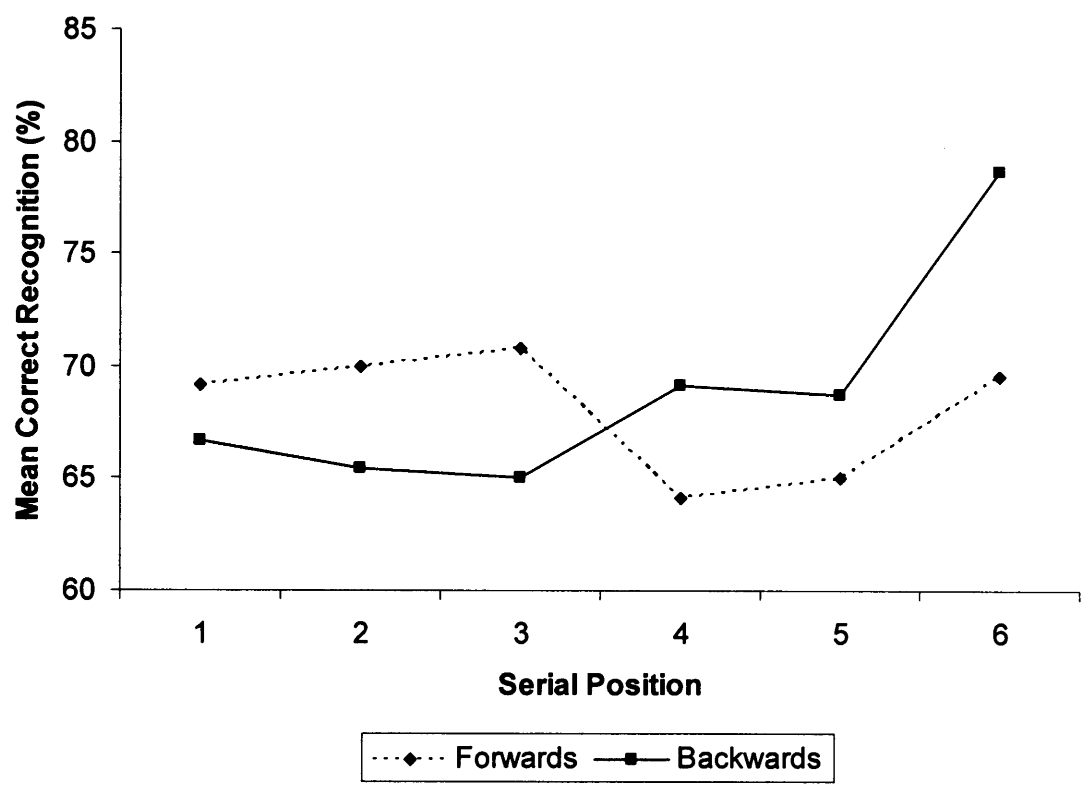


Figure 1.2: Mean percentage correct recognition for the forward and backward testing procedures as a function of serial position.

Trend Analysis

The important predicted interaction between serial position and testing procedure failed to achieve significance, F=1.57. Nevertheless, the pattern of correct recognition for Experiment 1.1b closely follows that observed in Experiment 1.1a: recency in the absence of primacy following the backward testing procedure. Indeed, trend analysis for the forward testing procedure demonstrated both the linear and quadratic components to be absent, both Fs<1. In contrast, trend analysis for the backward testing procedure revealed both quadratic, $F(1,23)=5.84$, MSe= 1.94, and linear components to be significant. Thus Figure 1.2 and the trend analysis for Experiment 1.1b demonstrate that recency observed in Experiment 1.1a for the backward testing procedure was not an artefact of the blocked design.

Order of Test-Pair Analysis

As in Experiment 1.1a, the position of the test probe in the 2AFC pair was investigated. A paired t-test was employed comparing terminal item recognition accuracy following the backward testing procedure when the probe odour was first (mean recognition accuracy = 84.17%) and when second in the test pair (mean recognition accuracy = 77.50%) and revealed a non-significant difference, $t(23)=1.50$, $p=.15$. To reiterate, duplex predicts a difference with respect to when the probe item is first or second, as storage of the terminal item within the STS is displaced when the novel item in the sequence is presented first in the test pair. The finding is again inconsistent with a duplex interpretation of the data.

Olfactory Fatigue Analysis

As in Experiment 1.1a, there was no evidence of olfactory fatigue throughout the 20 trials (360 odour presentations).A paired *t*-test compared recognition rates of the first six trials (trials 1-6; mean recognition accuracy = 66.20%) with recognition rates of the final six trials (trials 15-20; mean recognition accuracy = 70.60%) and revealed a non-significant difference, $t(23)=1.37$, $p=.19$. Six trials were employed in order to contain an equal number of trials in the forward and backward testing procedures.

Analysis of Blocked/Mixed Testing Procedure

To check further that the effect of testing procedure was not a product of blocking trials, the data for Experiment 1.1a were combined with those for Experiment 1.1b. A 3-factor (2x2x6) mixed design ANOVA (experiment × testing procedure × serial position) was computed on the correct recognition scores. The effect of experiment was non-significant, $F=1.46$ confirming the equivalent rates of recognition for both experiments (mean recognition rate of Experiment 1.1a = 71.59%, Experiment 1.1b = 68.55%). Critically, the interaction between experiment, test procedure and serial position was non-significant, $F<1$.

Experiment 1.1a and 1.1b Discussion

Experiment 1.1a and 1.1b succeeded in providing an appropriate test of the duplex theory using olfactory stimuli. As in the original Phillips and Christie (1977) methodology, participants received both novel items within each trial and a series of 2AFC probes at test. The adapted methodology, which employed sequential rather than simultaneous presentation of test-pair items, provided an additional test of duplex. Following backward testing, when the terminal sequence item is presented first in the test pair, a duplex account predicts enhanced recognition due to a match between the test item and the item held within the fragile attentional store. However, when that terminal item is second within the test-pair, the novel item in the pair intervenes between presentation and test of that terminal sequence item. A duplex account predicts that this intervening item acts as a de facto suffix, displacing the terminal item from the STS and into the less accurate LTS. When displaced into the LTS, recognition levels of this item should be equivalent to the pre-rececny items. However, in direct conflict to this duplex account prediction, no significant differences were reported in either Experiment 1.1a or 1.1b between recognition for the terminal sequence item when presented first or second in the first backward test-pair.

In further contradiction to a duplex account, a linear function following backward testing was observed in Experiment 1.1a. This is opposed to the single-item recency function predicted by duplex. A duplex interpretation predicts equivalent, yet reduced, recognition rates of pre-recency items following transfer to the long term store. However, following the backward testing procedure in Experiment 1.1a, there is a general decline in recognition rates, with evidence of extended recency.

This linear function is, therefore, more consistent with single-store accounts of short-term memory (e.g. temporal distinctiveness, Neath, 1993), whereby, in an equally distributed list, more recent items are more distinct and, therefore, recalled with greater accuracy. However, temporal distinctiveness accounts have been questioned by Lewandowsky, Brown, Wright, and Nimmo (2006) who found that increasing temporal isolation of sequence items (i.e. increasing the ISI and, therefore, the temporal distinctiveness of an item) did not, of itself, improve item recall. Rather, the authors propose that output interference during recall influences the serial position function. Indeed, Lewandowsky (personal communication) has argued that the current data set might be explained in terms of number of items intervening between presentation and test of an item. On this account, increasing the number of items intervening between presentation and test should have a detrimental impact on memory.

In the light of this account, the present data were reanalysed wherein the number of items intervening between presentation and test was the independent variable. For example, following the backward testing procedure the terminal sequence item was presented in the first test pair and therefore, on average, 0.5 items intervened between presentation and test. However, for the forward testing procedure, the terminal sequence item was presented following five test pairs and therefore, on average, 10.5 items intervened between presentation and test. By this account, one might predict superior recall for the terminal sequence item following backward compared to forward testing. In addition, extended recency following backward testing is predicted as the number of items intervening between presentation and test increase for pre-recency items. According to this account, combining data across testing procedures should produce a line of best fit that demonstrates a linear decline in performance as the number of items intervening between presentation and test increases. This hypothesis is examined in Figure 1.3(a-b) wherein the relationship between number of items intervening and recognition accuracy for the combined forward and backward data is plotted for both Experiments 1.1a and 1.1b.

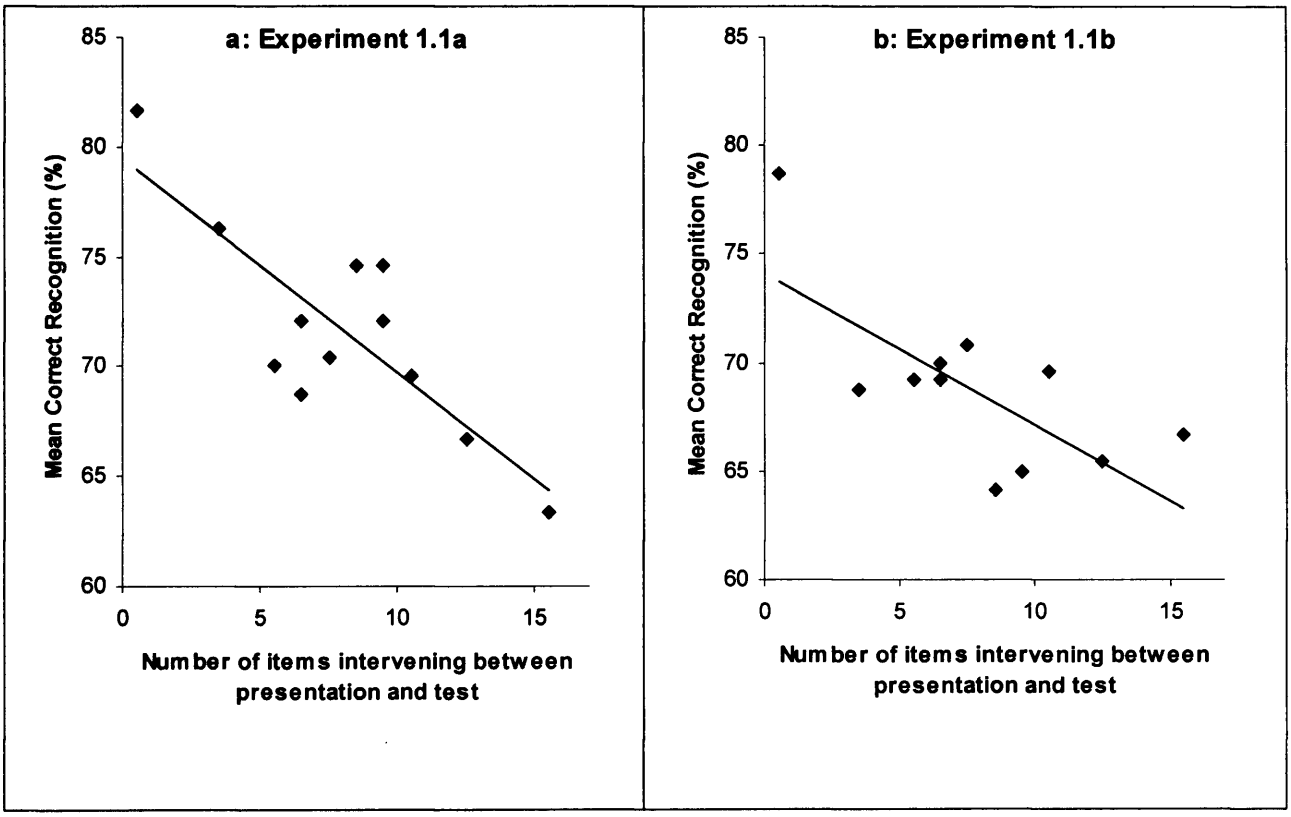


Figure 1.3(a-b): Mean percentage correct recognition for Experiments 1.1a and 1.1b in both the forward and backward testing procedure as a function of the number of

items intervening between presentation and test. The trend line indicates the line of best fit.

A strong significant negative correlation between recognition accuracy and number of items intervening is found for both Experiment 1.1a (R=-0.82, p<.05) and Experiment 1.1b (R=-0.70, p<.05). Following the significant Pearson's correlation, a linear regression was conducted and revealed that number of items intervening between presentation and test was a significant predictor of recognition accuracy for both Experiment 1.1a (R^2=0.67; F(1,10)=20.02, MSe=8.33) and Experiment 1.1b (R^2=0.50; F(1,10)=9.79, MSe=8.64). The data for both Experiments 1.1a and 1.1b are consistent with an intervening-item based account, such that a linear decline in recognition accuracy is observed as number of items intervening between presentation and test increases. This finding is inconsistent with a duplex interpretation.

The current explanation broadens the output interference account (Lewandowsky et al., 2006) to encompass not only self-generated items (i.e. those generated during the recall process) but also items presented after that particular item in the presentation phase and items presented at test as recognition probes. The account in this form fails to differentiate if the effect of items intervening between presentation and test is driven by interference from intervening items or by elapsed time. Lewandowsky et al. (2004) have questioned the role of elapsed time in producing the serial position function. In their study, the speed at which participants recalled a list of items was manipulated and no interaction between recall time and serial position was reported, indicating that elapsed time does not influence the serial position function. Therefore, interference from items output during test, rather than elapsed time, was employed to explain the serial position effects.

Recency following the backward testing procedure in both Experiments 1.1a and 1.1b further substantiated the finding that olfactory 2AFC recognition is characterised by recency when the terminal sequence item is tested first (Miles and Hodder, 2005; Reed, 2000). However, the current findings fail to replicate the presence of primacy reported by Reed (2000) following 2AFC recognition. It is argued that the present data are better explained in terms of the number of items separating presentation and test (as proposed by Lewandowsky, personal communication).

Experiment 1.2

The serial position functions produced for olfactory recognition in Experiment 1.1a and b might be accommodated more effectively by a number-of-interfering-items account of memory rather than dual-store theory. The finding is inconsistent with the employment of other modalities to the 2AFC paradigm, wherein the backward testing procedure produced single-item recency and equivalent, yet reduced, recognition rates of the pre-recency items (e.g. Phillips and Christie, 1977; Ward et al, 2005). This finding demonstrated cross-modal differences and indicates that olfactory and visual 2AFC recognition may be explicable via differing mechanisms.

However, the difference in the serial position function between olfactory and visual stimuli for 2AFC recognition might also be explained via methodological disparities between Experiment 1.1a and b and the aforementioned studies. In previous 2AFC recognition studies employing visual stimuli (e.g. Phillips and Christie, 1977), the test-pair has been presented simultaneously and the participant is required to make a binary judgment with respect to which of the test probes featured in the previous sequence. This methodology could not be applied to olfactory stimuli as when employing odours it is not possible for participants to perceive two odours simultaneously. Therefore, as described in Experiment 1.1a and b, the items that comprised the test-pair were presented individually (and the position of the probe item, i.e. if first or second, was counterbalanced). Since the task was altered slightly at test, i.e. the paradigm no longer allows simultaneous comparison between the test pair, it is possible that the methodological difference underpinned the apparent cross-modal differences.

Therefore, in Experiment 1.2, the altered 2AFC recognition paradigm employed in Experiments 1.1a and b was applied to visual stimuli. Analogous to Experiment 1.1, sequences of 6-unfamiliar faces were presented followed by a series of test-pairs presented either in the original order of presentation (forward testing procedure) or in the reverse order of presentation (backward testing procedure). Presentation time was decreased to 600 ms as a pilot study (n=6), in which faces were presented for 3000 ms, produced performance at ceiling. The presentation time/ISI ratio was kept consistent (3:2) with Experiment 1.1, incorporating ISIs of 400 ms.

If the adapted 2AFC recognition paradigm applied to visual stimuli produced the same function reported by Phillips and Christie (1977), one might again predict a significant interaction between testing procedure (forward and backward) and serial position. Under a duplex conceptualisation, this interaction will be driven by increased recognition for the terminal sequence item in the backward testing procedure.

Method.

Participants. Twenty-four (6 males, 18 females: mean age = 21 years 3 months) Cardiff University volunteer undergraduates from a variety of disciplines participated and each received a £3.00 honorarium upon completion of the study. None had participated in Experiments 1.1(a-b).

Materials. The stimuli set comprised 72 faces of which 60 were employed for experimental trials and 12 employed for a practice trial. The face stimuli were presented in colour. The faces were obtained from a database on the Stirling University website and were Caucasian adult males with short hair and a neutral facial expression. A frontal view of each face was presented individually and centrally on a computer screen with a white background using the experimental program Super Lab Pro 2. The faces were of equivalent size and each appeared within a rectangular frame with the dimensions 115mm by 140mm.

Design. The design was as described for Experiment 1.1b, wherein each of the 60 faces were presented on four occasions throughout the experiment once within each quartile of the experiment.

Procedure. The procedure was analogous to Experiment 1.1a and b. Participants were tested individually in a well-ventilated, soundproofed laboratory and sat at a desk facing the computer screen. For each trial the participant was presented with a sequence of 6 unfamiliar-faces. Each trial was initiated by the experimenter. Each face was presented on a computer screen located approximately 50cm in front of the participant. Each face was presented for a period of 600 ms. The participant was instructed to focus on each face throughout the duration of each face presentation. There was an ISI of 400 ms after which the next face was presented. This procedure continued to the presentation of the sixth face.

A retention interval of approximately 1400 ms followed sequential presentation of the 6-faces. For the test phase the participant was presented with a series of 2AFC recognition tests, where one of the test faces was the target-probe face taken from the previous sequence and the other was a novel face. Both the rate of presentation of the test faces and the ISI between test-pairs were the same as those employed in the presentation phase. The participant was required to state verbally if the first or the second face in the test pair was familiar from the previous sequence by responding "first" or "second".

In the forward testing procedure the target face in the first test-pair presented was the faceimjujik presented first in the previous sequence. This procedure was repeated for the second test-pair which comprised the face presented second in the previous sequence and a novel face. This pattern of testing continued until each face in the sequence had been tested against a novel face. The order of testing was, therefore, identical to the order of presentation. The backward testing procedure followed that described for the forward testing procedure, with the exception that the sequence of test pairs tracked backwards through the sequence previously presented. Thus, the first test-pair presented comprised the face presented last in the preceding sequence paired with a novel face. The position of the target face (first or second) within test-pairs was randomly assigned with the proviso that it occurred an equal number of times in each position and that there was a maximum of two consecutive trials in which the position of the target odour was unchanged. Each trial was followed by an interval of approximately 5000 ms and the participant was given the option of a 1 min rest after every 5 trials. The complete experiment lasted approximately 20 minutes.

Results and Discussion.

Serial Position Analysis

Figure 1.4 shows the mean percentage correct recognition at each serial position for both the forward and the backward testing procedures. A 2-factor (2x6) within-subjects Analysis of Variance (ANOVA) was computed on the correct recognition scores where the first factor represents test procedure (forward versus backward) and the second factor represents serial position (1-6). A null effect of testing procedure was found, $F<1$ (forward mean correct recognition = 86.04%; backward mean correct recognition = 84.86%) and a main effect of serial position, $F(5,115)=4.35$, $MSe=1.01$. Importantly, a significant interaction between serial position and testing procedure was reported, $F(5,115)=5.34$, $MSe=0.83$.

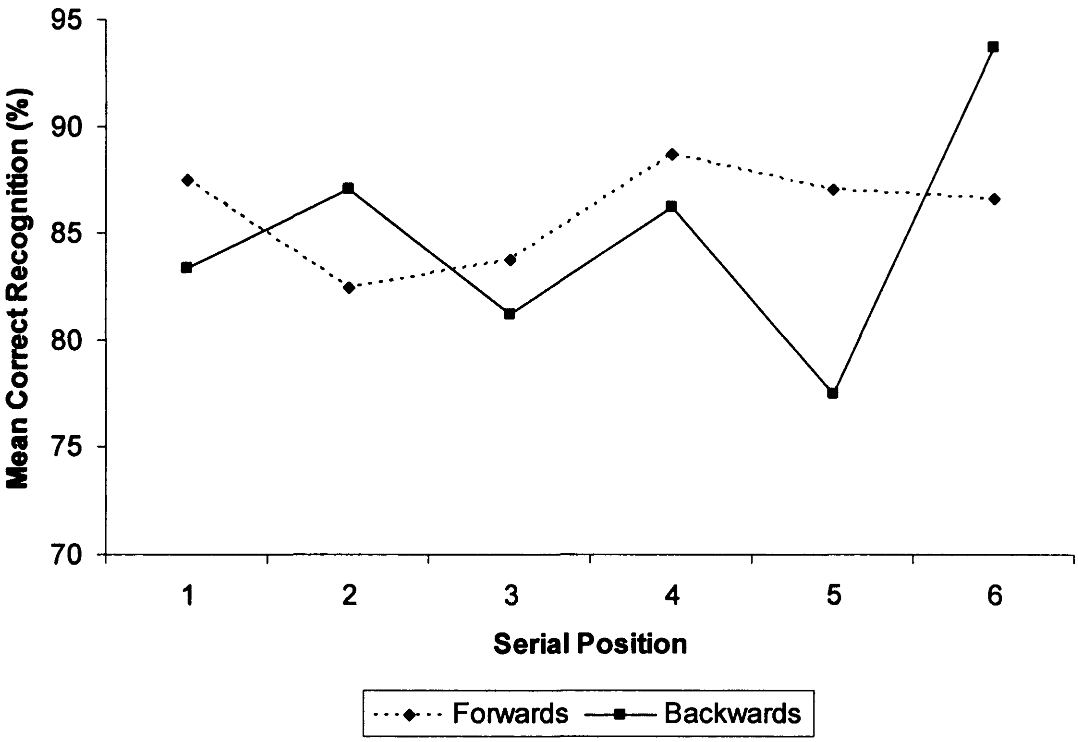


Figure 1.4: Mean percentage correct recognition for the forward and backward testing procedures as a function of serial position.

Further analysis of the interaction (Newman Keuls) showed that for the forward testing procedure there were no significant differences between serial positions. In contrast, for the backward testing procedure, recognition at serial position six was significantly greater than that at serial positions one, two, three, four and five. Pairwise comparisons between the testing procedures at each serial position revealed a significant difference only at serial position five. However, a one-tailed t-test comparison of recognition scores at serial position six (mean correct recall following the backward testing of serial position 6 = 93.75%; mean correct recall following the forward testing of serial position 6 = 86.67%) revealed a backward testing condition advantage, $t(23)=2.60$, $p<.05$.

Trend Analysis

Trend analysis for the forward testing procedure showed both non-significant linear and quadratic trends, both *F*s<1. In contrast, trend analysis for the backward testing procedure revealed a significant quadratic, $F(1,23)=9.23$, $Mse=0.80$, and a borderline significant linear component, $F(1,23)=3.00$, $MSe=0.92$, $p=.10$. The trend analyses are consistent with the predicted quadratic and linear functions for backward testing and flat function for forward testing (see Experiments 1.1a and 1.1b). A mean increase in recognition accuracy as a function of serial position underpinned the linear component and the sharp increase in recognition performance for the terminal sequence item produced the quadratic component.

Order of Test-Pair Analysis

As in Experiment 1.1a and 1.1b an additional test of the duplex theory was employed whereby the position of the test probe in the first backward 2AFC test-pair was investigated. A paired *t*-test was employed comparing terminal item recognition accuracy following the backward testing procedure when the probe odour was first (mean recognition accuracy = 95.83%) and when the probe face was second (mean recognition accuracy = 91.67%) and revealed a non-significant difference, $t(23)=0.57$, $p=.58$. The finding is again inconsistent with a duplex interpretation of the data.

Intervening Items Analysis

It was argued that the pattern of data produced for olfactory stimuli in Experiments 1.1a and 1.1b might be accommodated by an interference-based account (Lewandowsky et al., 2006). Within such an account, the accumulation of items intervening between presentation and test acts as a powerful, negative predictor of recognition accuracy. This analysis, combining data from both the forward and backward testing procedures, was computed for the present data set and the results are plotted in Figure 1.5. A Pearson correlation, in contrast to Experiments 1.1a and 1.1b revealed a non-significant association between recognition accuracy and the number of items intervening between presentation and test ($R=-0.19$, $p=.55$).

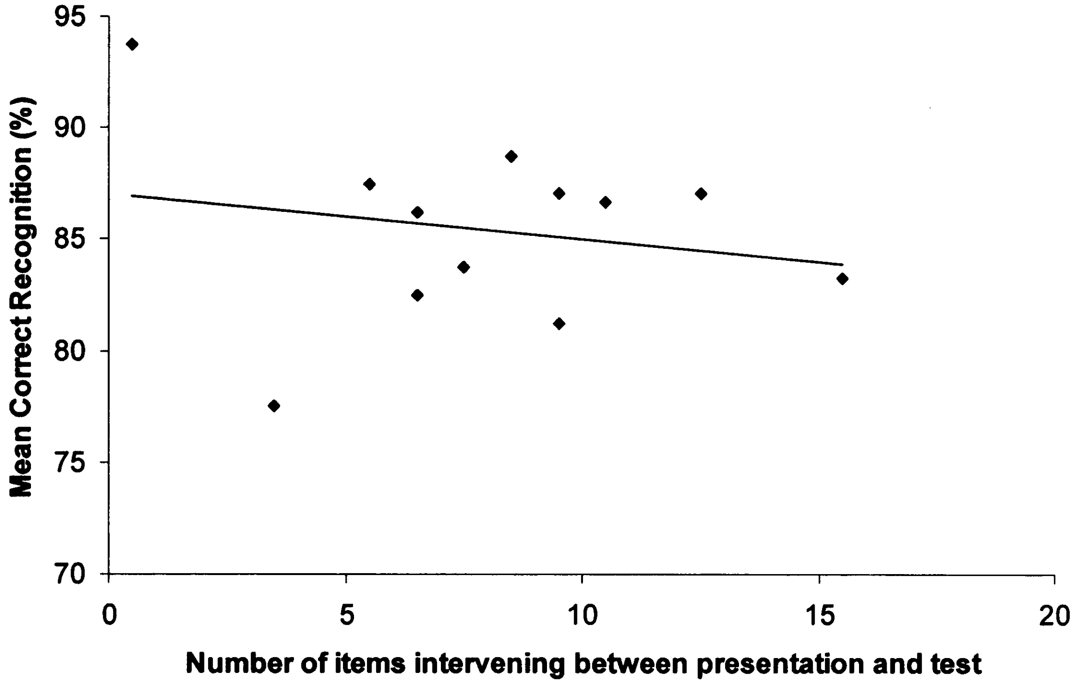


Figure 1.5: Mean percentage correct recognition for both the forward and backward testing procedure as a function of the number of items intervening between presentation and test. The trend line indicates the line of best fit.

The data trend observed in Experiment 1.2 for unfamiliar-faces is inconsistent with both the duplex and intervening items accounts of 2AFC recognition. Unlike previous studies investigating 2AFC recognition for unfamiliar faces, the present paradigm permits an additional test of duplex whereby the effect of position in the test pair can be assessed. This supplementary analysis suggests that recency for unfamiliar faces following the backward testing procedure is not a product of a fragile STS. Nor, unlike the olfactory data, can the present data be accounted for by the number of items intervening between presentation and test. The findings suggest that, although superficially the functions produced for odours and unfamiliar faces appear congruent, they are underpinned via different mechanisms/mnemonics.

Experiment 1.3

The findings from Experiment 1.2 raised serious doubts with respect to whether the duplex account (Phillips and Christie, 1977) provides an adequate account of recency in the 2AFC recognition paradigm. Duplex predicts that when the terminal item is tested first in the backward testing procedure, recognition would be significantly greater when the test probe is presented first in the test-pair compared to when second. This was not found. Therefore, despite storage of the terminal sequence item within the STS being overwritten by the distracter intervening item, a recognition benefit is still observed. This additional analysis of duplex was not possible in the original Phillips and Christie (1977) paradigm, therefore, one might argue that the analysis in Experiment 1.2 provides evidence that duplex cannot account for the original Phillips and Christie (1977) data.

However, an important caveat to emphasise is that the original Phillips and Christie (1977) study differs qualitatively to that described in Experiment 1.2. In Phillips and Christie (1977) the test-pair items were presented simultaneously, whereas in Experiment 1.2 the test-pair items were presented sequentially. In Phillips and Christie (1977) therefore, the participants were able to make the binary judgment based upon simultaneous comparisons between memorial representations of the test-items. Due to sequential presentation, this was not possible in Experiment 1.2. It is therefore conceivable, that these disparate test constraints induce a shift in strategy between the Phillips and Christie (1977) and the Experiment 1.2 paradigm. In short, although duplex cannot account for the recency observed in Experiment 1.2, it is conceivable that duplex may still account for performance in the Phillips and Christie (1977) paradigm.

In Experiment 1.3 the simultaneous presentation of test-pair items (Phillips and Christie, 1977) is compared to the sequential presentation of test-pair items (Experiment 1.2). In both conditions unfamiliar-faces are employed with identical presentation and ISI durations; the conditions differ only with respect to whether the test-pair items are presented sequentially or simultaneously. The functions produced following forward and backward testing are then compared across the sequential and simultaneous conditions. Although qualitatively equivalent functions produced for the sequential and simultaneous conditions do not empirically demonstrate that the same strategies are being employed for both tasks, such a conclusion would be the most parsimonious explanation. Therefore, if qualitatively equivalent functions are produced following simultaneous and sequential test-pair presentation, one might predict a non-significant interaction between serial position and test-pair presentation condition for the forward and, particularly important, the backward testing procedure. Specifically, a demonstration that recency is equivalent across simultaneous and sequential test-pair presentation would be problematic for a duplex account interpretation.

Method.

Participants. Twenty-four (3 males, 21 females: mean age = 23 years 7 months) Cardiff University volunteer undergraduates from a variety of disciplines participated and each received a £5.00 honorarium upon completion of the study. None had participated in Experiments 1.1(a-b) or in Experiment 1.2.

Materials. The stimuli set were as described for Experiment 1.2.

Design. A 2x2x6 within-subjects factorial design was adopted in a two-alternative forced-choice (2AFC) recognition paradigm. The factors were as described for Experiment 1.2 with the exception of an additional factor which represents the method of test-pair presentation (simultaneous versus sequential). Participants performed the experiment on consecutive days. The tasks were identical but for the simultaneous/sequential test-pair manipulation. The order in which these conditions were presented was counterbalanced.

Procedure. The procedure for the sequential test-pair presentation condition was identical to that described for 2AFC recognition for unfamiliar-faces in Experiment 1.2. The procedure for the simultaneous test-pair presentation condition was very similar except that the test-pair faces were presented simultaneously at test. The test-face that was presented first in the sequential condition was presented on the participant's left of the screen (-220 pixels from the centre of the screen) and the test-face that was presented second in the sequential condition was now presented simultaneously on the participant's right of the screen (220 pixels from the centre of the screen). The test-pair was presented on the screen for 1200 ms (as in the sequential condition each test-face was presented for 600 ms). An interval of 800 ms followed the simultaneous presentation of the test-pair (this was intended to account for the 400 ms interval between the two test-faces in the sequential condition plus the

400 ms interval between presentation of the second test-face and test). Following the 800 ms, participants were instructed to state if the first test-face (or the face on the participant's left) or the second test-face (or the face on the participant's right) was presented in the previous sequence. These presentation duration alterations ensured that the testing procedure lasted an identical period (1200 ms plus individual differences with respect to response speed) across the sequential and simultaneous test-pair presentation conditions.

Results and Discussion

Serial Position Analysis

Performance for the sequential and simultaneous test-pair presentation conditions was compared for the forward and backward testing procedures. Figure 1.6a demonstrates the mean percentage correct recognition for the simultaneous and sequential test-pair presentation following forward testing procedure. Figure 1.6b demonstrates the mean correct *Z*-score recognition for the simultaneous and sequential test-pair presentation following forward testing procedure. A 2-factor (2x6) within-subjects ANOVA was computed on the standardised data where the first factor represents the test-pair presentation condition (simultaneous versus sequential) and the second factor represents serial position (1-6). A non-significant main effect of test-pair presentation was found, F=1.83 (sequential mean correct recognition = 85.07%; simultaneous mean correct recognition = 81.74%), and a borderline main effect of serial position, $F(5,115)=2.17$, MSe=0.82, p=.06. Importantly, the interaction between test-pair presentation condition and serial position was non-significant, $F<1$.

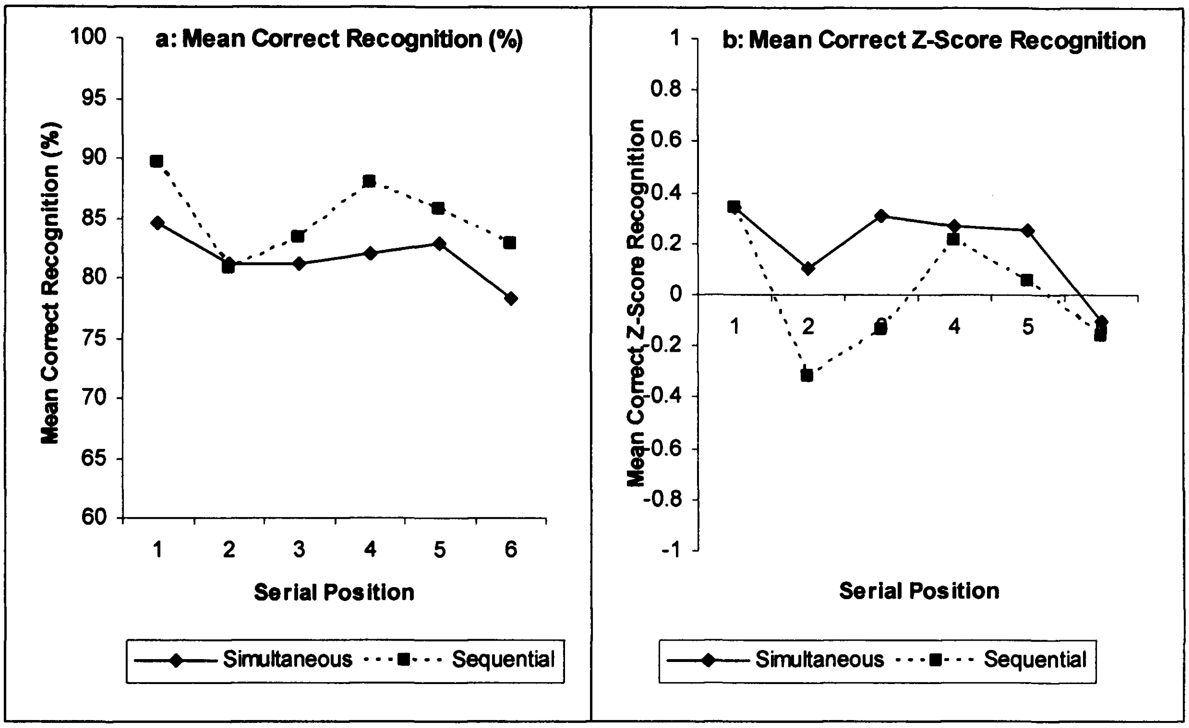


Figure 1.6(a-b): Mean percentage correct recognition (a) and mean correct *Z*-score recognition (b) for the simultaneous and sequential test-pair presentation following the forward testing procedure and as a function of serial position.

Figures 1.7a demonstrates the mean percentage correct recognition for the simultaneous and sequential test-pair presentation conditions following the backward testing procedure. Figure 1.7b demonstrates the mean correct *Z*-score recognition for the simultaneous and sequential test-pair presentation following the backward testing procedure. A 2-factor (2x6) within-subjects ANOVA was computed on the standardised data where the first factor represents the test-pair presentation condition (simultaneous versus sequential) and the second factor represents serial position (1-6). A non-significant main effect of test-pair presentation was found, $F<1$ (sequential mean correct recognition = 86.39%; simultaneous mean correct recognition = 82.92%), and a main effect of serial position, $F(5,115)=11.71$, $MSe=0.85$. Importantly, a significant interaction between test-pair presentation condition and serial position was found, $F(5,115)=2.96$, $MSe=0.47$).

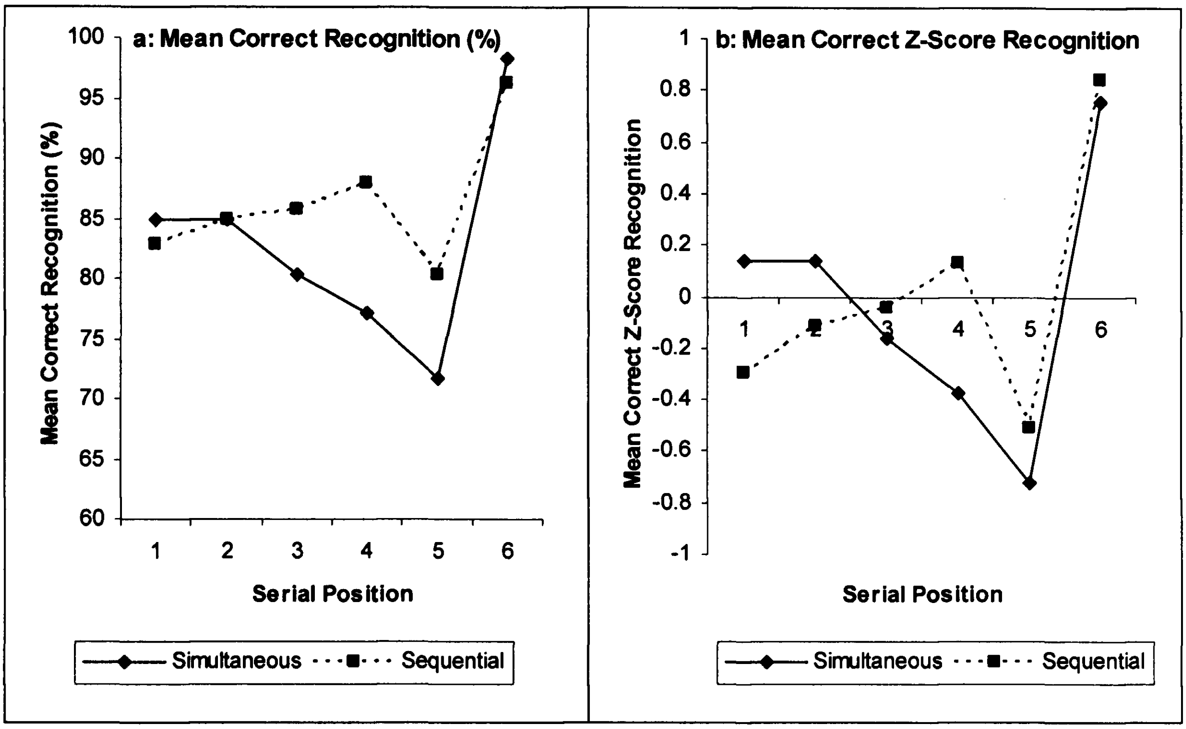


Figure 1.7(a-b): Mean percentage correct recognition (a) and mean correct *Z*-score recognition (b) for the simultaneous and sequential test-pair presentation following the backward testing procedure and as a function serial position.

The significant interaction between testing procedure and serial position is contrary to the hypothesis that the two tasks produce qualitatively equivalent functions. Specifically, that following the backward testing procedure both simultaneous and sequential test-pair presentation produce single-item recency. However, further analysis of the interaction (Newman Keuls) reveals no significant differences between the simultaneous and sequential test-pair presentation conditions when compared at each serial position. The difference between the two test-pair conditions is apparent when comparisons are made between serial positions within each test-pair condition. Following the sequential test-pair condition recognition for serial position 6 is significantly greater than that of positions 1-5. No other significant differences are found. The finding is characteristic of single-item recency. Following the simultaneous test-pair condition, recognition for serial position 6 is significantly greater than that of positions 1-5. However, in addition, recognition for serial position 1 and 2 is significantly greater than that of position 5. The interaction is, therefore, governed by relatively poor recognition levels for serial position 5 in the simultaneous test-pair condition. Crucially, the simultaneous and sequential test-pair conditions do not differ following comparisons at each serial position. Furthermore, the recency component of the sequential and simultaneous conditions matches extremely closely.

Moreover, further analysis (Newman Keuls) on the main effect of serial position reveal that mean *Z*-score recognition for serial position 6 is significantly greater than that of positions 1, 2, 3, 4 and 5. This finding is consistent with single-item recency for both test-pair presentation conditions. In addition mean *Z*-score recognition for serial position 5 was significantly lower than that of positions 1, 2, 3 and 4. This again, is driven by the low recognition for serial position 5 in the simultaneous test-pair presentation condition.

Trend Analysis

As in Experiments 1.1a, 1.1b and 1.2, trend analyses were conducted. Trend analysis for the forward testing procedure revealed non-significant linear and quadratic components for both the simultaneous (F=1.05 and F<1, respectively) and the sequential test-pair conditions (both Fs<1). The finding indicates that analogous flat functions were produced for the forward testing procedure following simultaneous and sequential test-pair presentation. Trend analysis for the backward testing procedure for the simultaneous test-pair presentation revealed a significant quadratic, $F(1,23)=30.46$, $Mse=1.58$, and non-significant linear component, $F<1$. Trend analysis for the backward testing procedure of the sequential test-pair presentation revealed a borderline significant quadratic, $F(1,23)=3.22$, $Mse=1.11$, $p=.09$, and significant linear component, $F(1,23)=9.67$, $MSe=1.07$. Inconsistent with the predicted equivalence, the simultaneous and sequential test-pair conditions produce different trends following backward testing. The absence of a linear trend for the simultaneous test-pair condition can be explained by poor relative recognition for serial position 5 producing greater curvature within the function.

Order of Test-Pair Analysis

Although not possible for the simultaneous test-pair presentation condition, for the sequential test-pair presentation condition the additional test of duplex was employed whereby the position of the test probe in the first backward 2AFC test-pair was investigated. A paired *t*-test was employed comparing terminal item recognition accuracy following the backward testing procedure when the probe face was first (mean recognition accuracy = 96.32%) compared to when the probe face was second (mean recognition accuracy = 94.17%) and revealed a non-significant difference, t(23)=1.74, p=.10. Although the *P* value approached significance, it is important to note that when second in the test-pair, recognition for the terminal face (mean recognition accuracy = 94.17%) remained substantially higher than the mean of positions 1-5 (mean recognition accuracy = 84.42%); a finding inconsistent with duplex.

This finding, therefore, demonstrates that the recency component of the sequential test-pair condition closely matched that of the simultaneous test-pair condition despite no effect of test-pair order for the first backward test-pair. Specifically, no performance difference was found for serial position 6 when tested immediately following the presentation phase or following a single distracter item. A duplex account predicts that when second in the test-pair, memory for the terminal item would be displaced from the STS due to the first test-pair item operating as a de facto suffix. This was not found. Duplex cannot, therefore, account for the recency in the sequential test-pair condition. Moreover, since recency is equivalent across the simultaneous and sequential test-pair conditions, the most parsimonious interpretation is that duplex, also, cannot account for recency in the simultaneous test-pair condition.

Intervening Items Analysis

In Experiment 1.2 it was found that the pattern of recognition could not be accounted for in terms of an interference-based explanation wherein number of items intervening between presentation and test predicted recognition accuracy. This analysis was applied to both the sequential and simultaneous test-pair presentation conditions. This analysis, combining data from both the forward and backward testing procedures was computed for the simultaneous and sequential test-pair presentation conditions and is plotted in Figures 1.8a and 1.8b respectively. For the simultaneous test-pair presentation condition a Pearson correlation revealed a non-significant negative correlation between recognition accuracy and the number of items intervening between presentation and test (R=-0.17, p=.59). For the sequential test-pair presentation condition a Pearson correlation revealed a non-significant negative correlation between recognition accuracy and the number of items intervening between presentation and test (R=-0.47, p=.13).

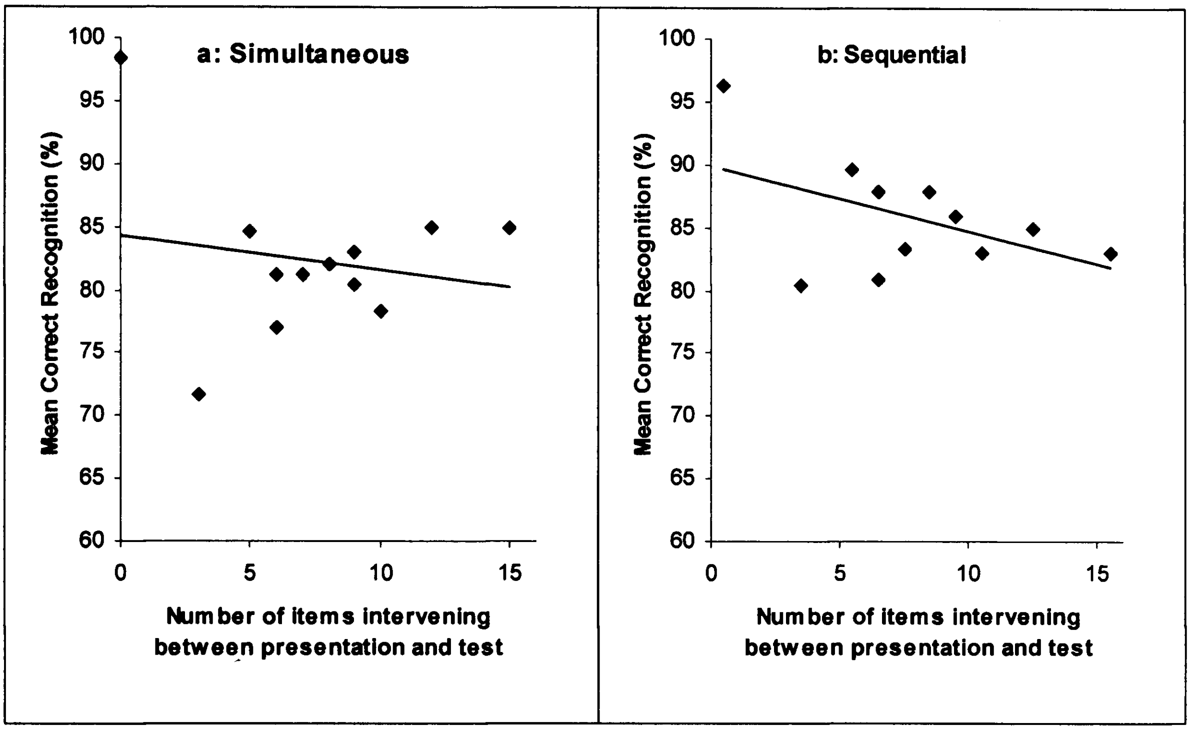


Figure 1.8(a-b): Mean percentage correct recognition following simultaneous (a) and sequential (b) test-pair presentation for both the forward and backward testing procedure as a function of the number of items intervening between presentation and test. The trend line indicates the line of best fit.

Experiment 1.3 replicated the recency reported for backward 2AFC recognition with unfamiliar-faces demonstrated in Experiment 1.2. In addition, it was demonstrated that the simultaneous test-pair paradigm (employed by Phillips and Christie, 1977) broadly produced a qualitatively equivalent function to that of the sequential test-pair paradigm employed in Experiment 1.2. That is, both simultaneous and sequential test-pair conditions produced an essentially flat function following the forward testing procedure and single-item recency following the backward testing procedure.

Crucially, following the backward testing procedure, the simultaneous and sequential test-pair presentation conditions produced equivalent recency components. This equivalence was found despite duplex being unable to account for the recency component in the sequential test-pair presentation condition. In the simultaneous condition it is not possible to perform this additional duplex analysis and compare the effect of order of test-pair. The tasks are identical apart from test-pair presentation and the functions produced for sequential and simultaneous presentation demonstrated equivalence. Since duplex cannot account for recency in the sequential condition, the most parsimonious explanation is that recency is also not explicable by duplex in the simultaneous condition.

As following 2AFC recognition for odours (Experiment 1.1) and unfamiliar-faces (Experiment 1.2), an interference-based account was applied to the data. As in Experiment 1.2 number of items intervening between presentation and test was found not to significantly correlate with mean correct recognition for neither the simultaneous nor the sequential test-pair presentation conditions. Therefore, neither a duplex account nor an interference-based account can fully account for the pattern of results observed for the simultaneous test-pair presentation condition (the Phillips and Christie paradigm) or sequential test-pair presentation.

Experiment 1.4

Sequential 2AFC recognition for unfamiliar-faces in Experiments 1.2 and 1.3 demonstrated that the cross-modal 2AFC recognition differences indicated in Experiment 1.1a and b with odours were not an artefact of methodological alterations at test, i.e. presentation of the test pair items individually. Unlike the olfactory data, number of items intervening between presentation and test was not predictive of 2AFC recognition for unfamiliar-faces (Experiment 1.2 and 1.3). The finding suggests that, although the functions produced for the forward and backward testing procedures are similar cross-modally, the mechanisms underpinning the functions may differ.

As described previously, the 2AFC recognition paradigm has been traditionally applied to visual stimuli, wherein the simultaneous presentation of the test pair necessitates a binary judgment of familiarity. This methodology restricts the task to visual (and arguably tactile) stimuli, consequently limiting any cross-modal comparison. In Experiment 1.4, the modified 2AFC recognition task was applied to sequences of 6-pure tones to assess if the auditory stimuli conform to the functions produced by visual stimuli.

Previous research suggested that auditory stimuli may be more amenable to a duplex-based memorial architecture of short-term recognition. Crowder and Morton (1969) argued that the auditory suffix effect (i.e. the disruption of memorial performance, specifically of the terminal item, when subsequent irrelevant acoustic stimuli separate the to-be-remembered sequence and test) and the modality effect (better recall of auditory compared to visual stimuli) were indicative of a sensory specific STM they termed the Pre-categorical Acoustic Store (PAS). This account has been subject to much critique, such as the detrimental effect on auditory speech lists not found for a non-speech suffix (Crowder and Morton, 1969) and the finding of a lip-read suffix reducing recall of an auditory list (Spoehr and Corin, 1978). However, the presence of a store structurally analogous to PAS and consistent with duplex can be investigated using the current 2AFC recognition paradigm. The work of Crowder and Morton (1969) suggests that the suffix and test items must be similar in form (i.e. in their study both speech-based) and, if this store can operate nonverbally, one might predict a fall in recency following a pure-tone suffix. Indeed, this proposition is supported by Mondor and Morin (2004) who found that following employment of pure-tone sequences in a yes/no single-probe recognition paradigm, a post list suffix of similar pitch and spatial location compromised the terminal item benefit. As described previously, when the terminal item is tested in the backward testing procedure, duplex predicts recency only when the terminal item is presented first in the test-pair. When the novel item is presented first in the test-pair, the novel item should operate as a de facto auditory suffix and attenuate the terminal item benefit.

The aims of the present experiment are, therefore, threefold: first, to assess the extent of functional equivalence for 2AFC recognition for auditory stimuli with odours and unfamiliar faces (a comparison not possible for the original Phillips and Christie, 1977 paradigm). Second, to assess if, consistent with the PAS architecture, single-item recency following the backward testing procedure is (a) found and (b) greatly attenuated when the probe item is second in the test pair. A third related aim is to investigate if the auditory suffix effect can be found in the 2AFC paradigm for non-speech auditory stimuli (as demonstrated in a single probe recognition domain by Mondor and Morin, 2004).

These three experimental principles produce three clear hypotheses. First, if pure-tones produce functional equivalence for 2AFC recognition with odours and unfamiliar-faces one would predict a significant interaction between testing procedure (forward and backward) and serial position. Consequently, this interaction might be driven by increased recognition for the terminal sequence item in backward testing procedure. Second, if backward testing recency can be explained by duplex, one might predict that when the probe tone is first in the initial backward testing procedure, recognition would be significantly greater than if second in the test-pair. Third, and related to the previous hypothesis, if a non-speech auditory suffix can be found in the 2AFC recognition paradigm, one might predict that when the probe tone is second in the initial backward testing procedure, recognition would be significantly reduced than if first in the test-pair. When presented first in the test-pair, the novel item might operate as a suffix compromising recognition for the item second in the test pair.

Engen and Ross (1973) argued that unlike immediate memory for auditory and visual stimuli, olfactory memory produced numerous immediate errors. Therefore, presentation time for the auditory stimuli followed that of the unfamiliar-faces in Experiment 1.2 in an attempt to reduce performance levels nearer to that of Experiment 1.1.

Method.

Participants. Twenty-four (5 males, 19 females: mean age = 20 years 11 months) Cardiff University volunteer undergraduates from a variety of disciplines participated and each received a £3.00 honorarium upon completion of the study. None had participated in Experiments 1.1-1.3.

Materials. Following the methodology reported by Suprenant (2001), a stimulus set of 60 pure tones of 600 ms duration was synthesised using Cool Edit 96 software. Each tone was generated by increasing the frequency of the previous tone by 4.5% (creating a set of pure tones ranging between 300-4024Hz). Pure tones were presented via headphones at a volume of 75dB using the Superlab program.

Experimental tones were divided into 12 groups each comprising 5 pure-tones, such that similar frequency items were grouped together, i.e. the first 5 tones exhibiting the lowest frequency became group 1. Sequences were constructed by taking one tone from each of the 12 groups and each test probe was also taken from the remaining groups. An additional constraint was employed such that any item within a sequence should not be within a frequency range of 4.5% of another sequence item. That is, items from the stimulus set that were adjacent in terms of frequency, were not included within the same sequence. The position of each tone within the sequence was randomised in order to prevent a strategy based upon ascending or descending frequency levels.

Design. The design was as described for Experiment 1.2. Each of the 60 tones was presented 4 times throughout the experiment and each tone was presented once within each quartile of the experiment. The order of trials was randomised for each participant.

Procedure. The procedure was as described for Experiment 1.2.

Results and Discussion.

Serial Position Analysis

Figure 1.9 shows the mean percentage correct recognition at each serial position of both the forward and the backward testing procedures. A 2-factor (2x6) within-subjects ANOVA was computed on the correct recognition scores where the first factor represents test procedure (forward versus backward) and the second factor represents serial position (1-6). A null effect of testing procedure was found, F=2.10 (forward mean correct recognition = 58.56%; backward mean correct recognition = 61.39%) and a main effect of serial position, $F(5,115)$=6.98, MSe=2.41. Importantly, a significant interaction between serial position and testing procedure was found, $F(5,115)$= 8.10, MSe=2.07.

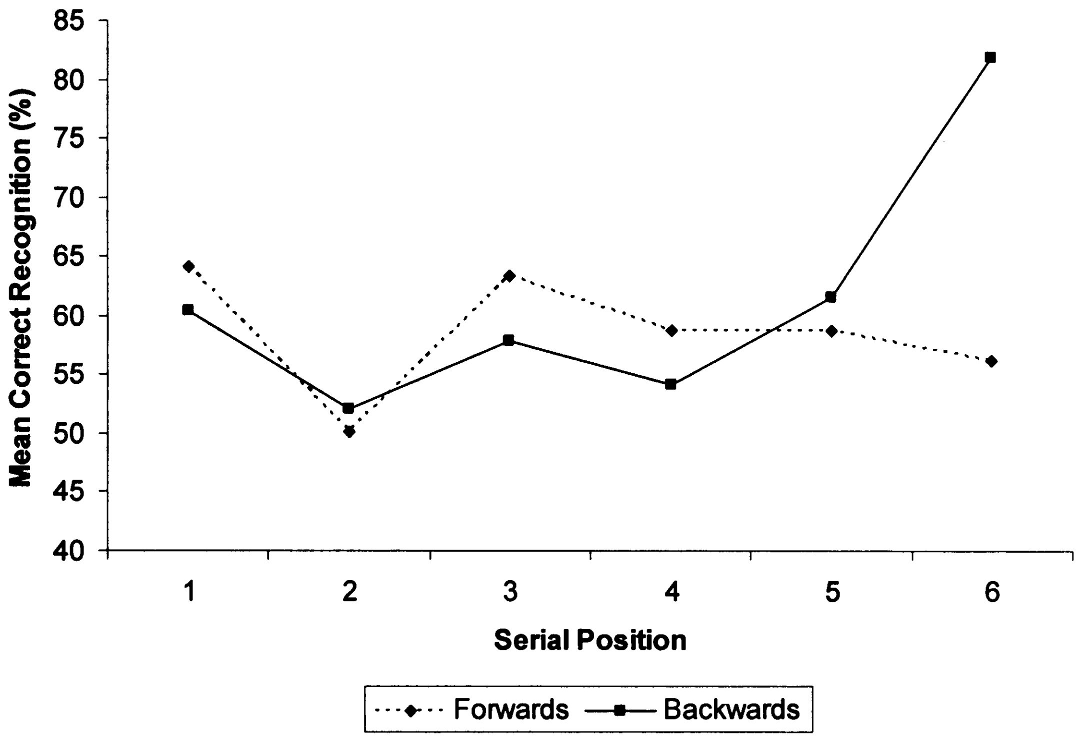


Figure 1.9: Mean percentage correct recognition for the forward and backward testing procedures as a function serial position.

Further analysis of the interaction (Newman Keuls) showed that for the forward testing procedure recognition for serial positions 1 and 3 was significantly greater than that at serial position 2. No other significant differences between serial positions were observed. In contrast, for the backward testing procedure, recognition at serial position six was significantly greater than that at serial positions one, two, three, four and five. Pairwise comparisons between testing procedures at each serial position revealed a significant difference only at serial position six, where superior recognition was observed following the backward testing procedure.

Trend Analysis

As in Experiments 1.1-1.3 trend analyses were conducted. Trend analysis for the forward testing procedure produced both non-significant linear and quadratic components, both $F\text{s}<1$. The non-significant linear and quadratic functions support the general trend of a horizontal line. In contrast, trend analysis for the backward testing procedure revealed significant quadratic, $F(1,23)=36.3$, $MSe=1.78$, and linear components. This trend is consistent with recency but not primacy for the backward testing procedure. The linear trend indicates that there is a general increase in recognition levels as a function of serial position. However, the significant quadratic component suggests an increase in recognition accuracy at the recency component of the function, consistent with single-item recency.

Order of Test Pair Analysis

As in Experiments 1.1(a-b) and 1.2 an additional test of duplex was employed whereby recognition accuracy of the terminal item following the backward testing procedure was compared when the probe item was first or second in the test-pair. A paired *t*-test was conducted comparing recognition when the sixth pure-tone in the sequence was first (mean recognition accuracy=96.67%) or second (mean recognition accuracy=69.17%) in the test-pair following the backward testing procedure. The *t*-test revealed that recognition was significantly better when the probe tone was first in the test pair, $t(23)= 8.75, p<.05$. This finding is consistent with a duplex interpretation of 2AFC recognition recency and also supports presence of the PAS (Crowder and Morton, 1969). Furthermore, the finding suggests that PAS operates for pure-tones, in addition to speech-based auditory stimuli. The significant difference is consistent with the novel item, when presented first in the test pair, functioning as an auditory suffix and displacing the terminal sequence item from the STS/PAS (consistent with pure-tone auditory suffix effect reported by Mondor and Morin, 2004). This finding is inconsistent with both the olfactory (Experiments 1.1a and b) and visual data (Experiments 1.2 and 1.3) where this apparent suffix effect was not found. This incongruity for auditory stimuli appears to reflect some form of sensory-specific acoustic echo not found perceptually analogous with odours or unfamiliar-faces.

Intervening Items Analysis

Although duplex appears to offer a good account of the auditory data, for completeness and, following the analysis of olfactory and visual stimuli, number of items intervening between presentation and test was examined. This analysis, in which data from both the forward and backward testing procedures was combined, was computed for the present data set and the results are plotted in Figure 1.10. A Pearson correlation revealed a borderline significant negative correlation between recognition accuracy and the number of items intervening between presentation and test (R=-0.54, p=.07).

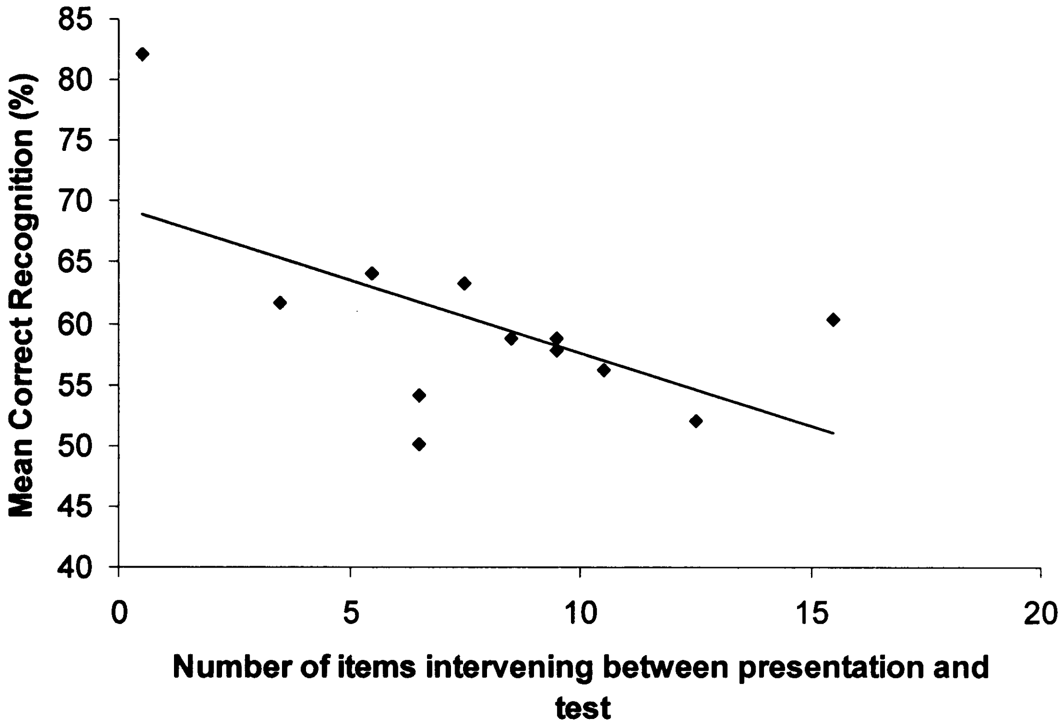


Figure 1.10: Mean percentage correct recognition for both the forward and backward testing procedure as a function of the number of items intervening between presentation and test. The trend line indicates the line of best fit.

There is, therefore, a caveat to the apparent neat duplex accommodation of the present data, that is, similar to odours, number of items intervening between presentation and test can, to some extent, explain the present trend. However, on viewing the scatterplot, specifically the line of best fit, it seems possible that both theories may account for the data; a short-term acoustic store responsible for heightened recency and the intervening items account (either via interference or temporal-based decay) predicting recognition for pre-recency items.

Cross-modal Comparison of 2AFC Recognition: Odours, Unfamiliar-Faces and Pure-Tones

Prior to cross-modal comparison, it should be noted that presentation and ISIs vary across stimuli. Ratio between presentation time and ISI was constant across modalities (3:2) but differed in absolute levels. Cross modal comparison is therefore limited, as interpretations are not based upon the factor of modality in isolation. Any modality effects might, therefore, be driven by differences in presentation times.

Serial Position Analysis

Forward and backward 2AFC mean percentage correct recognition for odours, unfamiliar-faces and pure-tones is demonstrated in Figure 1.11a and b respectively. The three modalities appear to demonstrate a recognition benefit for the terminal sequence item in the backward testing procedure.

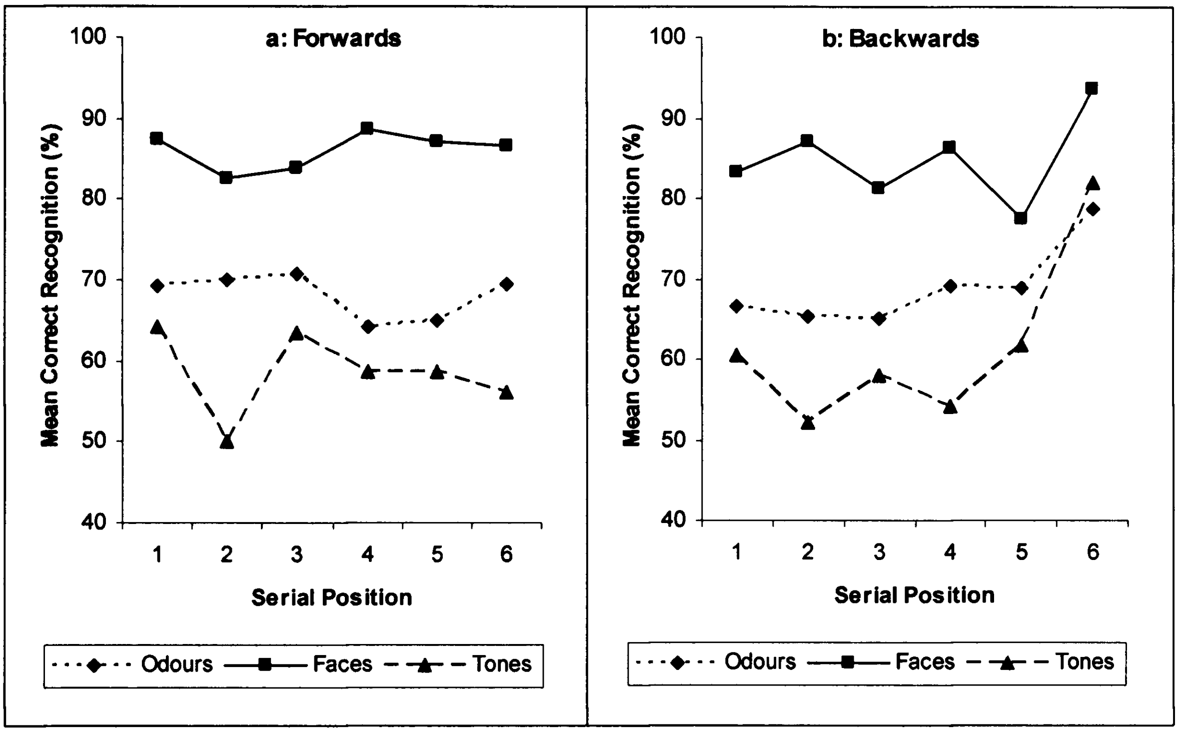


Figure 1.11(a-b): Mean percentage correct recognition following the forward (a) and the backward (b) testing procedures for olfactory, visual and auditory stimuli as a function of serial position.

As detailed in the Statistical Methodology section (Chapter 2), statistical cross-modal comparison is performed following a standardisation of scores to *Z*-scores. Although recognition scores are quantitatively different across the three modalities (mean olfactory recognition = 68.54%; mean visual recognition = 85.45%; mean auditory recognition = 59.97%), it is the extent to which the functions differ qualitatively that is of interest. That is, the extent to which the different modalities produce functions of equivalent shapes. If the functions qualitatively differ for the odours, unfamiliar-faces and pure-tones one might predict a significant interaction between serial position and modality of stimuli. The mean correct *Z*-score recognition for both testing procedures is depicted in Figure 1.12(a-b). The testing procedures were assessed separately to assess the role of modality on serial position irrespective of order of test.

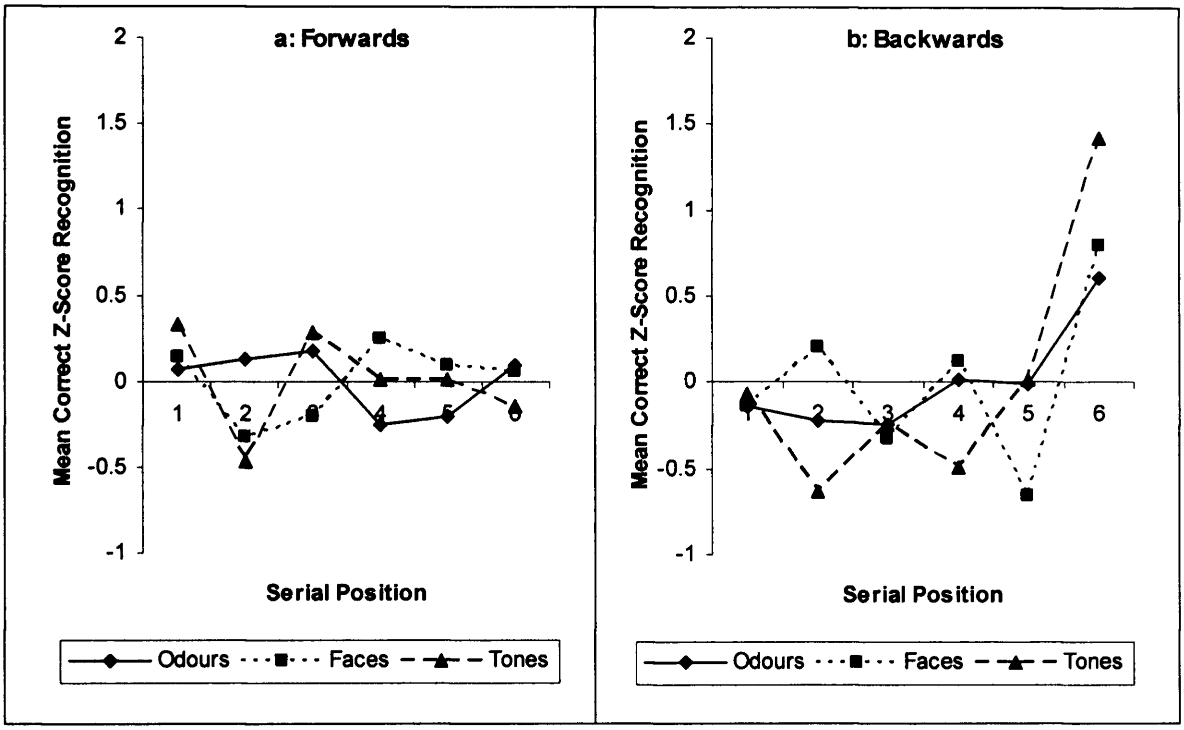


Figure 1.12(a-b): Mean correct *Z*-score recognition following the forward (a) and backward testing procedure (b) for olfactory, visual and auditory stimuli as a function of serial position

A 2-factor (3x6) mixed design ANOVA was computed on the forward testing procedure data, where the between-subjects factor represents the modality of stimuli presentation (olfactory, visual and auditory) and the within-subjects factor represents serial position (1-6). Both a null effect of stimuli modality, $F<1$, and a null effect of serial position was found, $F=1.45$. Crucially, the interaction between serial position and modality was non-significant, $F=1.56$. This finding demonstrates that, consistent with previous studies in which a series of 2AFC test pairs are presented in the same order of presentation (e.g. Avons, 1998; Avons and Mason, 1999), the forward testing procedure produces an absence of serial position effects. That is, a flat function. This finding, originally depicted for abstract visual patterns, has now been generalised to other visual stimuli (unfamiliar faces) and more interestingly to other non-verbal stimuli (odours and pure-tones). Ostensibly, the forward testing procedure provides evidence in favour of a duplex interpretation of 2AFC recognition. Equivalent recognition levels for all items are consistent with these items being displaced into the more durable LTS. And this duplex congruency appears present across olfactory, visual and auditory domains.

A 2-factor (3x6) mixed design ANOVA was computed on the backward testing procedure. Consistent with the forward testing procedure, a null effect of modality was found, $F<1$. In contrast to the forward testing procedure, both a significant main effect of serial position, $F(5,69)=19.62$, $MSe=0.80$, and a significant interaction between modality and serial position was also observed, $F(5,69)=3.67$, $MSe=0.80$. Further analysis (Newman Keuls) indicates that the interaction was driven by poor relative recognition rates at serial position 5 in the visual modality. All three modalities produce terminal item recognition superior to that at positions 1, 2, 3, 4 and 5. However, in the visual modality, recognition for serial positions 2 and 4 are significantly greater than that of position 5. Cross-modal comparison of the backward testing procedure provides evidence of recency for this paradigm consistent with previous studies employing backward testing (e.g. Phillips and Christie, 1977; Ward et al, 2005). Across the three paradigms there is no evidence of primacy for backwards 2AFC recognition. The *Z*-score analysis demonstrates single-item recency for both olfactory and auditory stimuli (consistent with Phillips and Christie, 1977). The function for unfamiliar-faces is similar but demonstrates slight elevation for positions 2 and 4.

Recency and Primacy Analysis

An additional analysis was conducted on 2AFC recognition data to assess the presence of primacy and recency for the olfactory (Experiment 1.1b), visual (Experiment 1.2) and auditory (Experiment 1.4) data. This method is described in the Statistical Methodology section (Chapter 2).

Olfactory (Experiment 1.1b):

Forward Testing – recognition for serial position 1 (mean correct recognition = 69.17%) was non-significantly different to that of the mean of positions 2-5 (mean correct recognition = 67.5%), $t<1$. Recognition for serial position 6 (mean correct recognition = 69.58%) was non-significantly greater than the mean of positions 2-5, $t<1$.

Backward Testing – recognition for serial position 1 (mean correct recognition = 66.67%) was non-significantly different to that of the mean of positions 2-5 (mean correct recognition = 67.08%), $t<1$. Recognition for serial position 6 (mean correct recognition = 78.75%) was significantly greater than the mean of positions 2-5, $t(23)=3.88, p<.05$.

Visual (Experiment 1.2):

Forward Testing – recognition for serial position 1 (mean correct recognition = 87.5%) was non-significantly different to that of the mean of positions 2-5 (mean correct recognition = 85.52%), $t=1.1$. Recognition for serial position 6 (mean correct recognition = 86.67%) was non-significantly greater than the mean of positions 2-5, $t<1$.

Backward Testing – recognition for serial position 1 (mean correct recognition = 83.33%) was non-significantly different to that of the mean of positions 2-5 (mean correct recognition = 83.02%), $t<1$. Recognition for serial position 6 (mean correct recognition = 93.75%) was significantly greater than the mean of positions 2-5, $t(23)=5.04, p<.05$.

Auditory (Experiment 1.4):

Forward Testing – recognition for serial position 1 (mean correct recognition = 64.17%) was non-significantly different to that of the mean of positions 2-5 (mean correct recognition = 57.92%), $t(23)=1.94, p=.07$. Recognition for serial position 6 (mean correct recognition = 56.25%) was non-significantly greater than the mean of positions 2-5, $t<1$.

Backward Testing – recognition for serial position 1 (mean correct recognition = 60.42%) was non-significantly different to that of the mean of positions 2-5 (mean correct recognition = 56.46%), $t=1.3$. Recognition for serial position 6 (mean correct recognition = 82.08%) was significantly greater than the mean of positions 2-5, $t(23)=11.15, p<.05$.

In summary, this additional analysis revealed neither primacy nor recency following the forward testing procedure for odours, unfamiliar-faces and pure-tones. In contrast, recency but not primacy was found following the backward testing procedure for odours, unfamiliar-faces and pure tones. The three stimulus types, therefore, produced the same pattern of data such that recency was only found following backward testing.

Chapter 3 Discussion

The experiments reported in Chapter 3 first attempted to reconcile the controversy concerning 2AFC recognition of odours. Employing a single 2AFC recognition paradigm, Reed (2000) reported both primacy and recency for sequences of 5- and 7-odours. However, in a very close methodological replication, Miles and Hodder (2005) were unable to replicate the primacy reported by Reed (2000) but did observe recency. It was argued that both these experiments were deviations from the original 2AFC paradigm employed by Phillips and Christie (1977) for two reasons. First, in Phillips and Christie (1977) each trial comprised a series of 2AFC test-pairs testing each item alongside a novel distracter in the reverse order of original presentation. In both Miles and Hodder (2005) and Reed (2000) only a single test-pair was employed per trial. Second, in Phillips and Christie (1977) a large stimulus set was employed. Both Reed (2000) and Miles and Hodder (2005) employed 8-odours throughout the entire experiment.

In Experiment 1.1a and 1.1b both a blocked and mixed design for the forward and backward testing produced an absence of serial position effects for the forward testing procedure and recency following the backward testing procedure. Both Experiments 1.1a and 1.1b produced evidence contrary to Reed (2000) as no primacy was observed. However, recency was observed following the backward testing procedure (consistent with both Reed, 2000 and Miles and Hodder, 2005). Moreover, the finding of extended recency (Experiment 1.1a) was also observed in Miles and Hodder (2005). On closer inspection, it is argued that the primacy observed by Reed (2000) may have been facilitated via verbalisation. Although Reed (2000) reports a non-significant main effect of articulatory suppression, the detrimental effect disproportionately impacts the primacy and recency components, such that recency decreased by approximately 5% and primacy by 20%.

Chapter 3 also assessed the extent to which the two-component duplex theory, originating from the Phillips and Christie (1977) paper, might account for recency following the backward testing procedure. An additional condition was included whereby the 2AFC recognition test-pairs were presented in the original order of presentation (as employed by Avons, 1998). Duplex predicts an interaction between forward and backward testing, such that an absence of serial position effects is found following the forward testing procedure and single-item recency is found following the backward testing procedure. The terminal sequence item is proposed to be recognised at a heightened level of accuracy due to storage within a fragile STS.

Ad hoc, the cross-modal comparisons of forward and backward testing appear consistent with the duplex theory predictions. That is, an absence of serial position effects followed the forward testing procedure and single-item recency followed the backward testing procedure (with the exception of positions 2 and 4 for the visual stimuli). The backward testing recency is accounted for via storage within the fragile STS. Serial position function equivalence suggests amodal, or at least analogous, processing across stimuli and contrasts with the views of Guérard and Tremblay (under review), who proposed that item-based tasks produced evidence in favour of modularity.

The finding of recency following the backward testing procedure for odours, unfamiliar faces and pure-tones is consistent with the duplex account of STM (Phillips and Christie, 1977). However, an additional analysis of the first test-pair in the backward testing procedure allows a further assessment of the duplex account. Under a strict duplex interpretation, recency should only be present when the last sequence item is tested first in the test pair, i.e. no items intervenes between presentation and test of that last sequence item. When second in the test-pair, the novel item intervenes between presentation and test of the last sequence item and operates as a de facto suffix displacing that last item from the STS. As previously detailed, only the auditory data were found to be consistent with this additional duplex analysis. Contrary to duplex, this trend is not observed for olfactory or visual stimuli.

In Experiment 1.3 the original 2AFC recognition paradigm described by Phillips and Christie (1977) was compared to the sequential test-pair 2AFC paradigm (as employed in Experiments 1.1-1.4). Unfamiliar-faces were employed in both paradigms. Equivalent functions were produced following simultaneous and sequential test-pair presentation. For the sequential test-pair condition, duplex was again demonstrated to provide a poor account of recency. Since equivalent recency components were observed for the simultaneous and sequential test-pair conditions it was argued that the most parsimonious interpretation is that analogous processes underpin performance of both tasks and, therefore, duplex cannot account for the simultaneous test-pair condition. Such a finding casts serious doubts upon the original duplex conceptualisation of 2AFC visual recognition (Phillips and Christie, 1977).

In contrast, if the last item is presented second in the test-pair for auditory stimuli recency is compromised. This is consistent with a duplex conceptualisation. However, one might argue that a duplex-based memorial architecture operates as a facilitative mechanism for auditory recency in addition to another mnemonic. Closer inspection of first test-pair in the backward testing procedure reveals evidence of recency even when the last list item is tested second in the test-pair. Although when the probe is second in the test-pair (mean percentage recognition correct = 69.17%) performance is significantly lower than when the probe is first in the test-pair (mean percentage recognition correct = 96.67%), mean percentage recognition correct is still substantially higher than the mean of positions 1-5 (mean percentage recognition correct = 57.25%; range 52.08%-60.42%). Under a strict duplex interpretation, one might predict the recognition for the terminal item when second in the initial test-pair would decrease to a level equivalent to all pre-recency items. That is, decrease due to displacement into the less accurate LTS. The finding suggests that (1) a duplex-type memory architecture exists with auditory memory that heightens the recency component (consistent with Phillips and Christie, 1977, and Crowder and Morton's, 1969, auditory-specific PAS), but (2) a mnemonic unique from duplex exists that promotes an initial base-level recency. The origins of this mnemonic along with the origins of the visual 2AFC function, at present, remain unresolved.

One possible explanation for recency explored was that the number of items intervening between presentation and test might predict recognition (Lewandowsky, personal communication). Indeed, Lewandowsky et al. (2004) argued that the effect of time is not due to temporal decay per se, but due to the interference between items. That is, the greater the number of items experienced between presentation and test, the greater the memorial impairment to that item. Number of intervening items separating presentation and test was found to be predictive of recognition accuracy for odours and revealed a borderline significant correlation ($p=.07$) for auditory recognition. The interference based account was unable to accommodate recognition of unfamiliar-faces.

However, on closer inspection it is possible that the correlation between number of intervening items and recognition was artificially induced via strong recency for the terminal item in the backward testing procedure (i.e. the item exhibiting the smallest number of items intervening between presentation and test). If number of items intervening between presentation and test truly predicts recognition, the correlation should remain when the terminal item in the backward procedure is removed from the analysis. This analysis was conducted on the olfactory data and the significant correlation remained for Experiment 1.1a ($R=-0.70$, $p<.05$) but was removed in Experiment 1.1b ($R=-0.47$, $p=.15$). In Experiment 1.1a number of items intervening between presentation and test remained a significant predictor of recognition accuracy ($R^2=0.50$; $F(1,9)=8.81$, $MSe=7.91$, $p<.05$). Interestingly, the borderline correlation between number of items intervening between presentation and test and recognition for pure-tones in Experiment 1.4 was greatly reduced when recognition for the terminal item following backward testing was removed from the analysis ($R=0.19$, $p=.58$). The finding indicates that the apparent correlation between number of items intervening and recognition accuracy for pure-tones was driven by strong recency in the backward testing procedure.

Only Experiment 1.1a, therefore, provided support for this interference-based account. This demonstrates that (i) recognition for both unfamiliar-faces and pure-tones is not predicted by number of items intervening between presentation and test and (ii) there is mixed evidence as to whether this interference account is an adequate predictor of olfactory performance. Indeed, a non-significant correlation between recognition and number of items intervening was found with odours following the mixed design (Experiment 1.1b): this was the same design employed for unfamiliar-faces and pure-tones and therefore demonstrates some cross-modal concordance. Specifically, recognition of odours, unfamiliar-faces and pure-tones is not affected by number of intervening items between presentation and test. This is contrary to Lewandowsky et al. (2004) who reported that output interference in verbal serial order recall was critical in producing the serial position function.

The finding that odour recognition was not affected by interference is consistent with the proposal that odours are stored as unitary entities that are impervious to interference (e.g. Chobor, 1992; Engen and Ross, 1973). Indeed, this finding is supported by Wilson and Stevenson (2006) who stated that a key characteristic of olfactory perception is the ability to recognise an odour amongst various chemical backgrounds and when the odour percept is compromised/degraded. One problem with odour memories conceptualised as unitary entities is that one might predict a flat serial position function. If each odour is stored uniquely as a separate impervious memorial entity, equivalent recognition for the odours would be observed. However, recency following the backward testing procedure was reported.

Both duplex and an interference account are, therefore, unable to account for the recency observed for odours and unfamiliar-faces and the base recency found with pure-tones. Since recency is found following backward testing but not forward testing it is evident that recent presentation of the last item is an important factor for recency production. However, the benefit of recent presentation is not due to storage within a STS or due to an absence of interference. One tentative explanation for these recognition functions is via Neath's (1993) temporal distinctiveness model. Under such an account, recently presented items appear more distinctive, analogous to a line of telegraph poles. However, when the retention interval is lengthened, e.g. for pre-recency items and for items tested in the forward testing procedure, these items become less distinct and are recognised less well. However, since evidence for graded recency is only found is Experiment 1.1a, distinctiveness must decline exponentially, rather than linearly, following increased retention intervals in order to account for the single-item recency functions observed.

An exponentially decreasing temporal distinctiveness model, therefore, provides a tentative preliminary account of recency following the backward testing procedure and a flat function following the forward testing procedure. Such an account is applicable amodally since analogous functions are produced for odours, unfamiliar-faces and pure-tones. Indeed, this serial position function equivalence is consistent with Ward et al. (2005) who proposed that the serial position function is determined by task rather than stimuli. Interpreting the 2AFC recognition data in terms of Neath's (1993) temporal distinctiveness model is more consistent with an amodal process account of memory proposed by Jones and colleagues (e.g. Jones et al., 2004). Under such an account there are not necessarily modality specific memory systems, but the serial position function is determined by how a series of items are organised.

However, there is a caveat to this temporal distinctiveness interpretation. Lewandowsky et al. (2006) questioned the role of temporal distinctiveness. They demonstrated that increasing temporal isolation of sequence items i.e. increasing the inter-stimulus-interval and, thereby, the temporal distinctiveness of an item, did not, of itself, improve item recall. Rather, the authors proposed that output interference during recall influences the serial position function. However, in the present experiments, interference from items represented at test was not found to determine recognition. Therefore, although there are empirical concerns regarding temporal distinctiveness, interference is an inadequate alternative explanation.

Key Findings

Qualitatively equivalent functions were found for odours, unfamiliar-faces and pure-tones following the modified 2AFC recognition forward and backward testing procedures. The forward testing procedure revealed an absence of serial position effects, whereas the backward testing procedure revealed recency but not primacy. The functions are consistent with the original Phillips and Christie (1977) paradigm. The findings suggest amodal, or analogous processes, underpin item memory for odours, unfamiliar-faces and pure-tones. However, evidence for different processes underpinning recency was reported. The olfactory and unfamiliar-face data were found not to be consistent with the two-store duplex account proposed to accommodate the 2AFC recognition task (Phillips and Christie, 1977). In contrast, the auditory data were consistent with this theory.

CHAPTER 4
SINGLE-PROBE SERIAL POSITION RECALL

Introduction

Overview

Chapter 4 investigates the serial position functions produced for single-probe serial position recall of olfactory, visual and auditory stimuli. In contrast to the item-based 2AFC recognition paradigm employed in Chapter 3, single-probe serial position recall necessitates the recollection of order. The introduction, therefore, begins with a discussion of the dissociation between item- and order-based tasks both empirically and neurologically. Evidence for a dissociation provides justification for an investigation of item- and order-based tasks separately. Order-based tasks, specifically the single-probe serial position recall paradigm are then discussed. In the experimental sections of Chapter 4, 3 main experiment groups are reported in which 4-, 5- and 6-item sequences of odours (Experiment 2.1), unfamiliar-faces (Experiment 2.2) and pure-tones (Experiment 2.3) are applied to the single-probe serial position recall paradigm. Serial position functions are then compared cross-modally for each list length.

The Familiarity-Recollection Dissociation: Empirical Evidence

Chapter 4 investigates memory for order. There appears an inherent importance to item recognition; is the item novel and consequently is it of danger? The importance of order, however, is less clear. Presumably, the qualities of certain stimuli are not constant but fluid over time. For example, a certain type of stimuli may be hazardous during particular seasons or at a certain time of the day. Therefore, it became important to encode temporal context alongside item information. However, one might argue that item and order memory are intrinsically linked (can one recall order of an item without recalling the item itself?), with an investigation of order a superfluous replication of Chapter 3. However, Nairne and Kelly (2004) identify item and order memory separately. Nairne and Kelly (2004) described the item recognition paradigm adopted in Experiments 1.1-1.3 as the "ability to remember that a particular item occurred in an experimental context" (pg. 113). Conversely, "order information is measured by the successful reconstruction of an item's absolute or relative position in a sequence or array" (pg. 113). These two tasks, therefore, appear functionally separable. However, there are cross task contamination considerations. For instance, Nairne and Kelly (2004) comment that "it seems reasonable to assume that we can remember an item without remembering the corresponding position, but how can the converse be true? In what sense is it possible to remember the position of an item without remembering the item itself" (pg. 115)? Indeed, for a task such as serial recall, in which the participant is required to recall the sequence items in the original order of presentation, recall of order firstly requires the participant to be able to recall the items. Such a task, therefore, can scarcely be described as "process pure" (Nairne and Kelly, 2004, pg. 113), i.e. uniquely taxing item or order memory.

Nevertheless, Nairne and Kelly (2004) reported a task that intended to separate pure order memory from an order/item contaminated task. A dissociation was demonstrated between the factors that affect the pure serial order memory task, compared to the order/item contaminated task. In their study an inclusion/exclusion paradigm was employed. In the inclusion condition participants were instructed to perform standard serial recall of a 5-word list, i.e. recalling all list items in order of presentation from first to last. In the exclusion condition, participants were instructed to free recall all items in any order, with the exception of the item that occurred in a designated serial position, e.g. serial position two. It was argued that errors in the exclusion condition reflect pure order loss. Phonological similarity (Experiment 1), semantic similarity (Experiment 2) and word frequency (Experiment 3) were all found to improve performance of the inclusion, but not the exclusion, task.

The findings of Experiments 1 and 2 in Nairne and Kelly (2004) appear intuitive, as when trying to recall items from a list, recall will be facilitated if it is known that the to-be-remembered item was phonologically or semantically similar to previous recalled items. That is, phonological/semantic information reduces item competition, thereby restricting the range of possible responses. However, knowledge that list items are phonologically/semantically similar does not provide additional information as to the serial position of these items. Moreover, phonological/semantic similarity may in fact inhibit order recall as associations between specific items and positions appear less distinct due to phonological similarity. Indeed, Nairne and Kelly argued that "knowing that a list is composed entirely of flowers, for example, provides distinctive information that should be useful in guiding recall; however, that same information provides no information about whether an item occurred in the second or third serial position" (pg. 123).

In summary, Nairne and Kelly (2004) concluded that item and order information are empirically separable. The findings add credence to previous studies that have employed alleged contaminated methodologies and revealed item-order dissociations, e.g. Healy (1974) and Bjork and Healy (1974) who found that order but not item errors produced a bowed serial position function. The proposed recognition-recall dissociation is supported by Avons and Mason (1999, Experiment 1) who found that visual similarity impaired serial recall of novel visual patterns, whereas item recognition remained unaffected.

The Familiarity-Recollection Dissociation: Neurological Evidence

Nairne and Kelly (2004) have demonstrated that a pure order task can be affected differ to that of an item-order contaminated task. However, it is conceivable that the 2AFC recognition paradigm reported in Experiments 1.1-1.4 can be performed employing either a familiarity (a process that does not require order information) or a recollection judgment (an explicit memory of the event that can include order memory; Mandler, 1980). In contrast, a serial recall task necessitates recollection alone. Recollection has been defined as "retrieval of qualitative information about a study event, such as when or where an item was encountered" (Yonelinas, Otten, Shaw, and Rugg, 2005, pg. 3002), whilst familiarity is described as an "assessment of continuous memory strength" (pg. 3002). In the 2AFC recognition task in Experiments 1.1-1.4, the participant has to decide which of the two test items was presented previously. This can be determined via either a familiarity judgment (e.g. "I think I received this item at some point") or via a recollection judgment (e.g. "I remember receiving this item, it was third in the sequence"). In contrast, the serial recall paradigm requires recollection information only, as the participant has to recall the point at which that item was presented.

These memorial strategies have been shown to be neurologically separable; that is, familiarity and recollection operate separately, rather than along a single memorial dimension. Brown and Aggleton (2001) argued that the perirhinal cortex underpins familiarity and the hippocampus is responsible for recollection. This dissociation is supported by Yonelinas and colleagues who found that patients exhibiting hippocampal atrophy (induced by mild hypoxia) suffered impaired recollection judgments, whilst familiarity remained intact (Yonelinas, Kroll, Quamme, Lazzara, Sauve, Widaman, and Knight, 2002). This dissociation was replicated with rodents by Fortin et al. (2002) who performed neurotoxic lesions upon the rat hippocampus. The lesion impaired performance of the relative recency task (a task that required recollection of order) but not performance of the 2AFC recognition task (a task that can be performed employing familiarity judgments only).

Furthermore, Yonelinas, Otten, Shaw, and Rugg (2005) employed functional magnetic resonance imaging (fMRI) to scan participants whilst they made recognition judgements on previously presented words. Participants were required to state (1) if they recollected viewing that word in the previous sequence, (2) their level of confidence that the word had been presented previously in the experiment (taken as an index of familiarity) or (3) state that the word was novel to the experiment. Yonelinas et al. (2005) demonstrated a double dissociation, wherein neural activity was qualitatively different across recollection and familiarity judgments. Furthermore, Woodruff, Johnson, Uncapher, and Rugg (2005) investigated the dissociation between recollection and familiarity via a reinstatement approach. According to this reinstatement interpretation, retrieval involves the reinstatement of cortical activity that occurred during the initial processing episode. Analogous to the Yonelinas et al. (2005) study, participants stated if they recollected or were familiar with the test probes. Woodruff et al. (2005) found that remembered items (recollection) elicited greater activation in the right hippocampus and parahippocampal gyrus than items given know (familiarity) judgments.

Moreover, in the clinical domain, evidence exists demonstrating a double dissociation between memory of content and context. Glisky, Polster, and Routhieaux (1995) divided elderly patients into two groups on the basis of frontal lobe function. The two groups did not differ on a test of sentence content memory. However, on a test of memory for the voice in which the sentence was spoken, the high-frontal function group outperformed those with low frontal function. When the same participants were then divided on basis of medial temporal lobe function (MTL), the high MTL functioning group outperformed the low group on sentence memory demonstrating no difference on memory for voice. The findings of the study suggest that separate cortical areas are employed for content and context memory.

The findings of Nairne and Kelly (2004) coupled with the neurological evidence of separate processes for familiarity and recall provides credence for investigating order memory. Brown and Aggleton (2001), for example, propose that familiarity (a strategy that could be employed for 2AFC recognition) utilises the perirhinal cortex, whereas recall (a strategy required for positional memory) utilises the hippocampus. If correct, these two systems may indeed operate differently and therefore merit investigation.

Positional Memory: The Relative-Recency Paradigm

The aforementioned studies indicate that item (e.g. recognition) and order memory (e.g. positional recall) differ with respect to both neurological origins and the effect of stimulus characteristics. However, despite the aforementioned empirical dissociations, there is some evidence that item and order tasks produce analogous serial position functions when the tasks are similar. For example, recency has been observed when a single sequence of items has been followed by a single 2AFC recognition pair. As previously described, this has been demonstrated for both visual matrices (Avons et al., 2004; Kerr et al., 1999) and odours (Miles and Hodder, 2005). The procedurally similar 2AFC relative recency task has been applied to both visual and olfactory stimuli. In this task, order, rather than item information is probed. Identical to the single 2AFC recognition test-pair paradigm, a sequence of items are presented to the participant followed directly by a single test-pair. In the 2AFC recognition paradigm, one item in the test-pair is familiar and the other item is novel; the response necessitates a familiarity judgment. In contrast, in the 2AFC relative recency paradigm, both items in the test-pair were in the previous sequence. One item was presented more recently in the sequence than the other. The participant is required to state which of the two test items appeared latest within the previous sequence. This task, therefore, does not necessitate item information, as the items are re-presented, but requires the participant to provide a recency order-based distinction.

The 2AFC recognition and relative recency tasks are, therefore, similar with respect to list presentation, interference levels at test (i.e. two items are experienced at test) and response type (i.e. a binary first/second decision). Avons et al. (2004, Experiment 2, 3b, 5) presented participants with sequences of 4-8 matrix patterns that were followed at test by a single 2AFC relative recency test-pair (wherein the test items were presented simultaneously) containing items of adjacent positions from the preceding sequence. Single-item recency was found in all but one instance (in Experiment 5, the 6-item sequence revealed recency which extended over the two most recent pairs). The equivalent performance for pre-recency items was not due to an inability to perform the task as accuracy remained above chance for all adjacent pairs. The findings demonstrate some similarity to the recency in the absence of primacy observed following a single 2AFC recognition test-pair (Avons et al., 2004, Experiment 1).

The 2AFC relative recency paradigm can produce problems for models devised to account for order memory. Avons et al. (2004) argued that the absence of primacy is contrary to serial order accounts that employ a vector discrimination model. For example, in Henson's (1998) Start-End Model, the first and terminal sequence items are employed as two-dimensional markers from which the position of each middle item is stored. According to such an account, recall at the pole items should be superior as middle item recall is dependent upon these items, i.e. the pole items are employed as markers for memory of middle items.

Similarly, it is argued that the single-item recency observed (i.e. the absence of graded recency) contradicts models that favour temporal distinctiveness (e.g. OSCAR; Brown, Preece, and Hulme, 2000). Under such an account, as items within the sequence become relatively less recent, their level of distinctiveness should gradually reduce. This should produce a graded recency as distinctiveness (the ability to discriminate between items) diminishes. However, graded recency was not observed.

However, the relative recency function, that lacks primacy, is argued by Avons et al. (2004) to be consistent with the Primacy Model (Page and Norris, 1998). This is because the "constant level of performance across pre-recency positions would suggest that serial order precision was constant throughout the list, a finding consistent with linear gradient of activations that form the basis of the primacy model" (pg. 873). It is argued that if the activation decreases linearly throughout the list, the activation level differences between successive list items will be equivalent (relatively but not absolutely). Therefore, when the relative recency judgment is required, the difference in activation levels between items in each test-pair will be equivalent, thus, producing equivalent performance levels for each test-pair. The model predicts, therefore, that serial position effects should not be found except for the terminal item which is held within a short-term visual memory.

However, the findings of Avons et al. (2004) were not replicated with verbal stimuli. Greene, Thapar, and Westerman (1998, Experiment 3) applied the 2AFC relative recency paradigm to 8-item sequences of 7-letter words. Each word was presented at a 3000 ms rate and sequences were followed by a pair of list items, from which the participants were required to indicate which of the words was presented latest in the list. In this experiment, the distance between the two alternatives was always four positions (i.e. the first position item was paired with the fifth, the second paired with the sixth, the third paired with seventh, and the fourth position paired with the eighth). No effect of test-pair composition was found ($F<1$), i.e. no evidence of recency or primacy. The absence of serial position effects was not an artefact of ceiling effects, as mean proportion correct was at 0.71. The finding suggests that the recency reported by Avons et al. (2004) may not generalise to verbal stimuli.

However, in direct contradiction to Greene et al. (1998), White and Treisman (White, 1992; White and Treisman, 1997) have applied the relative recency paradigm to odours and verbal stimuli and reported serial position effects for both modalities. Unlike the Avons et al. (2004) and Greene et al. (1998) studies where the test-pair items were presented simultaneously, odours cannot be perceived concurrently and, therefore, the test-pair items were presented sequentially. Initially, the task was applied to verbal stimuli, wherein a sequence of 10 consonants was followed by a test-pair that comprised adjacent items. White (1992) found strong recency and some evidence of primacy (Experiment 4). This primacy component was heightened following the introduction of lengthened ISIs (Experiment 5), a finding consistent with increased opportunities for verbal rehearsal. The presence of primacy is consistent with Donaldson and Glathe (1969) who presented participants with a sequence of 5-digits (each presented for 500 ms, followed by a 500 ms ISI). Following an intervening series of eight digits, a single test-pair comprising adjacent list items was presented and the participant was required to state if the test-pair was in the same or reversed order compared to the original sequence. Participants demonstrated both strong primacy and recency, indicating that 2AFC relative recency discriminations of verbal stimuli may be characterised by both the presence of primacy and recency.

However, White and Treisman (1997) were unable to replicate the finding of primacy with either employing odour names (Experiment 1) or consonants presented at a faster rate (Experiment 2). In both experiments graded recency was found but no evidence of primacy. The authors then applied the task to olfactory stimuli and revealed recency but no evidence of primacy for a 10-odour sequence (White, 1992, Experiments 3 and 7) and recency confined to the last pair for a 5-odour sequence (White and Treisman, 1997, Experiment 3).

The White (1992) and White and Treisman (1997) studies are important for two reasons. First, they demonstrated serial position effects for order memory of olfactory stimuli; a paradigm in its infancy. Second, these studies demonstrated that olfactory stimuli, analogous to both visual-verbal (White and Treisman, 1997) and visual-non-verbal (Avons et al., 2004), demonstrated recency but not primacy in 2AFC relative recency judgments. However, in the adapted 2AFC relative recency paradigm employing sequential presentation of the test-pair (White, 1992; White and Treisman, 1997), only the 5-odour sequence produced the single item recency reported by Avons et al. (2004). However, it is unclear the extent to which these cross-paradigm discrepancies are due to the task, i.e. does simultaneous presentation of the test-pair induce a different memorial mechanism/strategy, or is the disparity due to presentation time differences (in the White and Treisman studies the retention interval was 3250 ms, whereas in Avons et al. the interval was 1000 ms). Furthermore, in White and Treisman (1997) an interleaving tone was employed between the presentations of each list item as a preparatory indicator of next item presentation. This manipulation was not employed in Avons et al. (2004).

The absence of primacy for 2AFC relative recency judgments of odours (White, 1992; White and Treisman, 1997), *a priori*, suggests that participants are not verbally labelling and sub-vocally rehearsing the odours. However, the absence of primacy for verbal 2AFC relative recency judgments (White and Treisman, 1997, Experiments 1 and 2) indicate that primacy can, in fact, be absent when verbalisation is present. The finding, therefore, suggests that the paradigm does not exhibit primacy irrespective of stimuli employed. The absence of primacy in the olfactory study does not, therefore, demonstrate that olfactory order memory can operate without verbal labelling/rehearsal.

As discussed in the introduction to Chapter 3, one method in which to eliminate the role of verbal labelling is via the use of a non-human animal sample. Fortin et al. (2002) presented rats with a sequence of 5 odours followed, at test, by a single 2AFC test-pair (the duration of each odour presentation was 2.5 mins followed by a 3 mins retention interval). Rats were rewarded for choosing the odour that occurred earliest in the sequence. The composition of the test-pair was divided into three sub-groups; Lag 1 (i.e. one item separated the two test items in the original sequence, e.g. positions 1 and 3 were tested), Lag 2 (i.e. two items separated the two test items in the original sequence, e.g. positions 1 and 4 were tested), Lag 3 (i.e. three items separated the two test items in the original sequence, e.g. positions 1 and 5 were tested). Lag increments appeared to produce greater accuracy consistent with the idea that the test items possessed higher temporal distinctiveness. Furthermore, following the Lag 2 condition, recency judgments were more accurate for the pair containing the terminal item in the sequence (recency). Following the Lag 1 condition, extended recency appeared evident, wherein accuracy for the pairs containing the terminal and penultimate sequence items was superior to the third pair containing the first sequence item.

The findings of Fortin et al. (2002) further substantiate the absence of primacy for the olfactory relative recency paradigm. However, the apparent extended recency contradicts the single-item recency reported for odours by White and Treisman (1997). However, it should be noted that (1) presentation times differed substantially between the two studies and (2) only adjacent list items were employed in the White and Treisman (1997) study. The role of 'lag' within the relative recency test-pair, therefore, necessitates further research.

It should be noted that despite the apparent similarities between the functions produced for 2AFC recognition (e.g. Avons et al., 2004, Experiment 1) and 2AFC relative recency (Avons et al., 2004, Experiment 2), neurological evidence exists dissociating the mechanisms that underpin each task. Milner, Corsi, and Leonard (1991) compared the impairment to an item recognition and relative recency task experienced by lesion patients. The temporal lobe excision groups were all impaired on the item recognition task except for the group exhibiting excisions extensively on the lateral, medial and orbitofrontal region. In contrast, impairment on the relative recency task was associated with groups exhibiting frontal lobe damage, whereas no impairment was found for patients exhibiting lesions confined to the right temporal lobe. Milner et al. (1991) argued the findings suggest neurological dissociation between the processes underlying recognition and order memory.

In summary, aforementioned studies have demonstrated that the 2AFC relative recency paradigm can produce serial position effects. The task does not require absolute recollection of order per se, but requires a judgment between two test items with respect to which occurred latest in the list. Crucially, this paradigm has been shown to produce serial position function effects with odours (White and Treisman, 1997) demonstrating that (1) participants are capable of remembering the order of odours and (2) odours possess a benefit for the latest list item in recalling order

Positional Memory: The Single-Probe Serial Recall Paradigm

Another method by which serial order is examined is via the single-probe serial recall paradigm. In this paradigm participants are presented with a sequence of items. At test a single item from the previous sequence is presented and the participant is required to state the serial position of that item in the preceding list. As previously described, the 2AFC relative recency task requires a binary judgment based upon which item in the pair appears more recent. In contrast to that task, single-probe serial recall necessitates the participant to recollect the exact position in the list from which the item derived; requiring an absolute, rather than relative, judgment.

Korsnes, Magnussen, and Reinvang (1996) presented participants with a sequence of 4-items followed at test by a single test probe in which they were required to state the absolute position of the item within the previous list. Although Korsnes et al. (1996) described the task as "a four-choice recognition task" (pg. 64), the depiction is clearly misleading, as an ability to recognise the stimuli will not facilitate task performance; the participant must, instead, recollect the temporal point in the sequence at which the item was presented. In Experiment 1 participants received a sequence of 4-black and white abstract patterns (0.5 s exposure time followed by a 1 s ISI). A single test probe followed a retention interval of 5 s, 15 s or 25 s. Korsnes et al. (1996) reported recency following the 5 s retention interval, a shift to primacy and recency at 15 s and a further shift to unitary primacy at intervals of 25 s. This transient shift was supported by pairwise analysis at each retention interval and by a significant interaction between serial position and retention interval.

Experiment 2 in Korsnes et al. (1996) closely followed the first experiment but employed nouns as the to-be-remembered stimuli. The test probe comprised of a pictorial representation of the probed noun so as to enforce a response based upon semantic information rather than a visual memory for the spatial pattern of the word. Korsnes et al. (1996) reported similar recency-to-primacy shifts as demonstrated in Experiment 1, with the exception that stronger primacy was found at the 5 s retention interval. The authors argued that this primacy component disparity for words was an artefact of verbal rehearsal within the ISIs. Despite these apparent cross-modal function inconsistencies, when compared across experiments, a main effect of stimuli was reported but, crucially, not a significant interaction between stimuli and serial position. Korsnes et al. (1996) argued that this finding indicates that similar memory processes are involved in the coding, storage and retrieval of visual-spatial and verbal stimuli.

Korsnes and Magnussen (1996) compared the data collected for young participants (23-35yrs) in Korsnes et al. (1996) to a sample of elderly participants (60-75yrs) employing identical methodologies. Korsnes and Magnussen (1996) found similar trends for older subjects compared to that of young participants (Korsnes et al. 1996) following employment of both abstract patterns and nouns across the three retention intervals (although overall accuracy levels were lower for the older group). The consistent trends across ages indicated that elderly memorial deficits are characterised by quantitative rather than qualitative variations.

Korsnes et al. (1996) argued that at the 5 s retention interval, the functions are consistent with a temporal distinctiveness account; whereby an item is better remembered if it appears more distinct/individual from the other list items (e.g. Neath, 1993). Following lengthened retention intervals, recency is attenuated as the apparent temporal separation between the terminal item and other pre-recency items is reduced. Korsnes et al. (1996) compared their functions to those predicted by Neath's (1993) distinctiveness model and found that although the model accommodates immediate testing well, it does not fully accommodate the extent of recency attenuation and primacy development following increased intervals.

Kerr et al. (1998) replicated the single-probe serial position methodology, presenting participants with a sequence of 4-unfamiliar faces (each face displayed for 1 s followed by a 1 s ISI). Following a retention interval of 0 or 10 s, a probe face taken from the previous sequence was presented. The participant was required to state the position of that item. At immediate testing, strong recency was found and some evidence of negative primacy. Following the 10 s retention interval, recency attenuated but there was no evidence of primacy developing.

However, analysis of response frequency in Kerr et al. (1998) revealed that the distribution of responses was biased, i.e. responses for serial positions were not equally distributed. At immediate testing a response bias was found at serial position 2 to the detriment of the first serial position. Following the 10 s retention interval, the response bias shifted, in that positions 1 and 2 were employed as responses more frequently to the detriment of positions 3 and 4. Such a bias produces a potentially disingenuous function, as the more frequently a position is employed as a response, the greater the probability that it will yield an accurate response. For example, if the participant is guessing throughout the experiment, a response bias for a position will increase the likelihood of inflated accuracy for that position, as the probability of a correct hit is increased. In contrast, the position that is employed as a response less frequently has a reduced probability of gaining a correct hit due to receiving fewer responses. The bias will, therefore, produce a distorted function based upon the frequency of responses rather than memory accuracy of these positions.

Kerr et al. (1998) employed a method of correction aimed at estimating the proportion of certain responses. Following the correction, a flat serial position function with unitary recency was observed at immediate testing and an apparent absence of serial position effects was found following the 10 s retention interval. This observation was supported by a significant interaction between serial position and retention interval for the corrected data. A simple main effect at serial position 4 was found to be responsible for the interaction and no other simple main effects of serial position were significant. These functions were replicated in Experiment 2 using a mixed order of intervals, i.e. a retention interval of 0 or 10 s was presented in random order rather than blocked. The finding suggests that the functions were not an artefact of implementing different encoding strategies at each retention interval.

Kerr et al. (1998) argued that the response bias observed for this paradigm is due to uncertainty. They proposed that (1) guessed responses are particularly predisposed to biased responding and (2) that participants were generally more confident of later list items (i.e. positions 3 and 4) and less confident of early list items, i.e. positions 1 and 2. Therefore, they proposed that participants were less likely to allocate guesses to positions they were more confident about (i.e. positions 3 and 4) and consequently, when unsure, assigned guesses to early list items. This strategy underpinned the response bias. This interpretation is supported empirically, as the participants who exhibit enhanced primacy over extended retention intervals generally demonstrated a high degree of response bias and poorer overall serial position recall.

The response bias highlighted by Kerr et al. (1998) indicates that the recency-to-primacy shift demonstrated by Korsnes and colleagues (Korsnes et al., 1996; Korsnes and Magnusssen, 1996) may not be characteristic of single-probe serial recall memory but artificially produced by more frequent responding for certain positions. These findings suggest that at immediate testing, single-item recency is present and primacy is absent. Following increased intervals, recency attenuates producing a flat serial position function. It is unclear what mechanism may underpin this function, although the attenuation of recency following increased intervals can be accommodated by several accounts. For example, under a duplex interpretation (Phillips and Christie, 1977), heightened serial position recall accuracy of the terminal list item might be explained via storage within the fragile STS at test. Following increased intervals, this item is displaced into the more durable, but less accurate, LTS. At lengthened retention intervals, storage of all items within this LTS predicts the absent of serial position effects. However, such an explanation extends the function of the STS to incorporate contextual information in addition to item knowledge. Since familiarity and recollection have been demonstrated as both functionally and neurologically distinct (e.g. Brown and Aggleton, 2001), recency for single-probe serial recall requires two distinct types of information held within the STS.

Alternatively, representation of the terminal sequence item within the STS may result in the participant deducing that the item was terminal in the sequence due to its strong trace of familiarity. Parsimoniously, the function might be explained in terms of an exponential decay in the temporal trace of each item, wherein a large initial decay in temporal accuracy occurs followed by a slowing of decay rate over longer retention intervals. At immediate testing, the terminal item, unlike the pre-recency items, might not have experienced the initial trace decay therefore producing single-item recency. Following increased retention intervals, all list items suffer the initial rapid decay in accuracy thus generating the flat function. As previously described, this recency attenuation is also accommodated by a temporal distinctiveness account (e.g. Neath, 1993). In this account increased intervals induce a reduction in apparent temporal separation between the terminal item and pre-recency items.

However, the aforementioned functions are difficult to accommodate with some models of memory. Models that attach a fundamental role of first item memory to subsequent list recall have problems accounting for the absence of primacy (even at immediate test) in the single-probe serial recall paradigm. For example, in Henson's (1998) Start-End Model, the employment of pole items as recall markers for middle positions suggests that recall of the first item should be superior to the middle items. Similarly, in the Primacy Model (Page and Norris, 1998), a linear activation gradient is generated during encoding wherein the first item has highest activation. Largest activation for the first item at encoding suggests that this serial position should be recalled with greatest accuracy, this was not found.

In summary, the single-probe serial position recall paradigm is a task that requires participants to proide an absolute positional judgment. That is, unlike the 2AFC relative recency paradigm the participant must recollect the exact position of the item in the sequence. Furthermore, this task also allows one to investigate the distribution of errors, i.e. how close a response is to the correct position. This also is not possible with the relative recency task. However, one problem with the paradigm is the inherent response bias highlighted by Kerr et al. (1998). Consequently, any reported functions must follow a correction for the bais. The correction, therefore, impacts the validity and reliability of reported functions.

Notwithstanding the aforementioned concerns, the following series of experiments investigates the functions produced for immediate single-probe serial position recall of a range of hard-to-name stimuli (odours, unfamiliar faces and pure-tones). Previous olfactory serial order recall studies have been contaminated by verbal labelling (e.g. Miles and Jenkins, 2000). Other odour order studies have been limited to the relative recency paradigm (White, 1992; White and Treisman, 1997). No known studies exist investigating the extent to which participants can retrieve the absolute position of odours. If participants can make these absolute positional judgments it is unclear if the function produced is equivalent to that generated by single-probe serial recall of other non-verbal stimuli.

Experiment 2.1

The aim of Experiment 2.1 was to identify the extent to which single-item recency, observed following single-probe serial recall with both faces (Kerr et al., 1998) and abstract patterns (Korsnes et al., 1996), extends to odours. Kerr et al. (1998) reported a response bias at earlier serial positions and proposed that the positions that participants were least certain of were employed as default guessing positions. Such a bias had been evident in pilot studies (n=24) employing longer exposure times than Kerr et al. (3000 ms exposure, 2000 ms ISI), wherein 5-odour sequences demonstrated a response bias at serial position 2 and 6-odour sequences demonstrated a bias at both positions 2 and 3. To investigate the hypothesis that uncertainty underpinned the response bias, an additional dependent variable of confidence rating was taken following each response.

Odour presentation times were shortened from the 3000 ms exposure time employed in Experiments 1.1a and b to 1000 ms in preparation for cross-modal comparisons. It was decided that the presentation procedure should be constant cross-modally and that longer presentation times for unfamiliar-faces may result in ceiling effects. Furthermore, there is evidence that a 1000 ms presentation time is sufficiently long for participants to perform olfactory memory tasks (Miles and Hodder, 2005, Experiment 2). In both Kerr et al. (1998) and Korsnes et al. (1996) only 4-item lists were employed. It is, therefore, unclear if the function reported in these studies can be generalised over varying sequence lengths. Although producing a main effect of sequence length, Ward et al. (2005) reported that changes in sequence length for nonword or abstract pattern lists did not qualitatively affect the serial position function produced for either serial order reconstruction or 2AFC recognition. Experiment 2.1(a-c) investigated the consistency of function for single-probe serial recall of olfactory stimuli for 4-, 5- and 6-odour sequences. If the functions produced for single-probe serial position recall of odours replicate that for visual stimuli (Kerr et al., 1998), one might predict a main effect of serial position and a terminal item benefit following further analysis. The methodology for each sub-experiment will be the same with the exception that sequence length differs.

Experiments 2.1(a-c)

Method.

Participants. There were twenty-four participants in each experiment. All were Cardiff University volunteer Psychology undergraduates who participated in exchange for course credit. Participants suffering from a blocked nose or cold were excluded. Participants were prevented from participating in more than one of the 3 experiments. Details of the participants are:

Experiment 2.1a (4-odour sequences): 1 male and 23 female (mean age 19 years and 1 month, 24 non-smokers).

Experiment 2.1b (5-odour sequences): 4 male and 20 female (mean age 19 years and 0 months, 21 non-smokers).

Experiment 2.1c (6-odour sequences): 5 male and 19 females (mean age 21 years and 4 months, 21 non-smokers).

Materials. Odours were selected at random from the 120 odours employed in Experiment 1.1a. In Experiment 2.1a, 40 odours were employed. In Experiment 2.1b, 50 odours were employed. In Experiment 2.1c 54 odours were employed.

Design. Experiments 2.1(a-c) employed a within-subjects design. The dependent variable was the proportion of correct serial position judgements for each serial position. The independent variable was serial position and comprised four levels (1, 2, 3 and 4) in Experiment 2.1a, five levels (1, 2, 3, 4 and 5) in Experiment 2.1b and six levels (1, 2, 3, 4, 5 and 6) in Experiment 2.1c. Each serial position was tested 10 times in Experiment 2.1a and 6 times in Experiments 2.1b and 2.1c. In Experiment 2.1a 40 trials were divided into ten blocks, with each block testing each of the four serial positions once in a randomised order. In Experiment 2.1b and Experiment 2.1c the 30 trials and 36 trials respectively were divided into 6 blocks, with each block testing each of the five/six serial positions once in a randomised order. The presentation order of blocks was randomised across the participants. In Experiment 2.1a each of the 40 odours was presented four times: once in each quartile of the experiment. In Experiment 2.1b each of the 50 odours was presented three times, once in each third of the experiment and in Experiment 2.1c each of the 54 odours were presented four times throughout the experiment, once in each quartile. The order of odour presentation, and indeed the odour set chosen for each participant, was randomised for each participant.

Procedure. The presentation phase was as described for Experiments 1.1a and b, with the exception that each odour was presented for 1000 ms with a 1000 ms ISI. The test phase reflected the method reported by Kerr et al. (1998). A single odour taken from the previous sequence was held under the nose of the participant for a period of 1000 ms and the participant was required to verbally identify the serial position of the test odour, i.e. "first", "second", "third", "fourth", "fifth" or "sixth". Following the response, participants were required to provide a confidence rating with respect to how certain they were of their response. The rating was on a scale of 1-5 with 1 being "not at all certain" and 5 "extremely confident".

Results

Non-Standardised Serial Position Recall Analysis

Figure 2.1(a-c) shows the mean percentage correct recall as a function of serial position for sequences of 4- (Figure 2.1a), 5- (Figure 2.1b) and 6- (Figure 2.1c) odours. A single-factor within-subjects ANOVA was computed for Experiments 2.1(a-c).

4-odour sequences: A null effect of serial position was found, $F<1$.

5-odour sequences: A null effect of serial position was found, $F<1$.

6-odour sequences: A null effect of serial position was found, $F=1.77$.

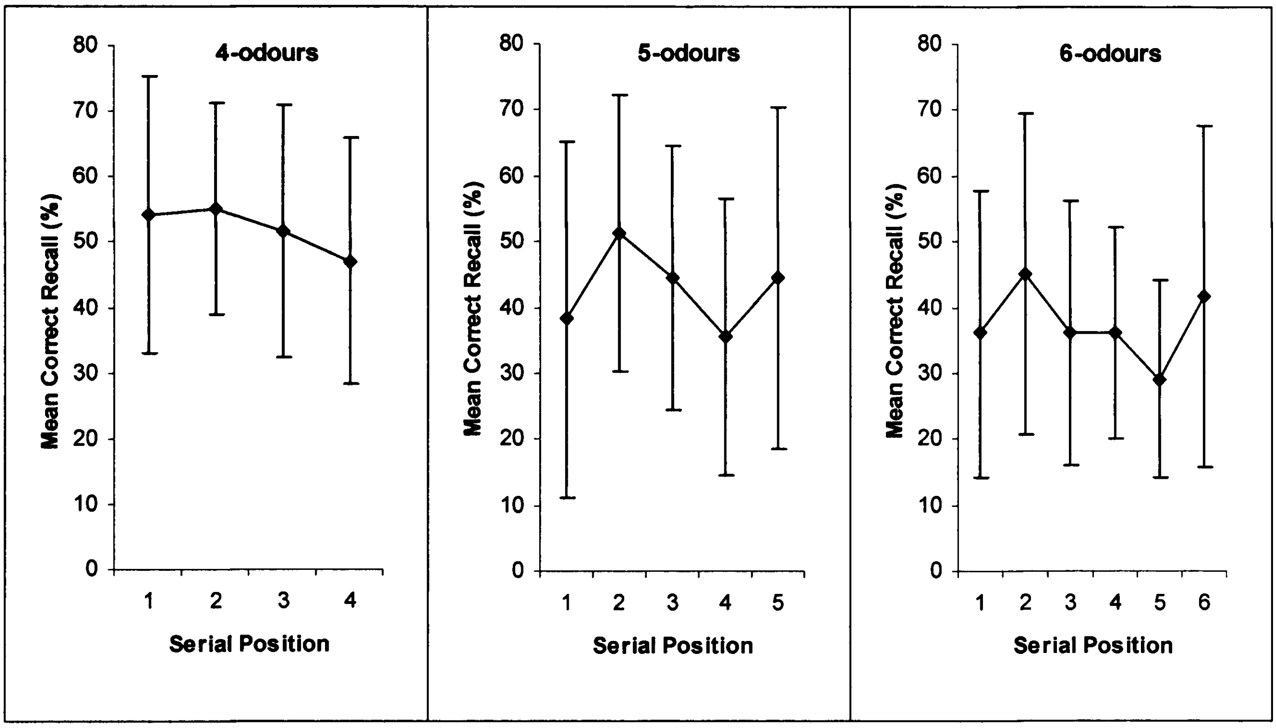


Figure 2.1(a-c): Mean percentage correct recall for sequences of 4- (a), 5- (b) and 6- (c) odours as a function of serial position. Error bars denote 1 standard deviation.

Response Bias Serial Position Analysis

There is no *a priori* rationale to predict the enhanced, although not significant, performance at serial position 2 across Experiments 2.1(a-c). However, based upon the findings of Kerr et al. (1998), it is possible that elevated performance reflects a response bias. Response distribution was, therefore, investigated to assess any potential confound induced by a position bias. Across Experiments 2.1(a-c), the distribution of responses was examined via single-factor within-subjects ANOVAs and revealed an uneven spread of responses across serial position (see Figure 2.2a-c).

4-odour sequences: Total responses attributed to positions 1-4 were 24.2%, 31.04%, 24.58% and 20.21% respectively (an equal distribution of responses across serial positions is denoted by the dotted line in Figure 2.2a). A significant main effect of serial position was found, $F(3,69)=5.45$, $MSe=14.18$. Further analysis (Newman Keuls) revealed that the response frequency for position 2 was significantly greater than positions 1, 3 and 4.

5-odour sequences: Total responses attributed to positions 1-5 were 15.42%, 25.69%, 23.47%, 17.22%, and 18.19% respectively (an equal distribution of responses across serial positions is denoted by the dotted line in Figure 2.2b). A significant main effect of serial position was found, $F(4,92)=7.20$, $MSe=5.68$. Further analysis (Newman Keuls) revealed that the response frequency for both positions 2 and 3 to be significantly greater than positions 1, 4 and 5.

6-odour sequences: Total responses attributed to positions 1-6 were 11.92%, 22.57%, 20.95%, 16.09%, 11.57% and 16.90% respectively (an equal distribution of responses across serial positions is denoted by the dotted line in Figure 2.2c). A significant main effect of serial position was found, $F(4,115)=7.11$, $MSe=8.93$. Further analysis (Newman Keuls) revealed that the response frequency for position 2 was significantly greater than positions 1, 4 and 5. Response frequency for position 3 was significantly greater than positions 1 and 5.

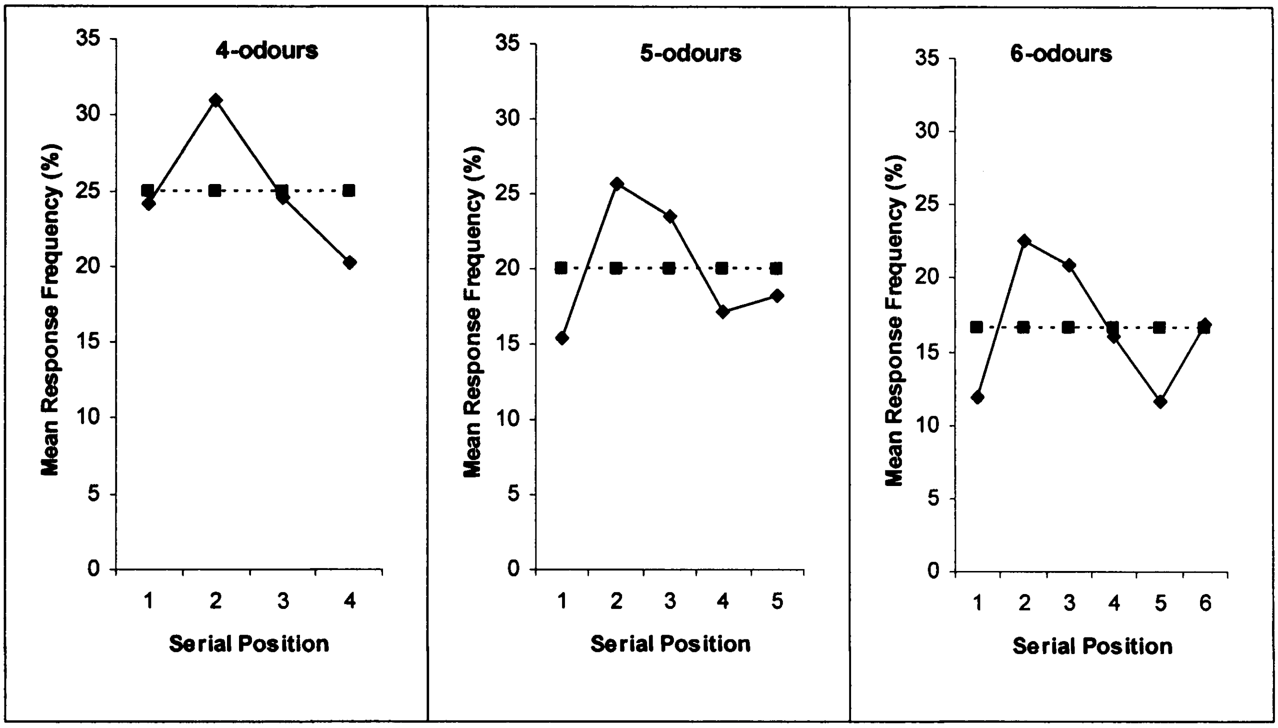


Figure 2.2(a-c): Mean percentage response frequency for sequences of 4- (a), 5- (b) and 6- (c) odours as a function of serial position. An equivalent distribution of responses across serial positions is depicted by the dotted line.

Corrected Recall Serial Position Analysis

An increase in total response frequency to a particular serial position increases the probability of a correct response for that position. Conversely, the probability of correctly responding for positions that receive fewer responses is reduced. Therefore, the bias was modified following the correction procedure proposed by Kerr et al. (1998), in which the corrected proportion of correct responses for each position is calculated via the "proportion of correct responses at each serial position multiplied by the number of responses correct for that serial position" (pg. 1319). Kerr et al. (1998) provide an equation for this correction: $k = (C_k/X) \times (C_k/N_k)$, where C_k is the number of correct responses at the serial position of k, X is the average number of responses for each serial position and N_k is the total number of position k responses. The calculation is applied to the responses for each serial position by each participant. For example, the first participant provided 7 correct answers for serial position 2 (Ck=7) and responded serial position 2 on a total of 12 occasions (Nk=12). The average number of responses for each serial position was 10 (X=10). Therefore:

Corrected responses for serial position k = $(C_k/X) \times (C_k/N_k)$

Corrected responses for serial position 2 = $(7/10) \times (7/12) = 0.41$ *(2dp)*

This method of correction aims to partial out those responses that are due to chance and, therefore, that are a product of guessing, whilst preserving the responses that the participant was certain about.

Figure 2.3(a-c) shows the mean correct recall at each serial position following correction of the data for the response bias in Experiments 2.1(a-c).

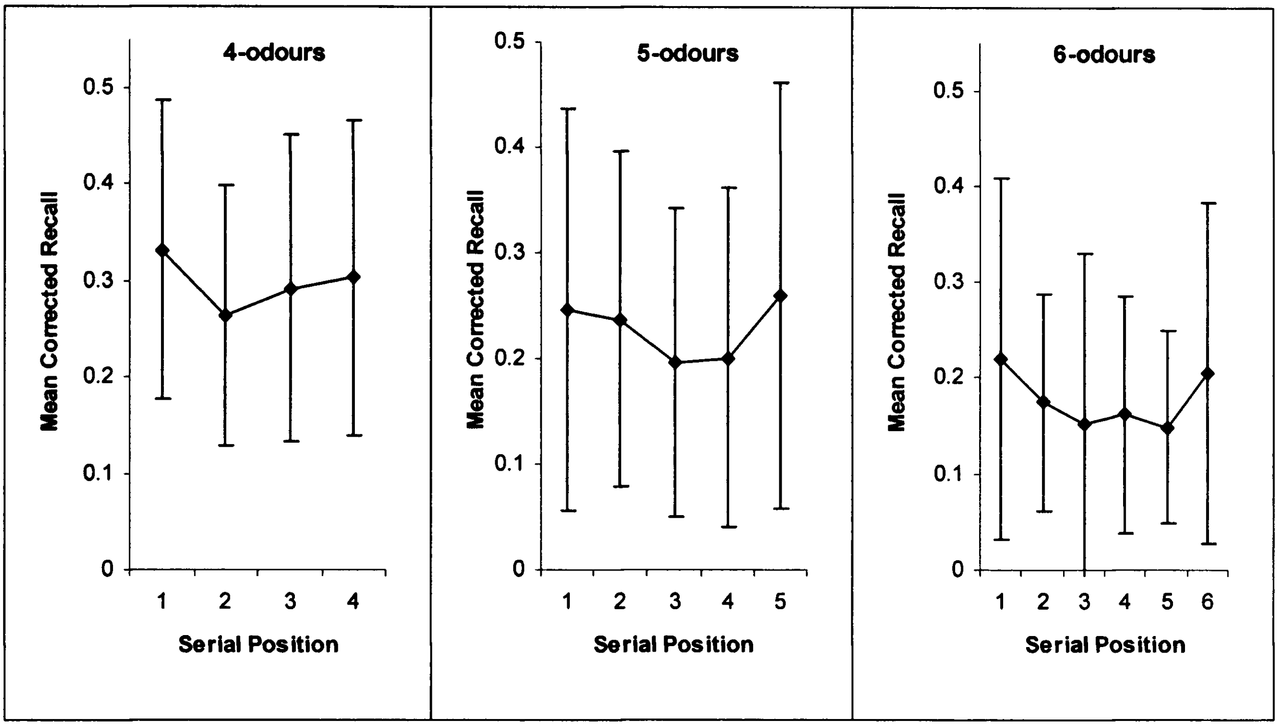


Figure 2.3(a-c): Mean corrected recall for sequences of 4- (a), 5- (b) and 6- (c) odours following a correction for response bias as a function of serial position. Error bars denote 1 standard deviation.

A single-factor within-subjects ANOVA was computed on the corrected recall data for Experiments 2.1(a-c).

4-odour sequences: A null effect of serial position was found, F=1.27

5-odour sequences: A borderline main effect of serial position was found, $F(4,92)=2.16$, MSe=1.55, $p=.08$.

6-odour sequences: A null effect of serial position was found, $F=1.08$

Trend Analysis

Trend analysis was performed on the corrected recall scores of Experiments 2.1(a-c).

4-odour sequences: Both a non-significant quadratic component, $F=2.49$, and a non-significant linear component, $F<1$, were found.

5-odour sequences: Both a non-significant quadratic component, $F=2.00$, and a non-significant linear component, $F<1$, were found.

6-odour sequences: Both a non-significant quadratic component, $F=2.45$, and a non-significant linear component, $F<1$, were found.

The non-significant trend components are consistent with the absence of serial position effects revealed by the serial position ANOVA.

Response Distribution Analysis

In a recent paper investigating the reconstruction of serial order for unfamiliar-faces, Smyth et al. (2005) reported the distribution of responses for each serial position to assess the extent to which transposition errors were close to the correct position. Smyth et al. (2005) found that transposition errors were most likely to occur with adjacent items. The same analysis was conducted on the responses for each serial position in Experiments 2.1(a-c). Figure 2.4 demonstrates the response distributions for positions 1-4 in Experiment 2.1a.

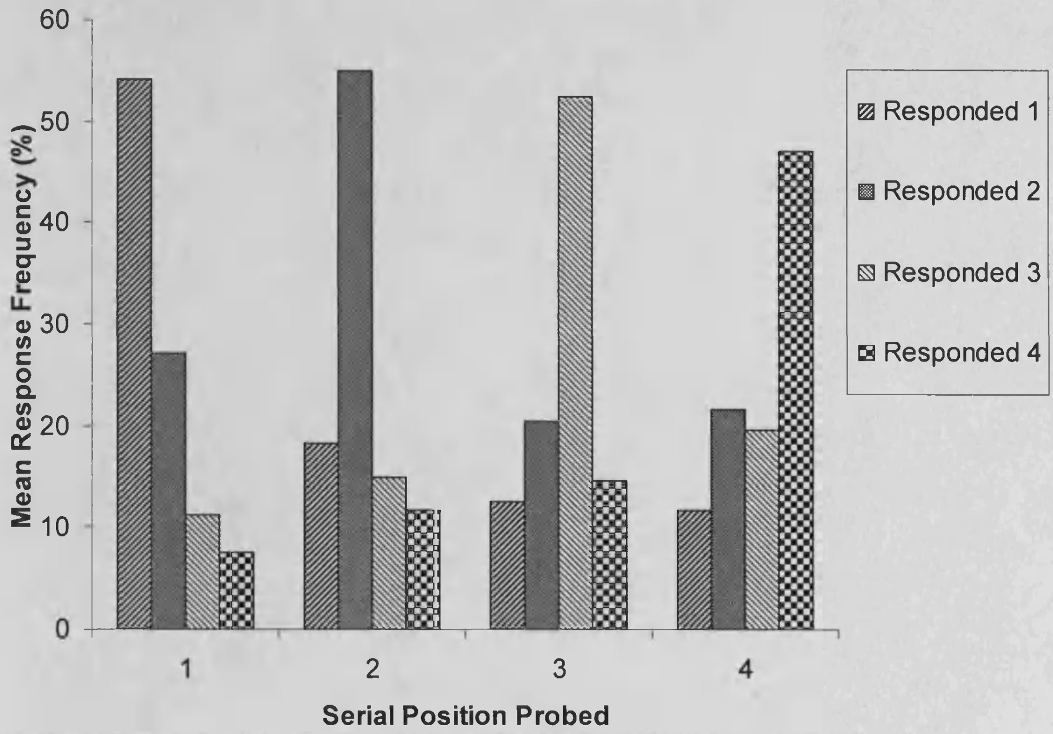


Figure 2.4: Mean percentage serial position response distribution for positions 1-4 as a function of serial position.

The mean displacement distance for incorrect responses (1, 2, or 3 serial positions) was calculated across the 40 trials for each participant. This was calculated by dividing the number of displacements for each displacement distance by the number of opportunities in which that type of error could be made (see Chapter 2: Statistical Methodology). For example, there are 6 different opportunities in which a displacement of 1 position can occur (i.e. this error can be made on adjacent positions when position 2 and 3 are probed and on one adjacent side of the terminal items), but only 2 opportunities in which a 3-position displacement can occur (i.e. when position 1 is probed but position 4 is erroneously recalled and vice versa). A single-factor ANOVA was computed on the displacement data for Experiments 2.1(a-c).

4-odour sequences: A main effect of displacement distance was found, $F(2,46)=9.31$, $MSe=9.31$. Further analysis (Newman Keuls) revealed that displacements were significantly more frequent for adjacent positions (i.e. a displacement of 1) than displacements of 2 or 3 positions. Furthermore, displacements of 2 positions were also found to be significantly more frequent than for 3 position displacements.

The same analysis was conducted for Experiment 2.1b, and the distribution of errors is demonstrated in Figure 2.5.

5-odour sequences: A main effect of displacement distance was found, $F(3,69)=5.05$, $MSe=0.21$. Further analysis (Newman Keuls) revealed that errors were allocated significantly more frequently to adjacent serial positions than across 2, 3 or 4 positions.

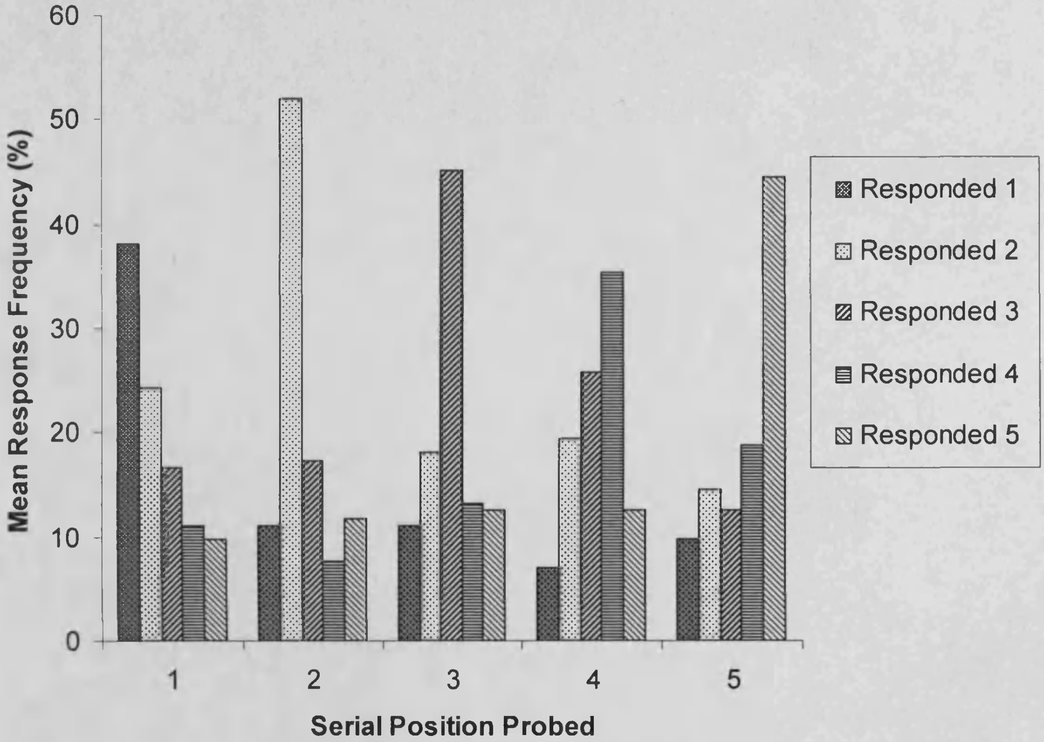


Figure 2.5: Mean percentage serial position response distribution for positions 1-5 as a function of serial position.

The distribution of responses for each serial position in Experiment 2.1c is demonstrated in Figure 2.6.

6-odour sequences: A main effect of displacement distance was found, $F(4,92)=10.74$, $MSe=0.12$. Further analysis (Newman Keuls) revealed that displacements of 1 serial position were significantly more frequently than displacements of 2, 3, 4 or 5 positions.

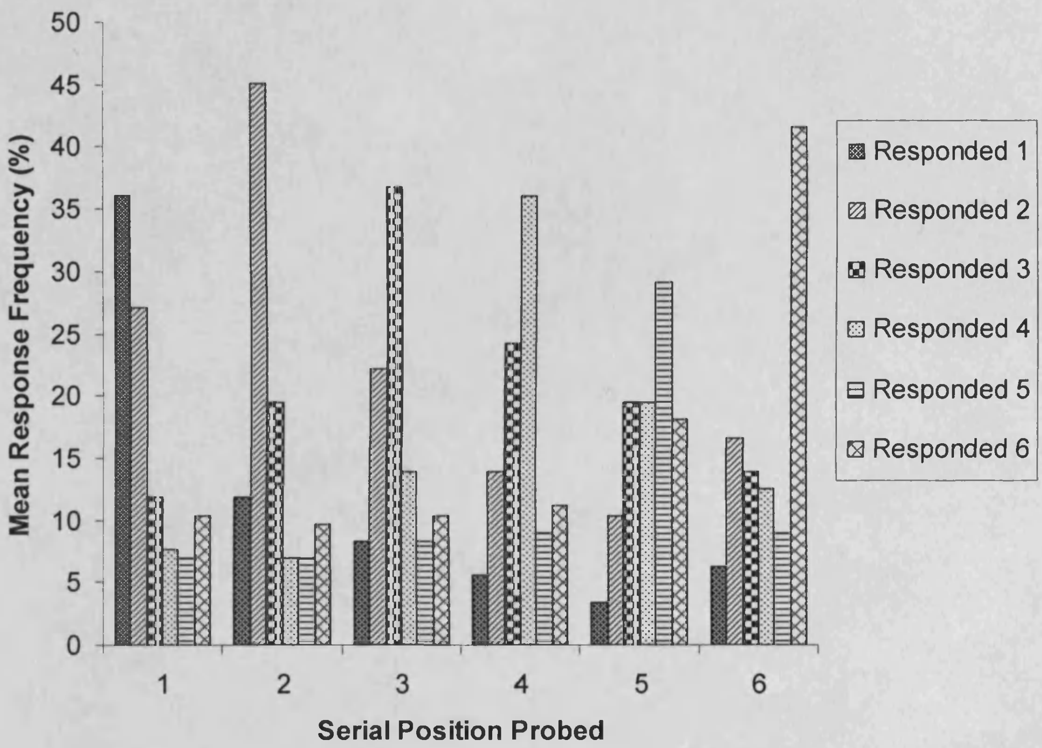


Figure 2.6: Mean percentage serial position response distribution for positions 1-6 as a function of serial position.

Confidence Ratings Analysis

Confidence ratings were taken to assess the extent to which the bias at serial position 2 was an artefact of uncertainty. In Experiment 2.1(a-c) a comparison between confidence ratings for correct and incorrect responses was computed to assess the extent to which participants have introspection with respect to the accuracy of their responses.

4-odour sequences: Confidence ratings for correct responses (mean rating=2.97) were significantly higher than ratings for erroneous responses (mean rating=2.42), $t(23)=6.81$, $p<.05$.

5-odour sequences: Confidence ratings for correct responses (mean rating=3.02) were significantly greater than incorrect response (mean rating=2.50), $t(23)=7.25$, $p<.05$.

6-odour sequences: Confidence ratings for correct responses (mean rating=3.25) were significantly greater than incorrect response (mean rating=2.67), $t(23)=7.53$, $p<.05$.

Figures 2.7a and 2.7b show the mean confidence rating for each serial position in Experiment 2.1a when the response is correct (Figure 2.7a) and when the response is incorrect (Figure 2.7b). A single-factor within-subjects ANOVA with four levels was computed on confidence ratings for both the correct and incorrect responses. Confidence ratings following a correct response revealed a significant main effect of serial position, $F(3,69)=4.56$, $MSe=0.43$. Further analyses (Newman Keuls) revealed that following a correct response, participants provided significantly higher confidence ratings for serial position 4 compared to positions 1, 2 and 3. Confidence ratings following an incorrect response produced a null effect of serial position, $F=1.12$ (although it should be noted that this ANOVA comprised 23 participants due to one individual not making any errors).

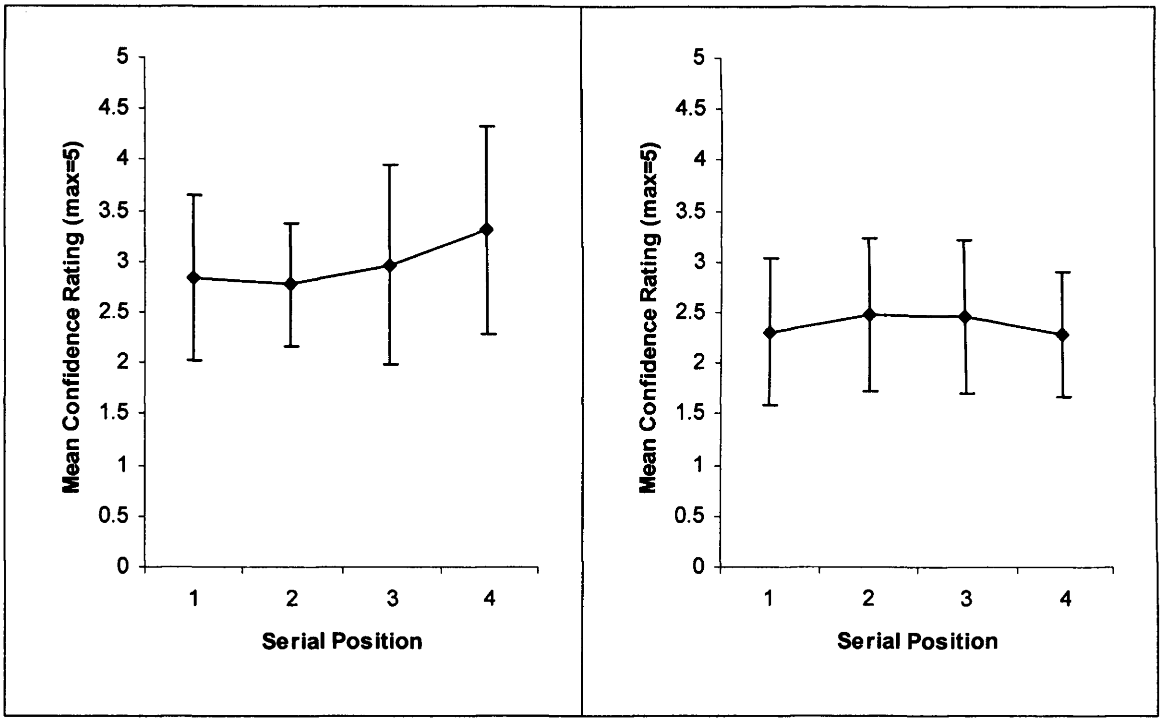


Figure 2.7(a-b): Mean confidence ratings for serial positions 1-4 following correct (a) and incorrect (b) responses.

The findings demonstrate that although accuracy levels produced an absence of serial position effects, confidence ratings generated the single-item recency function consistent with that of Kerr et al. (1998) and Korsnes et al. (1996) at immediate testing. The trend is not simply an effect of participants demonstrating greater confidence levels whenever responding with the fourth serial position, as single-item recency is found only following confidence ratings when the response is correct; the confidence ratings following incorrect responses fail to produce serial position effects. Therefore, although not demonstrated in terms of recall accuracy, olfactory stimuli, consistent with 4-item sequences of abstract patterns (Avons et al., 1998; Korsnes et al., 1996) and nouns (Kornses et al., 1996) appears to demonstrate some terminal item advantage.

The same analysis was performed on the confidence ratings for the 5-odour sequences in Experiment 2.1b. Figures 2.8a and 2.8b demonstrate the mean confidence ratings following correct (Figure 2.8a) and incorrect responses (Figure 2.8b) for each serial position. A single-factor within-subjects ANOVA with five levels was computed on confidence ratings for both the correct and incorrect responses. Confidence ratings following a correct response revealed a borderline significant main effect of serial position, $F(4,64)=2.42$, $MSe=0.57$, $p=.05$ (it should be noted that the ANOVA is formulated from 17 participants as 7 participants did not make any correct responses for at least one position). Confidence ratings following incorrect responses revealed a non-significant main effect of serial position, $F<1$ (the ANOVA comprises of 21 participants as 3 participants did not make any errors for at least one serial position).

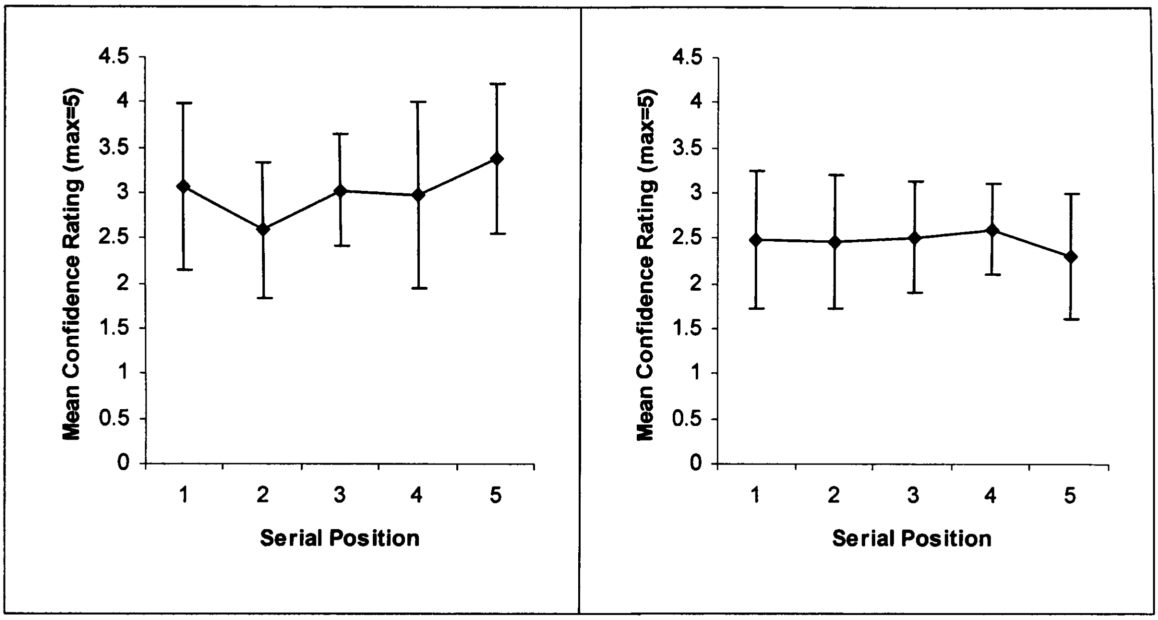


Figure 2.7(a-b): Mean confidence ratings for serial positions 1-5 following correct (a) and incorrect (b) responses.

As in Experiment 2.1a, the confidence rating serial position function for correct responses (although not statistically significant) appears, to some extent, consistent with the recency observed for visual stimuli in this paradigm (e.g. Kerr et al., 1998). To reiterate, this effect is not simply due to overall higher confidence ratings for the terminal position as this trend is not observed for incorrect responses.

Confidence ratings for correct (see Figure 2.8a) and incorrect responses (see Figure 2.8b) were investigated for the 6-odour sequences in Experiment 2.1c. A single-factor within-subjects ANOVA with six levels was computed on confidence ratings for both the correct and incorrect responses. Confidence ratings following a correct response revealed a non-significant main effect of serial position, $F(5,17)=1.89$, $MSe=0.74$, $p=.11$ (it should be noted that the ANOVA is formulated from 18 participants as 6 participants did not make any correct responses for at least one position). Confidence ratings following incorrect responses revealed a non-significant main effect of serial position, $F(5,22)=1.79$, $MSe=0.28$, $p=.12$ (the ANOVA comprises of 23 participants as 1 participant did not make any errors for at least one serial position).

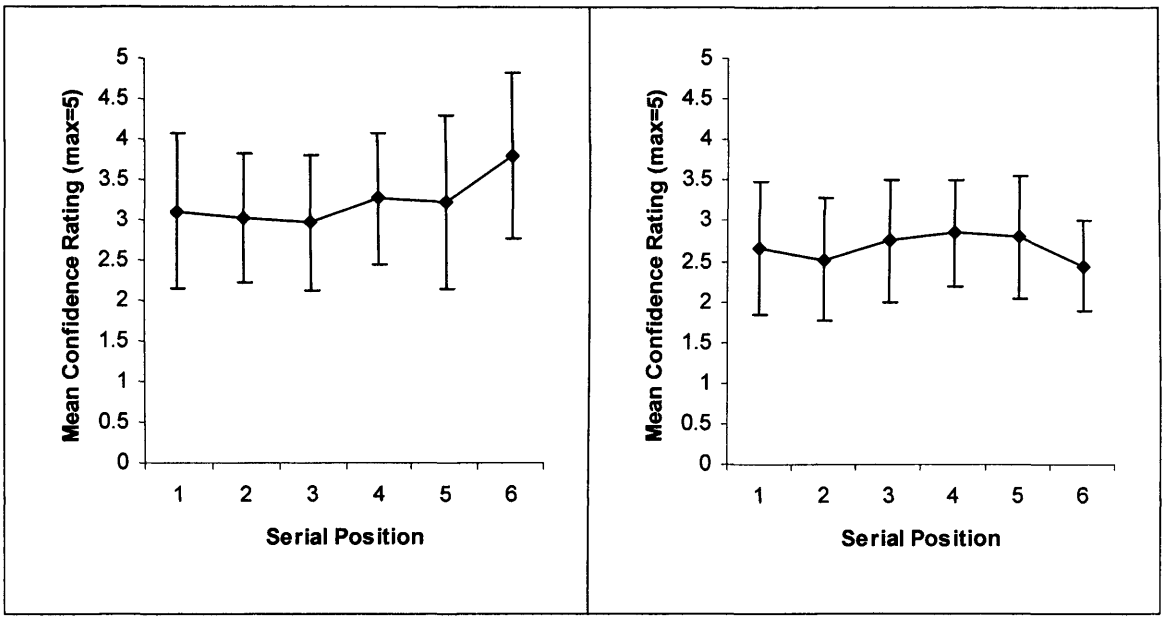


Figure 2.8(a-b): Mean confidence ratings for serial positions 1-6 following correct (a) and incorrect responses (b).

Kerr et al. (1998) hypothesised that the bias observed at positions 1 and 2 may derive from participants being more confident about positions 3 and 4 and, therefore, less reluctant to allocate guesses to those positions; instead, using positions 1 and 2 as default guessing options when uncertain. To investigate this proposal, confidence data were analysed following instances in which participants responded with a particular serial position but incorrectly (this is displayed in Figures 2.9a-c). For example, if the response bias is driven by guessing, one might predict significantly lower confidence ratings for serial position 2 when that item is being recalled erroneously.

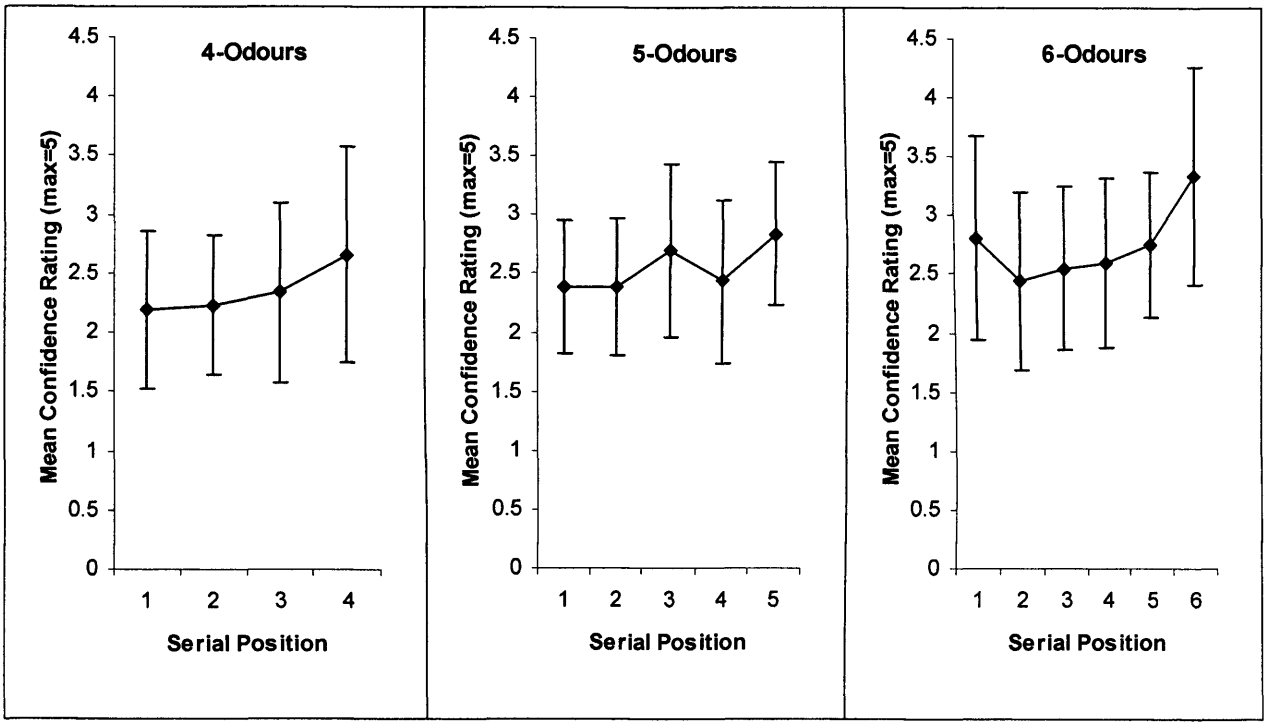


Figure 2.9(a-c): Mean confidence ratings when participants respond for one of the serial positions erroneously. This is demonstrated for sequences of 4, 5 and 6 odour sequences.

The confidence ratings for these erroneous responses in Experiment 2.1(a-c) were analysed in a single-factor within-subjects ANOVA. Kerr et al. (1998) argued that the response bias is driven though uncertainty; specifically allocating guesses to positions that the participant is less certain of. Indeed, if guess allocation was underpinned via uncertainty, one might predict a negative correlation between number of occasions in which a participant had erroneously responded "position 2" and mean confidence rating when these erroneous responses are given. Expressly, the less confident a participant is regarding serial position the more frequently that position should be employed erroneously.

4-odour sequences: A borderline main effect of serial position was found, $F(3,54)=2.39$, $MSe=0.28$, $p=.08$ (it should again be noted that only 19 participants are included in this ANOVA following 5 participants not responding with one, or all, of the positions erroneously). A negligible ($R=0.06$) non-significant ($p=.98$) correlation was found between mean confidence rating of erroneous serial position 2 responses and frequency of erroneously responding "serial position 2".

5-odour sequences: A borderline main effect of serial position, $F(4,76)=2.46$, $MSe=0.31$, $p=.05$ (the ANOVA comprises of only 20 participants as 4 participants did not use at least one of the serial positions erroneously). A negative ($R=-0.17$) non-significant ($p=.43$) correlation was found between mean confidence rating of erroneous serial position 2 responses and frequency of erroneously responding "serial position 2".

6-odour sequences: A main effect of serial position, $F(5,13)=7.18$, $MSe=0.33$. Further analysis (Newman Keuls) revealed that confidence ratings for serial position 6 were significantly greater than positions 1, 2, 3, 4 and 5. A positive ($R=0.23$) non-significant ($p=.29$) correlation was found between mean confidence rating of erroneous serial position 2 responses and frequency of erroneously responding "serial position 2".

Although borderline and significant main effects of serial position are reported, this does not support the hypothesis that the response bias is driven by incorporating a default guessing position(s). Following the observed response bias at serial position 2, one might predict a negative spike in confidence when participants are erroneously responding "serial position 2". This is not found in Experiments 2.1(a-c). This hypothesis is further contradicted by the failure to find a significant negative correlation between mean confidence ratings for erroneous serial position 2 responses and the frequency that a participant erroneously responds "serial position 2". In summary, the response bias does not appear to be governed by uncertainty.

Olfactory Fatigue Analysis

As following the 2AFC recognition paradigm (Experiment 1.1a and 1.1b), the impact of olfactory fatigue was investigated.

4-odour sequences: Recall at the first quartile (mean correct recall = 54.58%) was compared to the last quartile (mean correct recall = 50%) and revealed a non-significant difference, $t=1.22$.

5-odour sequences: Recall at the first fifth of trials (mean correct recall = 47.22%) was compared to the last fifth[6] (mean correct recall = 39.58%) and revealed a non-significant difference, t=1.22.

6-odour sequences: Recall at the first quartile (mean correct recall = 37.5%) was compared to the last quartile (mean correct recall = 36.11%) and revealed a non-significant difference, t<1.

These findings add further support to the absence of olfactory fatigue in olfactory STM (e.g. Experiments 1.1a and b; Miles and Hodder, 2005) and expand the apparent immunity from perceptual fatigue to the single-probe serial position recall paradigm. Moreover, it should be noted that in Experiment 2.1c participants received 252 odour exposures and yet an absence of significant perceptual fatigue was observed.

Experiment 2.1(a-c): Discussion

Experiments 2.1(a-c) applied the single-probe serial position recall paradigm to sequences of 4-, 5- and 6-odours and demonstrated that participants are capable of retrieving the absolute position of odours within 4- (mean recall=51.98%; chance=25%), 5- (mean recall=42.78%; chance=20%) and 6-odour sequences (mean recall=37.39%; chance=16.67%) to a level above chance. However, contrary to previous studies in this paradigm (e.g. Kerr et al., 1998) odour recall accuracy did not produce any serial position effects. However, single-item recency was reported for confidence ratings following correct responses of the 4-odours sequences. Some evidence of recency for confidence ratings for correct responses was found for 5-odour but not 6-odour sequences. No evidence was found that the response bias is driven by guesses being allocated to positions for which the participant is uncertain.

Mean recall accuracy of 4- (51.98%), 5- (42.78%) and 6-odour (37.40%) sequences was compared in a single-factor ANOVA with three levels and revealed a main effect of sequence length, $F(2,71)=9.30$, $MSe=160.58$. Further analysis (Newman Keuls) revealed that recall levels following the 4-odour sequences were significantly higher

[6] Fifths were employed for the 5-odour sequence due to the total number of trials for that experiment (30) not being divisible by 4.

than both 5- and 6-odour sequences. No significant recall level differences were found between the 5- and 6-odour sequences. Following correction for the response bias (employing the equation provided by Kerr et al., 1998) an absence of significant serial position effects were observed for sequences of 4-, 5- and 6-odours. The functions contradict the finding of single-item recency for abstract patterns (Kerr et al., 1998; Korsnes et al., 1996) and visually presented nouns (Korsnes et al., 1996) observed for this paradigm.

The current finding also contradicts the 2AFC recognition of odours in Experiments 1.1a and b where serial position effects were observed following a series of 2AFC recognition test-pairs tested in the reverse order of original presentation. In Experiments 1.1a and b odours were presented for 3000 ms, whereas in the Experiments 2.1(a-c) exposure time was reduced to 1000 ms. However, the reduction in exposure time does not appear responsible for the absence of serial position effects as performance was substantially above the level predicted by chance at all three sequence lengths. This finding is supported by Miles and Hodder (2005, Experiment 2) who demonstrated that odour recognition remained substantially above chance at a 1000 ms presentation duration. Single-probe serial recall has not previously been applied to olfactory stimuli but the current finding does appear to contradict another order task (2AFC relative recency) where a terminal item benefit was reported for odours (White, 1992; White and Treisman, 1997).

Variance is high across the three sequence lengths. However, despite the relatively large error bars the response distribution for each serial position appears consistent with other studies investigating serial order error distribution (e.g. Smyth et al., 2005), i.e. items are most frequently erroneously allocated to adjacent serial positions. This error distribution suggests that even when responding erroneously, participants possess a vague temporal context as to the approximate location of the item within the sequence (see Henson, 1999).

The absence of recency is contrary to application of a duplex account of odour STM. If the terminal item is stored in the fragile, yet highly accurate STS, when that item is immediately probed a match should occur promoting superior recall. This was not found. However, it may be possible that the duplex conceptualisation of the STS cannot be expanded to encompass the storage of positional information. In a recognition task the participant is able to match the item held in the store to the test item. However, in a positional recall task the item held in the store lacks a positional code.

Some limited evidence of a terminal item benefit is observed with respect to confidence ratings. For the 4-odour sequence, single-item recency is found following confidence ratings for correct responses, indicating enhanced memorial traces of the terminal item. Similarly, a borderline main effect of serial position was reported following confidence ratings for correct responses of 5-odour sequences (ratings were highest for the terminal list item) and although not significant, confidence ratings were highest for the terminal item following 6-odour sequences. These findings were not merely an artefact of higher ratings when responding with the terminal item, as null effects of serial position were found when confidence ratings were analysed following incorrect responses. This apparent increased salience for the terminal item suggests that memory of that terminal item may possess unique characteristic to other list items. However, these characteristics do not promote increased levels of serial order recall compared to other positions.

Experiments 2.1(a-c) replicated the observation by Kerr et al. (1998) of a response bias within this paradigm. However, contrary to Kerr et al. (1998) who reported the bias for early list items (i.e. positions 1 and 2 for sequences of 4-unfamiliar faces), the present experiments observed the bias confined to serial position 2 (and position 3 for 5- and 6-odour sequences). Kerr et al. (1998) argued that the response bias was a result of uncertainty, wherein participants were reluctant to allocate guesses to positions they were certain of. As a result, positions that participants are uncertain of are employed as default guessing responses, therefore, producing an asymmetrical response distribution.

However, an analysis was conducted on the confidence ratings when responding with each serial position erroneously. The analysis failed to demonstrate that confidence was significantly lower for positions 2. If uncertainty produced the response bias, one might predict a significant negative correlation between response frequency for the biased position and confidence rating when erroneously responding with that position.

This was not found for sequences of 4-, 5- or 6-odours. One possible counter-argument for the finding concerns the reliability of the 5-point likert confidence scale. However, there is at least some validating evidence that the scale measures certainty, as confidence ratings were significantly higher for correct compared to incorrect responses across the three experiments.

The mechanism underpinning the response bias remains unresolved. The extent of participant naivety to experimental design procedures is unknown, i.e. the extent to which participants anticipate each serial position to be probed equally across the experiment. Therefore, it is not possible to determine if (1) participants did not consider that their response propensity for a particular position(s) violated a model of equal distribution for each position at test or (2) if they lacked the ability to self-monitor the frequency in which they responded for each serial position.

In a review of participant introspection, Nisbett and Wilson (1977) reported limited self-awareness of response biases and motivations for such a predilection. Passers-by were asked to choose a favourite garment from either four position-counterbalanced different nightgowns (n=378) or four position counterbalanced identical nylon stockings. The authors found a strong left-to-right positional bias, such that the terminal item was chosen at a far greater frequency. When subjects were interviewed regarding their strategy, none described the role of position in formulating a preference. Indeed, when asked about the positional bias "virtually all subjects denied it, usually with a worried glance at the interviewer suggesting that they felt either that they had misunderstood the question or were dealing with a mad-man" (pg. 244). Nisbett and Wilson (1977) mused that "precisely why the position effect occurs is not obvious. It is possible that subjects carried into the judgment task the consumer's habit of "shopping around," holding off on choice of early-seen garments on the left in favour of later-seen garments on the right" (pg. 244). Such an explanation does not elucidate on the present bias as a greater response frequency was observed for early list items. However, it does suggest that participants can be drawn towards a position without conscious recollection.

Experiment 2.2(a-c)

The flat single-probe serial position recall functions observed in Experiments 2.1(a-c) for odours at immediate testing contradict the single-item recency reported by Korsnes et al. (1996) at 5 s retention intervals for abstract patterns and nouns. Furthermore, following the correction for response bias, an absence of serial position effects persisted, contrary to the post-correction single-item recency reported for unfamiliar-faces (Kerr et al., 1998).

Kerr et al. (1998) and Korsnes et al. (1996) report consistent trends despite methodological variations, i.e. exposure time varies between 500 ms and 1000 ms (Korsnes et al. and Kerr et al. respectively) and retention intervals for the immediate condition vary from 0 to 5000 ms (Kerr et al. and Korsnes et al. respectively). In Experiments 2.2(a-c), the single probe serial position recall methodology employed in Experiments 2.1(a-c) was applied to visual stimuli (unfamiliar-faces). Experiment 2.2a methodologically replicated Kerr et al. (1998) at immediate testing and assessed if the olfactory function for single-probe serial recall is qualitatively different from visual stimuli. Experiments 2.2b-c increases the sequence length to assess if the functions reported by Kerr et al. (1998) and Korsnes et al. (1996) are robust across sequence lengths. If the functions produced for single-probe serial position of unfamiliar-faces are consistent with odours one might predict an absence of serial position effects. However, if consistent with Kerr et al. one might predict serial position effects driven by a benefit for the terminal item.

Method.

Participants. There were twenty-four participants in each experiment. All were Cardiff University volunteer Psychology undergraduates who participated in exchange for course credit. None had participated in Experiments 2.1(a-c) and were prevented from participating in more than one of the Experiment 2.2 studies. Details of the participants are:

Experiment 2.2a (4-unfamiliar face sequences): 8 male and 16 female (mean age 22 years and 3 months).

Experiment 2.2b (5-unfamiliar face sequences): 3 male and 21 female (mean age 19 years and 5 months).

Experiment 2.2c (6-unfamiliar face sequences): 3 male and 21 females (mean age 19 years and 5 months).

Materials. The stimuli set were as described for Experiment 1.2. In Experiment 2.2a, 40 unfamiliar-faces were employed. In Experiment 2.2b, 50 unfamiliar-faces were employed and in Experiment 2.2c, 54 unfamiliar-faces were employed.

In Experiment 2.2a, experimental faces were divided into 4 groups of 10 faces. Each sequence then comprised one face taken from each of the four groups. In Experiment 2.2b, experimental faces were divided into 5 groups of 10 faces. Each sequence then comprised one face taken from each of the five groups. In Experiment 2.2c, experimental faces were divided into 6 groups of 9 faces. Each sequence then comprised one face taken from each of the six groups.

Design. The design was as described for Experiments 2.1(a-c).

Procedure. Participants sat at a desk facing a computer screen positioned approximately 50cm away. Prior to commencement of each trial a message appeared on the screen instructing the experimenter to press a key to begin. The experimenter then initiated the trial. The experimental procedure followed closely that for Experiments 2.1(a-c). A sequence of 4- (Experiment 2.2a), 5- (Experiment 2.2b) or 6-unfamiliar faces (Experiment 2.2c) was then presented on the computer screen, with each face presented for 1000 ms followed by a 1000 ms ISI. Following presentation of the terminal face in the sequence a message appeared on the screen indicating commencement of the test phase. A single face taken from the previous sequence was then presented and the participant was required to state the position of that item within the previous sequence, i.e. first, second, third, fourth, fifth or sixth. Once a response had been given the experimenter noted the response, pressed a key and the next trial was cued.

Results

Non-Standardised Serial Position Recall Analysis

Figure 2.10(a-c) shows the mean percentage correct recall as a function of serial position for sequences of 4- (Figure 2.2a), 5- (Figure 2.2b) and 6-unfamiliar faces (Figure 2.2c). A single-factor within-subjects ANOVA was computed for Experiments 2.2(a-c).

4-unfamiliar-face sequences: A main effect of serial position was found, $F(3,69)=14.37$, $MSe=1.49$.

5-unfamiliar-face sequences: A main effect of serial position was found, $F(4,92)=9.43$, $MSe=1.52$.

6-unfamiliar-face sequences: A main effect of serial position was found, $F(5,115)=13.09$, $MSe=1.13$.

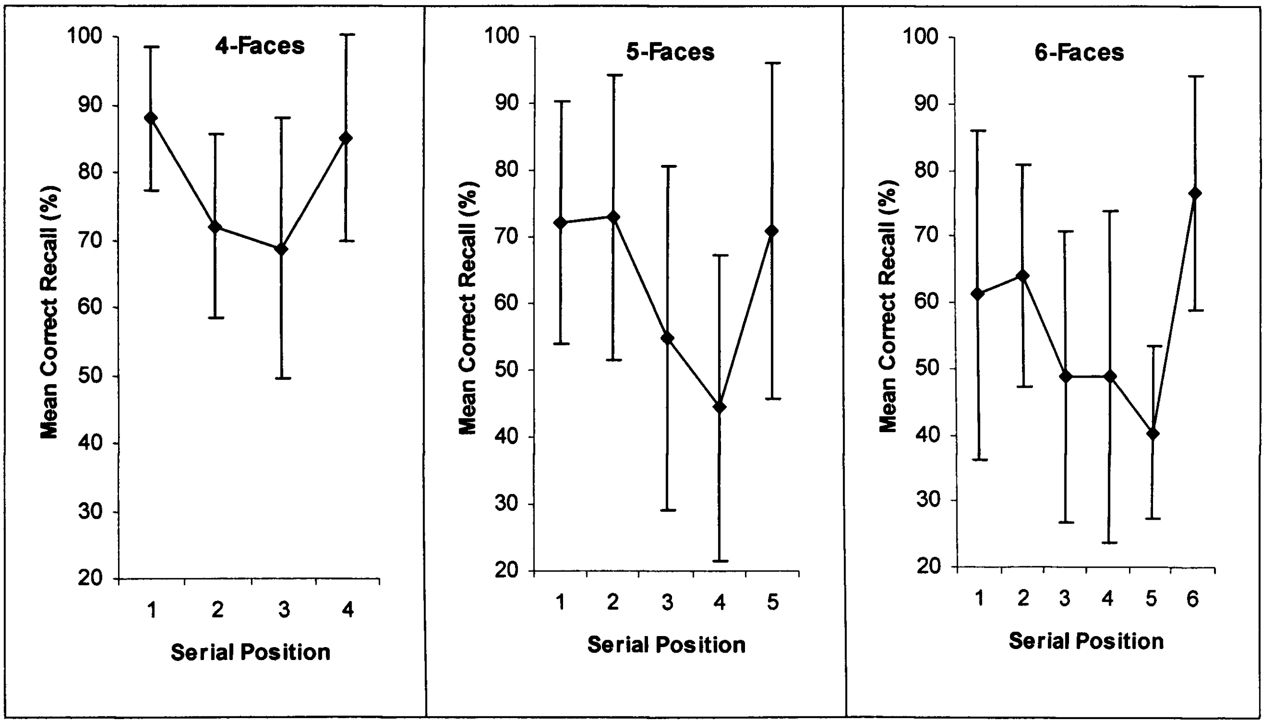


Figure 2.10(a-c): Mean percentage correct recall for sequences of 4- (a), 5- (b) and 6-unfamiliar faces (c) as a function of serial position. Error bars denote 1 standard deviation.

Response Bias Serial Position Analysis

Since a response bias was reported in the original Kerr et al. (1998) study and in Experiments 2.1(a-c), the response distribution was investigated for the current studies. Response distributions for 4-, 5- and 6-unfamiliar face sequences are demonstrated in Figure 2.11(a-c).

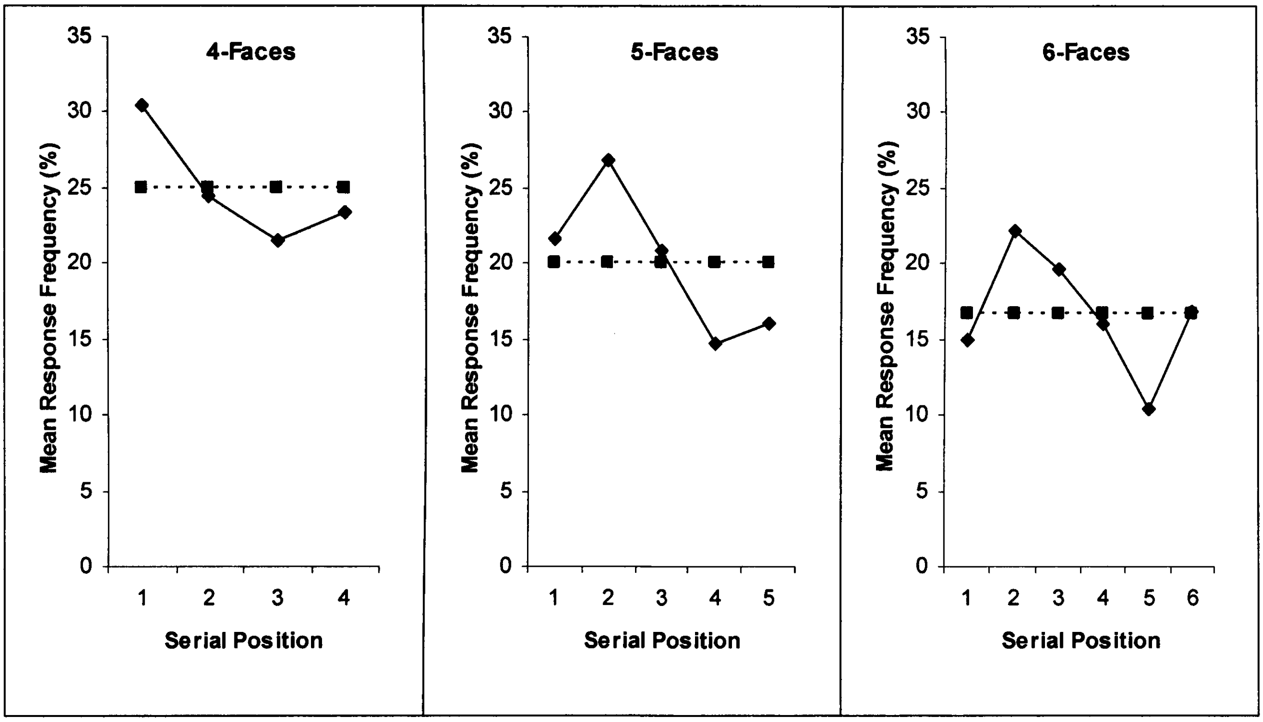


Figure 2.11(a-c): Mean percentage response frequency for sequences of 4- (a), 5- (b) and 6- (c) odours as a function of serial position. An equivalent distribution of responses across serial positions is depicted by the dotted line.

Single-factor within-subjects ANOVAs were computed on the response frequencies following Experiments 2.2(a-c).

4-unfamiliar-face sequences: A significant main effect of serial position was found, $F(3,69)=10.90$, $MSe=5.51$. Further analysis (Newman Keuls) revealed response frequency for serial position 1 to be significantly greater than that of positions 2, 3 and 4.

5-unfamiliar-face sequences: A significant main effect of serial position was found, $F(4,92)=11.88$, $MSe=4.26$. Further analysis (Newman Keuls) revealed response frequency for serial position 2 to be significantly greater than that of positions 1, 3, 4 and 5. Response frequency for both serial positions 1 and 3 were also significantly greater than that of both positions 4 and 5.

6-unfamiliar-face sequences: A significant main effect of serial position was found, $F(5,115)=11.70$, $MSe=4.31$. Further analysis (Newman Keuls) revealed response frequency for serial position 2 to be significantly greater than that of positions 1, 3, 4, 5 and 6. Response frequency for serial positions 1, 3, 4 and 6 were also significantly greater than that of position 5.

Corrected Recall Serial Position Analysis

As in Experiments 2.1(a-c) the data were corrected for the response bias employing the equation described by Kerr et al. (1998). Figure 2.12(a-c) demonstrates the mean correct recall at each serial position for 4-, 5- and 6-unfamiliar faces following correction of the data for the response bias.

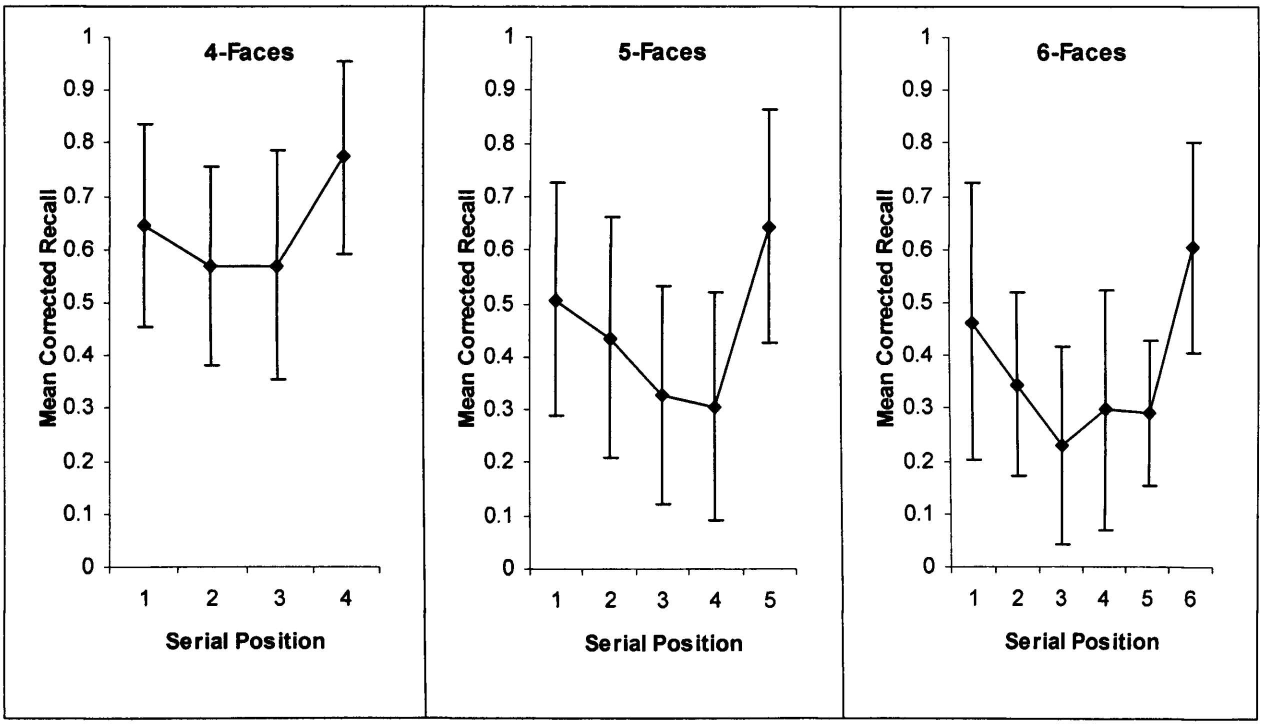


Figure 2.12(a-c): Mean corrected recall for sequences of 4- (a), 5- (b) and 6- (c) unfamiliar-faces following a correction for the response bias and as a function of serial position. Error bars denote 1 standard deviation.

A single-factor within-subjects ANOVA was computed on the corrected recall data for Experiments 2.2(a-c).

4-unfamiliar-face sequences: A main effect of serial position was found, $F(3,69)=14.70$, $MSe=0.02$. Further analysis (Newman Keuls) revealed that corrected recall at serial position 4 was significantly greater than that of positions 1, 2 and 3. Corrected recall at serial position 1 was significantly greater than that of position 2.

5-unfamiliar-face sequences: A main effect of serial position was found, $F(4,92)=14.18$, $MSe=0.03$. Further analysis (Newman Keuls) revealed that corrected recall at serial position 5 was significantly greater than that of positions 1, 2, 3 and 4. Corrected recall at both serial positions 1 and 2 was significantly greater than that of positions 3 and 4.

6-unfamiliar-face sequences: A main effect of serial position was found, $F(5,115)=17.72$, $MSe=0.03$. Further analysis (Newman Keuls) revealed that corrected recall at serial position 6 was significantly greater than that of positions 1, 2, 3, 4 and 5. Corrected recall for serial position 1 was significantly greater than that of positions 2, 3, 4 and 5.

Trend Analysis

Trend analyses was performed on the corrected recall scores of Experiments 2.2(a-c).

4-unfamiliar-face sequences: Both significant quadratic, $F(1,23)=18.32$, $MSe=0.03$, and linear components were found.

5-unfamiliar-face sequences: A significant quadratic component, $F(1,23)=56.30$, $MSe=0.03$, and a non-significant linear component, $F<1$, were found.

6-unfamiliar-face sequences: A significant quadratic component, $F(1,23)=52.30$, $MSe=0.04$, and a borderline significant linear component, $F(1,23)=3.13$, $MSe=0.04$, $p=.09$, were found.

The significant quadratic components are consistent with the first and terminal item benefits revealed by the serial position analysis ANOVA.

Response Distribution Analysis

As in Experiment 2.1(a-c), response distributions were assessed for each serial position. The figures representing the distributions of erroneous responses for the unfamiliar-faces are similar to that reported for odours and can be found in Appendix 4. A single-factor within-subjects ANOVA was computed on the displacement distance of erroneous responses following Experiments 2.2(a-c).

> **4-unfamiliar-face sequences**: A main effect of displacement distance was found, $F(2,46)=16.41$, $MSe=0.22$. Further analysis (Newman Keuls) revealed that displacements of 1 serial position were significantly more frequent than displacements of both 2 and 3 positions.

> **5-unfamiliar-face sequences**: A main effect of displacement distance was found, $F(3,69)=42.21$, $MSe=0.10$. Further analysis (Newman Keuls) revealed that displacements of 1 serial position were significantly more frequent than displacements of 2, 3 and 4 positions. . Furthermore, displacements of 2 serial positions were significantly more frequent than displacements of both 3 and 4 positions.

> **6-unfamiliar-face sequences**: A main effect of displacement distance was found $F(4,92)=62.65$, $MSe=0.04$. Further analysis (Newman Keuls) revealed that displacements of 1 serial position were significantly more frequent than displacements of 2, 3, 4 and 5 positions. Furthermore, displacements of 2 serial positions were significantly more frequent than displacements of 3, 4 and 5 positions. Displacements of 3 and 4 positions were both significantly more frequent than 5 position displacements.

Consistent with Smyth et al. (2005) and Experiment 2.1(a-c), these findings demonstrate that erroneous responses for a particular position decrease in probability as distance increases from the correct probe. The findings suggest that even when incorrect, the participant possesses an association between the item and a vague positional context within the sequence.

Experiment 2.2(a-c): Discussion

Experiments 2.2(a-c) applied the single probe serial recall paradigm to sequences of 4-, 5- and 6-unfamiliar face sequences. A single-factor between-subjects ANOVA with three levels was conducted and revealed a main effect of sequence length, $F(2,71)=22.24$, $MSe=213.47$. Consistent with the pattern observed for odours, further analysis (Newman Keuls) revealed that performance levels for 4-item sequences (78.45%) were significantly greater than performance for 5-face (63.06%) and 6-face (56.39%) sequences.

Experiments 2.2(a-c) demonstrated functions that exhibit strong recency and some evidence of primacy, for sequences of 4-, 5- and 6-unfamiliar faces. The findings support the observed recency for immediate single-probe serial recall for sequences of 4-unfamiliar-faces (Kerr et al., 1998) and 4-abstract patterns (Korsnes et al., 1996). The observation of primacy starkly contrasts the absence of a first item benefit observed for unfamiliar-faces by Kerr et al. (1998). This absence was not an artefact of lower performance levels in Kerr et al. obscuring the observation of primacy, as when sequences of 5- and 6-unfamiliar faces were employed, the first item benefit was observed despite lower performance levels than Kerr et al. (1998). The first item benefit is more consistent with the moderate first item upturn (albeit non-significant) observable for abstract patterns (Korsnes et al., 1996).

Although both Kerr et al. and Experiment 2.2a employed identical exposure and ISI durations, the methodologies differ with respect to the type of unfamiliar faces employed. In Kerr et al. (1998) the faces were constructed from the Mac-a-Mug software and presented in greyscale. In the present experiment the faces were presented in colour and the stimuli are arguably, therefore, more distinctive. This is reflected in overall performance levels. Proportion correct for the Kerr et al. (1998) immediate testing data was at approximately 0.55, compared to 0.64 in the present (4-item) study. Moreover, the cross-experiment differences appear to be mediated by elevated terminal item recall accuracy for the Kerr et al. (1998) study (proportion of responses correct for position 4 = approximately 0.91, compared to 0.77 in Experiment 2.2a). When performance levels are compared across experiments with terminal item recall omitted, cross-experiment differences are inflated; the mean proportional accuracy for the Kerr et al. (1998) study was approximately 0.43 and the present study 0.59. One possible explanation for the absence of primacy in Kerr et al. (1998) is via the relatively lower performance levels obscuring the presence of primacy. Although substantially higher than floor performance (recalling at chance = 0.25), it is possible that the bowed serial positron function is flattened somewhat by reduced recall rates.

However, in Experiment 2.2c primacy was still apparent despite a fall in mean corrected proportion accuracy to 0.37. The performance level is less than Kerr et al. (1998) at immediate testing (approximately 0.55) and comparable to the level of recall in Kerr et al. (1998) when the high terminal item recall is discounted (approximately 0.43). The finding indicates that the lack of primacy in Kerr et al. (1998) is not an artefact of lower performance flattening the function and consequently obscuring the first item benefit.

The recency and moderate primacy functions reported for single-probe serial position recall contradicts the flat serial position functions reported for odours. It seems unlikely that the absence of serial position effects in the odour experiment was due to comparably reduced recall levels as recall for the 4-odour experiment (mean recall accuracy = 51.98%) was comparable to the 6-face experiment (mean recall accuracy = 56.39%) where both primacy and recency was observed. Despite differing serial position functions, the visual experiments produced similar trends with respect to error data, wherein errors are more frequently allocated to adjacent serial positions.

Consistent with the olfactory experiments, a response bias is generally observed at position 2 (with the exception of the 4-face experiment where the bias focussed upon the first position). The 4-item bias is contrary to Kerr et al. (1998) who reported highest response frequencies for position 2, wherein the first item was employed as a response least frequently. Together these findings indicate a predisposition to responding with the second position irrespective of sequence length and demonstrated for both odours and unfamiliar-faces. However, the mechanism underpinning the bias remains unresolved.

Experiments 2.3(a-c)

Qualitatively different functions have been demonstrated for olfactory and visual stimuli following the single probe serial position recall paradigm; olfactory recall characterised by an absence of serial position effects and unfamiliar faces typified by recency and some primacy. It is unclear the extent to which this evidence of modularity is driven by the proposed qualitative difference in olfactory perception (Köster, 2005), wherein this chemical sense evolved to operate in a functionally different manner to other "far" senses such as visual and auditory perception (Møller et al., 2004). Under such a conceptualisation one might predict that the function produced for auditory single-probe serial position recall may be qualitatively comparable to the visual (i.e. produce serial position effects exhibiting both primacy and recency) rather than olfactory stimuli (i.e. an absence of serial position effects). To the present knowledge of the author, the single probe serial recall paradigm is yet to be applied to hard-to-name auditory stimuli. Thus, in Experiment 2.3(a-c) participants received a sequence of 4-, 5- and 6-pure-tones, respectively, followed by a single positional test probe.

Method.

Participants. There were twenty-four participants in each experiment. All were Cardiff University volunteer Psychology undergraduates who participated in exchange for course credit. Participants with impaired hearing were excluded. None had participated in Experiments 2.1(a-c) and 2.2(a-c) and were prevented from participating in more than one of the Experiment 2.3 studies. Details of the participants are:

> **Experiment 2.3a (4-pure tones sequences)**: 9 male and 15 female (mean age 23 years and 0 months).
>
> **Experiment 2.3b (5-pure tones sequences)**: 8 male and 16 female (mean age 21 years and 10 months).
>
> **Experiment 2.3c (6-pure tones sequences)**: 2 male and 22 females (mean age 20 years and 4 months).

Materials. The stimulus set was as described for Experiment 1.3. In Experiment 2.3a, 40 pure tones were employed. In Experiment 2.3b, 50 pure-tones were employed and in Experiment 2.3c, 54 pure-tones were employed.

An additional constraint was employed such that any item within a sequence should not be within a frequency range of 4.5% of another sequence item. That is, items from the stimulus set that were adjacent in terms of frequency, were not included within the same sequence. The position of each tone within the sequence was randomised to prevent a strategy based upon ascending or descending frequency levels.

Design. The design was as described for Experiment 2.1(a-c).

Procedure. The procedure was as described for Experiment 2.2(a-c) with the addition that the stimuli were presented via headphones at a loudness of 75dB.

Results

Non-Standardised Serial Position Recall Analysis

Figure 2.13(a-c) shows the mean percentage correct recall as a function of serial position for sequences of 4- (Figure 2.13a), 5- (Figure 2.13b) and 6- (Figure 2.13c) pure-tones. A single-factor within-subjects ANOVA was computed for Experiments 2.3(a-c).

4-pure tone sequences: A main effect of serial position was found, $F(3,69)=21.95$, $MSe=2.88$.

5-pure-tone sequences: A main effect of serial position was found, $F(4,92)=28.93$, $MSe=1.27$.

6-pure-tone sequences: A main effect of serial position was found, $F(5,115)=49.06$, $MSe=1.25$.

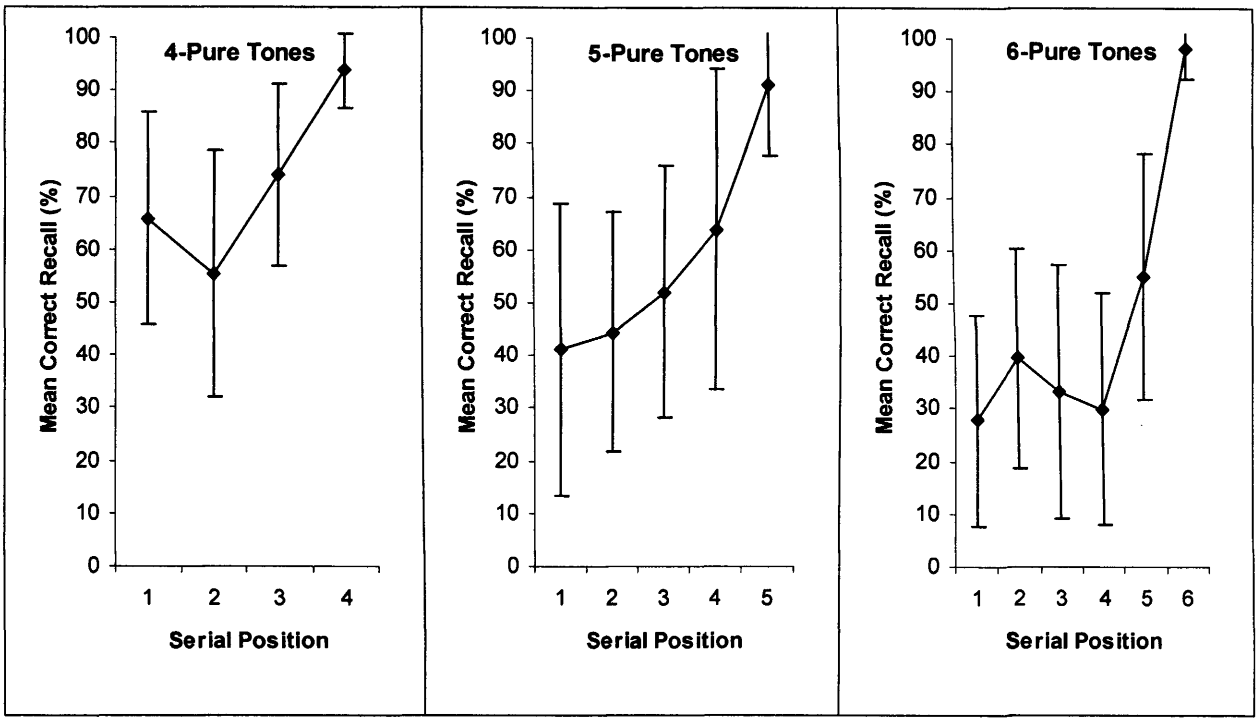


Figure 2.13(a-c): Mean percentage correct recall for sequences of 4- (a), 5- (b) and 6- (c) pure-tones as a function of serial position. Error bars denote 1 standard deviation.

Response Bias Serial Position Analysis

As in the single-probe serial position recall experiments employing odours and unfamiliar-faces (Experiments 2.1a-c and 2.2a-c, respectively), frequency of responses for each serial position were assessed to determine the presence of any response biases. Figure 2.14(a-c) demonstrates the response frequencies for 4-, 5- and 6-pure tone sequences.

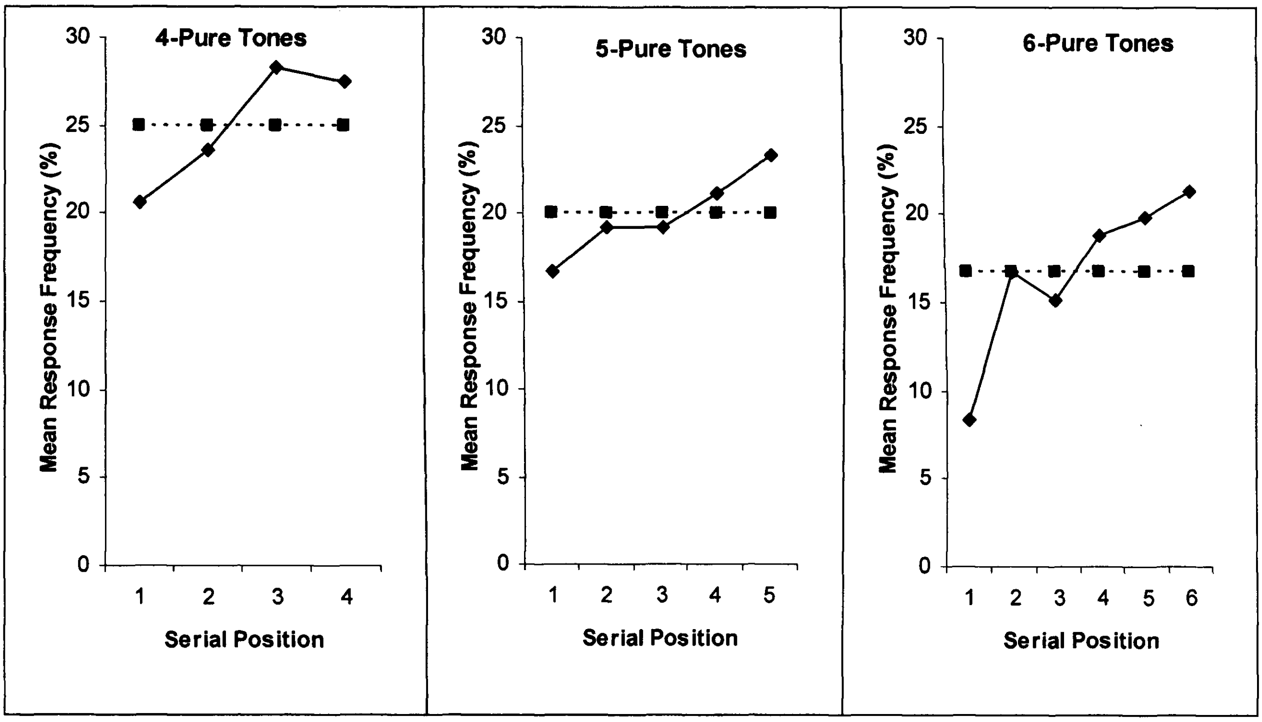


Figure 2.14(a-c): Mean percentage response frequency for sequences of 4- (a), 5- (b) and 6- (c) pure-tones as a function of serial position. An equivalent distribution of responses across serial positions is depicted by the dotted line.

Contrary to olfactory and visual stimuli, Figure 2.14(a-c) demonstrates a response bias at the latter, rather than earlier, serial positions. Single-factor within-subjects ANOVAs were computed on the response frequencies following Experiments 2.3(a-c).

4-pure tone sequences: A significant main effect of serial position was found, $F(3,69)=6.23$, $MSe=8.23$. Further analysis (Newman Keuls) revealed response frequencies for both serial positions 3 and 4 to be significantly greater than that of serial position 1.

5-pure tone sequences: A significant main effect of serial position was found, $F(4,92)=2.74$, $MSe=5.21$. Further analysis (Newman Keuls) revealed response frequency for serial position 5 to be significantly greater than that of position 1.

6-pure tone sequences: A significant main effect of serial position was found, $F(5,115)=16.54$, $MSe=4.06$. Further analysis (Newman Keuls) revealed response frequency for serial position 6 to be significantly greater than that of positions 1, 2 and 3. Response frequency for serial positions 2, 3, 4 and 5 were also significantly greater than that of position 1.

Corrected Recall Serial Position Analysis

Following the response bias, responses were again corrected using the procedure described in Experiment 2.1(a-c). Figure 2.15(a-c) demonstrates the mean correct single probe serial position recall functions for 4-, 5- and 6-pure tones following the correction for response bias.

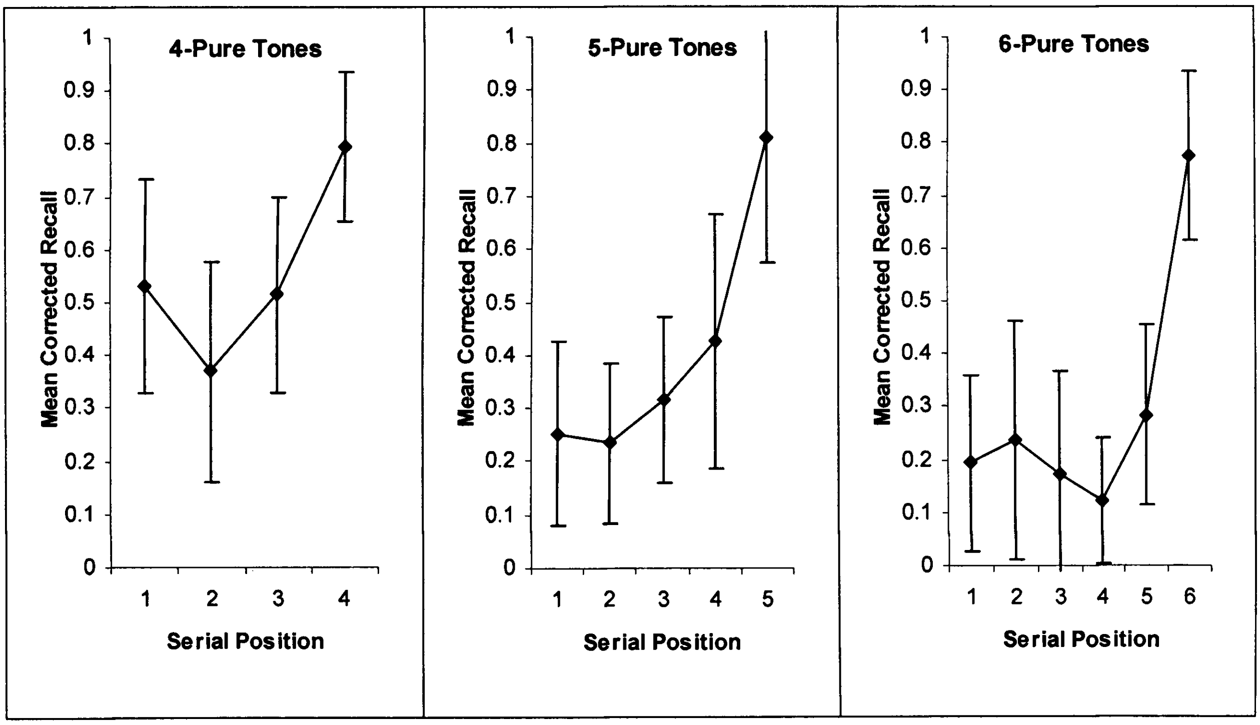


Figure 2.15(a-c): Mean corrected recall for sequences of 4- (a), 5- (b) and 6- (c) pure-tones following correction for response bias as a function of serial position. Error bars denote 1 standard deviation.

A single-factor within-subjects ANOVA was computed on the corrected recall data for Experiments 2.3(a-c).

4-pure tone sequences: A main effect of serial position was found, $F(3,69)=40.51$, $MSe=0.02$. Further analysis (Newman Keuls) revealed that corrected recall at serial position 4 was significantly greater than that of positions 1, 2 and 3. Corrected recall at both serial positions 1 and 3 was significantly greater than that of position 2.

5-pure tone sequences: A main effect of serial position was found, $F(4,92)=50.93$, $MSe=0.03$. Further analysis (Newman Keuls) revealed that corrected recall at serial position 5 was significantly greater than that of positions 1, 2, 3 and 4. Corrected recall at serial position 4 was significantly greater than that of positions 1, 2 and 3.

6-pure tone sequences: A main effect of serial position was found, $F(5,115)=56.13$, $MSe=0.03$. Further analysis (Newman Keuls) revealed that corrected recall at serial position 6 was significantly greater than that of positions 1, 2, 3, 4 and 5. Additionally, corrected recall at serial position 5 was significantly greater than that of position 4.

Trend Analysis

Trend analysis was performed on the corrected recall scores for Experiments 2.3(a-c).

4-pure tone sequences: Both significant quadratic, $F(1,23)=47.02$, $MSe=0.03$, and linear components were found.

5-pure tone sequences: Both significant quadratic, $F(1,23)=51.04$, $MSe=0.02$, and linear components were found.

6-pure tone sequences: Both significant quadratic, $F(1,23)=115.20$, $MSe=0.02$, and linear components were found.

The findings of significant linear and quadratic components are consistent with strong recency and some curvature within the data.

Response Distribution Analysis

As in Experiments 2.1(a-c) and 2.2(a-c), response distributions were assessed for each serial position. The figures representing the distributions of erroneous responses for the pure-tones are similar to that reported for unfamiliar-faces and odours and can be found in Appendix 4. A single-factor within-subjects ANOVA was computed on the displacement distance of erroneous responses following Experiments 2.3(a-c).

4-pure tone sequences: A main effect of displacement distance was found, $F(2,46)=30.11$, $MSe=0.23$. Further analysis (Newman Keuls) revealed that displacements of 1 serial position were significantly more frequent than displacements of both 2 and 3 positions.

5-pure tone sequences: A main effect of displacement distance was found, $F(3,69)=22.23$, $MSe=0.08$. Further analysis (Newman Keuls) revealed that displacements of both 1 and 2 serial positions were significantly more frequent than displacements of both 3 and 4 positions. Additionally, 3-position displacements occurred significantly more often than displacements of 4 positions.

6-pure tone sequences: A main effect of displacement distance was found, $F(4,92)=30.78$, $MSe=0.08$. Further analysis (Newman Keuls) revealed that displacements of 1 serial position were significantly more frequent than displacements of 2, 3, 4 and 5 positions. Displacements of both 2 and 3 serial positions were significantly more frequent than displacements of both 4 and 5 positions. Finally, displacements of 4 serial positions occurred significantly more frequently than displacements of 5 positions.

Experiment 2.3(a-c): Discussion

The effect of sequence length was analysed using a single factor between-subjects ANOVA with three levels and revealed a main effect of sequence length, $F(2,71)=23.93$, $MSe=239.68$. Further analysis (Newman Keuls) revealed that recall following the 4-item sequences (mean correct recall = 72.29%) was significantly greater than recall following 5-item (57.74%) and 6-item (47.22%) sequences.

Furthermore, recall of the 5-tone sequences was significantly greater than recall of 6-tone sequences.

Experiments 2.3(a-c) demonstrated single-item recency for sequences of 4-, 5- and 6-pure tones. The observation of serial position effects contradicts the flat functions reported for the single-probe serial position recall at olfactory stimuli in Experiments 2.1(a-c). The presence of recency is consistent with the unfamiliar-face stimuli. However, unlike the visual experiments, there was no substantive evidence of primacy. For instance, in Experiment 2.3a (single-probe serial recall of 4-pure tones), poor recall levels for serial position 2 creates the impression of curvature within the data; consistent with the bowed trend produced for sequences of 4-unfamiliar faces. However, this function does not appear genuine evidence of primacy for pure-tones since (1) position 1 and 3 recall levels are equivalent and both substantially lower than position 4 and (2) there is no evidence of primacy for sequences of 5- and 6-pure tones. The finding suggests that poor position 2 recall in Experiment 2.3a is manufacturing the apparent curvature/primacy in the data.

The auditory function is consistent with both duplex (Phillips and Christie, 1977) and pre-categorical acoustic store (Crowder and Morton, 1969) accounts, whereby the terminal item is recalled at superior levels due to storage within a fragile, yet highly accurate, store.

Further indication of modularity is apparent following analysis of the response bias. Contrasting olfactory and visual stimuli, where a bias is situated for earlier list items (typically serial position 2), responses for the auditory stimuli demonstrate a bias for later serial position (typically the terminal and penultimate items). The positioning of the bias is consistent with the aforementioned preference bias observed by Nisbett and Wilson (1977) for identical consumer goods. Despite this divergence, the distribution of errors for auditory stimuli is analogous to that observed for visual and olfactory stimuli, wherein errors were most frequently allocated to adjacent serial positions.

Cross-Modal Comparison of Single-Probe Serial Position Recall: 4-Item Sequences of Odours, Unfamiliar-Faces and Pure-Tones

Serial Position Analysis

Performance across the three modalities was compared for single probe serial recall of 4-item sequences. As detailed in the statistical methodology section, cross-modal comparisons were performed following a *Z*-score standardisation to eradicate quantitative differences in performance (mean corrected recall of odours = 0.30; mean corrected recall of unfamiliar-faces = 0.64; mean corrected recall of pure-tones = 0.55) Standardised mean *Z*-score recall for sequences of 4-odous, 4-unfamiliar-faces and 4-pure-tones are demonstrated in Figure 2.16. This analysis, therefore, assesses the extent to which qualitatively different functions are produced for the three stimulus types. Such a difference would be characterised by a significant interaction between serial position and modality of stimuli. The standardised data for the three modalities were analysed within a 2-factor (3x4) mixed ANOVA, where the between subjects factor represents stimuli (odours, unfamiliar-faces and pure-tones) and the within-subjects factor represents serial position (1-4). A null effect of stimuli was found, $F<1$, and a main effect of serial position, $F(3,69)=20.91$, $MSe=0.88$. Importantly, a significant interaction between stimuli and serial position was found, $F(6,69)=6.44$, $MSe=0.88$.

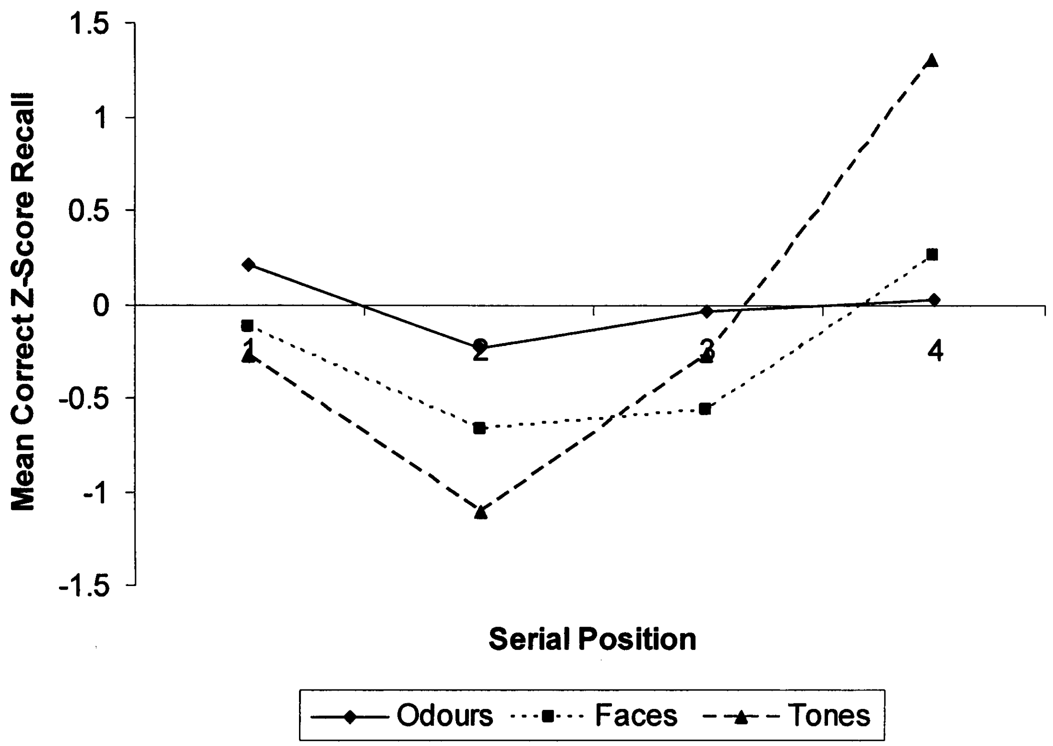


Figure 2.16: Mean recall *Z*-scores of the corrected recall scores for 4-item sequences of odours (Experiment 2.1a), unfamiliar-faces (Experiment 2.2a) and pure-tones (Experiment 2.3a) as a function of serial position.

Further analysis of the interaction (Newman Keuls) revealed that recall across the three stimuli differed only at serial position 4, wherein *Z*-scores for pure-tones were significantly greater than that of odours and unfamiliar-faces. Analysis within each modality revealed no significant differences between positions following single-probe serial recall of odours. The recall of unfamiliar-faces revealed *Z*-scores for serial position 4 significantly greater than that of both positions 2 and 3. Following the pure-tone experiment, *Z*-scores for serial position 4 were significantly greater than that of positions 1, 2 and 3. Additionally, *Z*-scores for serial positions 1 and 3 were significantly greater than that of position 2.

Primacy and Recency Analysis

Recency and primacy was assessed across the odour, unfamiliar-face and pure-tone 4-item sequences by comparing the mean of the first and terminal items against the mean of the middle items.

Odours (Experiment 2.1a): Mean correct *Z*-score recall at serial position 1 (mean *Z*-score recall = 0.21) was non-significantly different to that of the mean of positions 2-3 (mean *Z*-score recall = -0.13), t=1.60. Mean correct *Z*-score recall at serial position 4 (mean *Z*-score recall = 0.02) was non-significantly different to that of the mean of positions 2-3, t=<1.

Unfamiliar-Faces (Experiment 2.2a): Mean correct *Z*-score recall at serial position 1 (mean *Z*-score recall = -0.12) was significantly greater than that of the mean of positions 2-3 (mean *Z*-score recall = -0.61), $t(23)=2.32$, $p<.05$. Mean correct *Z*-score recall at serial position 4 (mean *Z*-score recall = 0.26) was significantly greater than that of the mean of positions 2-3, $t(23)=2.67$, $p<.05$.

Pure-Tones (Experiment 2.3a): Mean correct *Z*-score recall at serial position 1 (mean *Z*-score recall = -0.28) was borderline significantly higher than that of the mean of positions 2-3 (mean *Z*-score recall = -0.69), $t(23)=1.81$, $p=.08$. Mean correct *Z*-score recall at serial position 4 (mean *Z*-score recall = 1.31) was significantly greater than that of the mean of positions 2-3, $t(23)=9.23$, $p<.05$.

Cross-Modal Comparison of Single-Probe Serial Position Recall: 5-Item Sequences of Odours, Unfamiliar-Faces and Pure-Tones

Serial Position Analysis

Corrected single-probe serial position recall for the 5-item sequences of odours (mean corrected recall = 0.23), unfamiliar-faces (mean corrected recall = 0.44) and pure-tones (mean corrected recall = 0.41) was standardised to *Z*-scores and are demonstrated in Figure 2.17. Standardised recall was compared within a 2-factor (3x5) mixed ANOVA where the between-subjects factor represents stimuli (odours, unfamiliar-faces and pure-tones) and the within-subjects factor represents serial position (1-5). As in the 4-item analysis, qualitatively different functions for odours, unfamiliar-faces and pure-tones would be characterised by a significant interaction between serial position and modality of stimuli. A null effect of stimuli was found, *F*<1, and a main effect of serial position, *F*(4,69)=37.46, *MSe*=0.71. Importantly, a significant interaction between serial position and stimuli, *F*(8,69)=14.92, *MSe*=0.71.

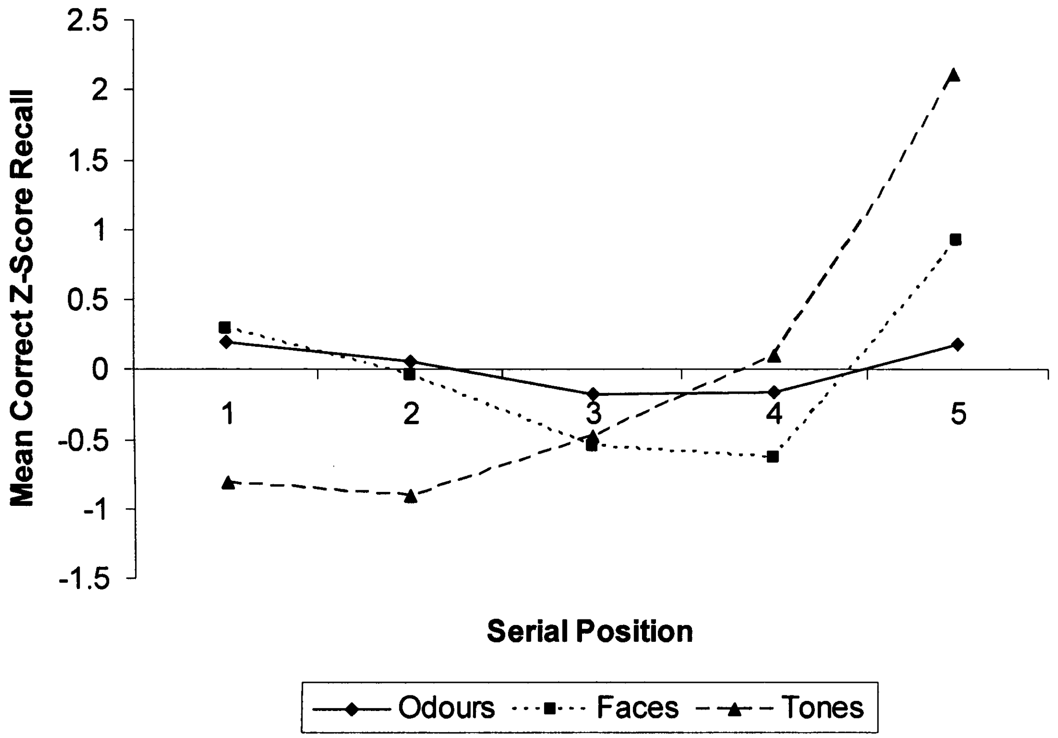


Figure 2.17: Mean recall *Z*-scores of the corrected recall scores for 5-item sequences of odours (Experiment 2.1b), unfamiliar-faces (Experiment 2.2b) and pure-tones (Experiment 2.3b) as a function of serial position.

Further analysis of the interaction (Newman Keul) revealed that, across stimuli, differences were only observed at the terminal items. At position 1, *Z*-scores for unfamiliar-faces and odours were significantly greater than that of pure-tones. At serial position 5, *Z*-scores of pure-tones were significantly greater than that of both unfamiliar-faces and odours. Analysis within each modality revealed no significant differences across serial position following single probe serial recall of odours. Within the unfamiliar-face experiment, *Z*-scores for serial position 5 were significantly greater than that of positions 1, 2, 3 and 4. *Z*-scores for serial position 1 were significantly greater than that of positions 3 and 4. Additionally, recall at position 2 was significantly greater than that of positions 3 and 4. Following single probe serial recall of pure tones, *Z*-scores for serial position 5 was significantly greater than that of positions 1, 2, 3 and 4. Extended recency was evident, wherein recall at serial position 4 was significantly greater than that of positions 1, 2 and 3.

Primacy and Recency Analysis

The same analysis was conducted on the 5-item sequences as performed for the 4-item lists.

Odours (Experiment 2.1b): Mean correct *Z*-score recall at serial position 1 (mean *Z*-score recall = 0.19) was non-significantly different to that of the mean of positions 2-4 (mean *Z*-score recall = -0.10), t=1.51. Mean correct *Z*-score recall at serial position 5 (mean *Z*-score recall = 0.18) was non-significantly different to that of the mean of positions 2-4, t=1.

Unfamiliar-Faces (Experiment 2.2b): Mean correct *Z*-score recall at serial position 1 (mean *Z*-score recall = 0.29) was significantly greater than that of the mean of positions 2-4 (mean *Z*-score recall = -0.41), $t(23)=4.01$, $p<.05$. Mean correct *Z*-score recall at serial position 5 (mean *Z*-score recall = 0.93) was significantly greater than that of the mean of positions 2-4, $t(23)=6.13$, $p<.05$.

Pure-Tones (Experiment 2.3b): Mean correct *Z*-score recall at serial position 1 (mean *Z*-score recall = -0.91) was borderline significantly lower than that of the mean of positions 2-4 (mean *Z*-score recall = -0.43), $t(23)=1.87$, $p=.07$. Mean correct *Z*-score recall at serial position 5 (mean *Z*-score recall = 2.11) was significantly greater than that of the mean of positions 2-4, $t(23)=12.27$, $p<.05$.

Cross-Modal Comparison of Single-Probe Serial Position Recall: 6-Item Sequences of Odours, Unfamiliar-Faces and Pure-Tones

Serial Position Analysis

Corrected single-probe serial position recall for the 6-item sequences of odours (mean corrected recall = 0.18), unfamiliar-faces (mean corrected recall = 0.37) and pure-tones (mean corrected recall = 0.30) was standardised to *Z*-scores and are demonstrated in Figure 2.18. As previously detailed, qualitatively different functions for odours, unfamiliar-faces and pure-tones would be characterised by a significant interaction between serial position and stimuli. Standardised recall was compared within a 2-factor (3x6) mixed ANOVA where the between-subjects factor represents stimuli (odours, unfamiliar-faces and pure-tones) and the within-subjects factor represents serial position (1-6). A null effect of stimuli was found, $F<1$ and a main effect of serial position, $F(5,69)=46.15$, $MSe=0.71$. Importantly, a significant interaction between serial position and stimuli was found, $F(10,69)=14.92$, $MSe=0.71$.

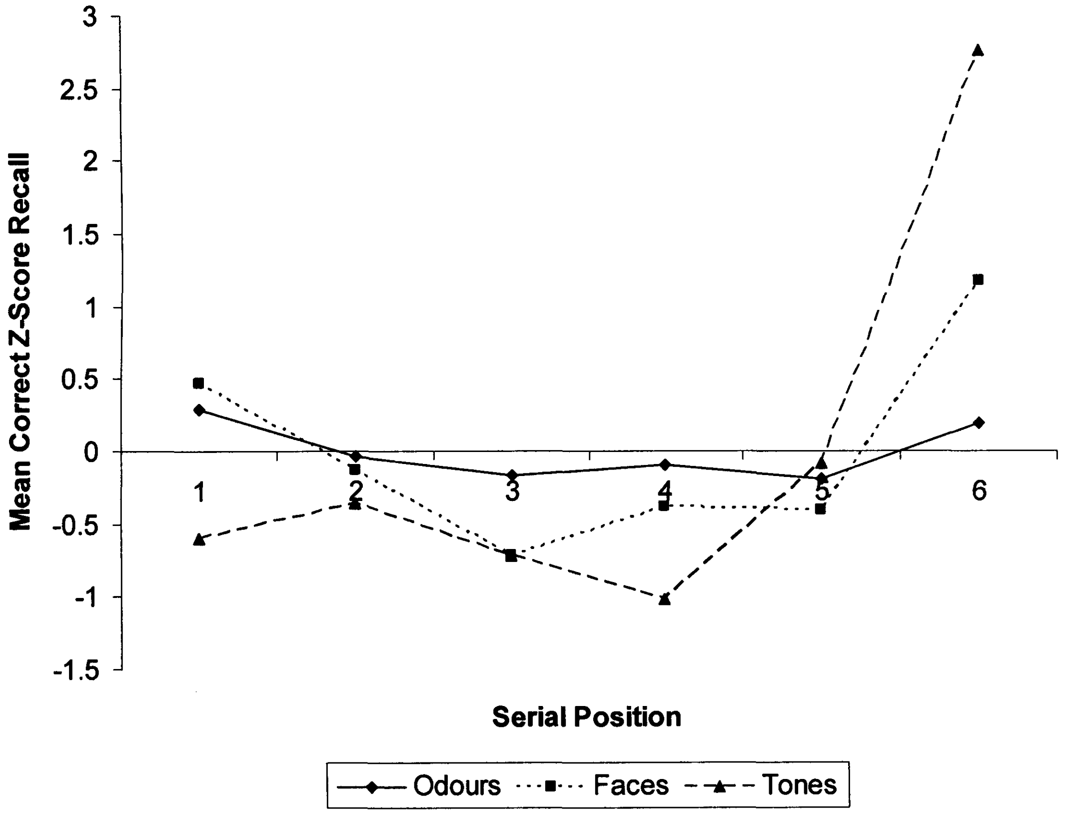


Figure 2.18: Mean recall Z-scores of the corrected recall scores for 6-item sequences of odours (Experiment 2.1c), unfamiliar-faces (Experiment 2.2c) and pure-tones (Experiment 2.3c) as a function of serial position.

Further analysis of the interaction (Newman Keuls) revealed significant differences across stimuli at each terminal serial position. Z-scores of both odours and unfamiliar-faces were significantly greater than that of pure-tones at position 1. At serial position 6, Z-scores of pure-tones were significantly greater than that of both unfamiliar-faces and odours. Additionally, *Z*-scores of unfamiliar-faces were also significantly greater than that of odours at the sixth serial position. Analysis within each modality revealed no significant differences across serial positions following single probe serial recall of odours. Following single-probe serial recall of unfamiliar-faces, *Z*-scores for serial position 6 were significantly greater than that of positions 1, 2, 3, 4 and 5. *Z*-scores for serial position 1 were significantly greater than that of positions 1, 2, 3, 4 and 5. Recall of pure-tones produced *Z*-scores for serial position 6 that were significantly greater than that of positions 2, 3, 4 and 5. *Z*-scores of position 5 were significantly greater than that of position 4.

Primacy and Recency Analysis

The primacy and recency analysis was conducted on the 6-item sequences of odours, unfamiliar-faces and pure-tones.

Odours (Experiment 2.1c): Mean correct *Z*-score recall at serial position 1 (mean *Z*-score recall = 0.29) was non-significantly different to that of the mean of positions 2-5 (mean *Z*-score recall = -0.12), t=1.61. Mean correct *Z*-score recall at serial position 6 (mean *Z*-score recall = 0.19) was non-significantly different to that of the mean of positions 2-5, t=1.26.

Unfamiliar-Faces (Experiment 2.2c): Mean correct *Z*-score recall at serial position 1 (mean *Z*-score recall = 0.47) was significantly greater than that of the mean of positions 2-5 (mean *Z*-score recall = -0.41), $t(23)=4.10$, $p<.05$. Mean correct *Z*-score recall at serial position 6 (mean *Z*-score recall = 1.17) was significantly greater than that of the mean of positions 2-5, $t(23)=7.41$, $p<.05$.

Pure-Tones (Experiment 2.3c): Mean correct *Z*-score recall at serial position 1 (mean *Z*-score recall = -0.60) was non-significantly different than that of the mean of positions 2-5 (mean *Z*-score recall = -0.54), $t<1$. Mean correct *Z*-score recall at serial position 6 (mean *Z*-score recall = 2.77) was significantly greater than that of the mean of positions 2-5, $t(23)=16.70$, $p<.05$.

Intervening Items Analysis of Experiments 2.1-2.3

In Chapter 3 (2AFC recognition) some evidence was found in favour of an interference-based account, whereby the number of items intervening between presentation and test predicted recognition accuracy (Experiments 1.1a and 1.1b). Number of items intervening between presentation and test was found to be a poor predictor of 2AFC recognition for both unfamiliar-faces and pure-tones, whereas some supporting evidence was found for odours.

The intervening-items-based analysis was applied to the single probe serial position recall performance for 4-, 5- and 6-item sequences of odours, unfamiliar-faces and pure-tones. If number of items intervening between presentation and test determines recall levels, list length should be irrelevant. Recall of earlier list items in longer sequences should demonstrate reduced recall due to a greater number of items intervening between presentation and test. On this basis, scores across different sequence lengths were combined for each modality. The correlations between number of items intervening between presentation and test and corrected recall are demonstrated in Figure 2.19(a-c).

Olfactory single-probe serial recall produced a negative non-significant correlation (R=-0.15, p=.60) between number of items intervening between presentation and test and corrected recall. For unfamiliar-faces a non-significant negative correlation was also found (R=-0.35, p=.20). A strong significant correlation (R=-0.75, p<.05) was found for the auditory stimuli and a regression analysis demonstrated that number of items intervening between presentation and test was a significant predictor of recall accuracy (R^2=0.57; $F(1,14)$=16.92, MSe=0.03). However, as suggested in Chapter 3, the heightened recency component for the auditory data may have artificially induced the significant negative linear correlation. When the correlation is repeated with terminal item recall omitted, the size of the correlation is greatly attenuated and non-significant (R=-0.45, p=.14). The finding indicates that as with the 2AFC paradigm, the significant negative correlation between number of items intervening and accuracy of auditory stimuli is driven by strong terminal item recall.

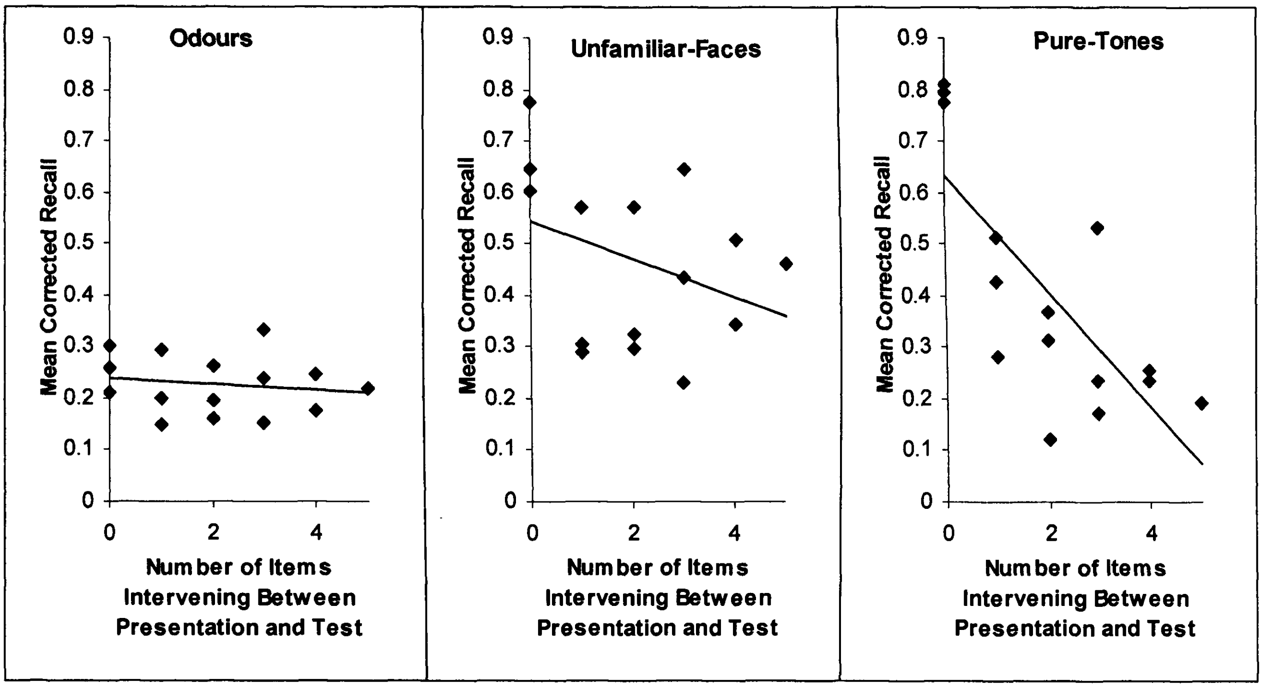


Figure 2.19(a-c): Scattergraphs demonstrating the relationship between number of items intervening between presentation and test and mean corrected single-probe serial position recall of the odour (a), unfamiliar-face (b) and pure-tone (c) experiments.

Experiment 2.4

Evidence of primacy was evident for single-probe serial position recall of unfamiliar-faces but absent with respect to both olfactory and auditory stimuli. One possible explanation for the primacy component found in the unfamiliar-face functions is via verbalisation of the stimuli and subsequent rehearsal. Rundus (1971) argued that the primacy component in the free recall of verbal stimuli was a product of high frequency rehearsal of early sequence items.

The role of verbalisation in memory for faces is controversial. In a study investigating memory for faces in a bank robbery, Schooler and Engstler-Schooler (1990) reported evidence of verbal overshadowing, wherein poorer memory performance was observed when participants were required to describe the facial features. Such a finding is consistent with the idea that faces are encoded holistically, such that the verbal feature-based encoding impairs memory. In contrast, Brown and Lloyd-Jones

(2005) found verbal description at encoding facilitated recognition for faces in a yes/no recognition paradigm.

The following experiment investigated the extent to which verbal labelling of the unfamiliar-face stimuli underpinned or facilitated the observed primacy component following single-probe serial position recall for unfamiliar-faces. For effective comparison between visual stimuli and auditory/olfactory stimuli, it is, therefore, imperative that the task is measuring those stimuli rather than a verbal representation of the stimuli.

Experiment 2.4 replicated the employment of 4-unfamiliar faces in the single probe serial position recall paradigm reported in Experiment 2.2a. During the presentation phase, participants performed articulatory suppression (by repeating the word "the" continuously). Articulatory suppression was performed during the presentation phase and not during recall for two reasons. First, prevention of verbal rehearsal is only required during encoding; if verbal labelling is restricted at encoding any early item benefit based upon verbal rehearsal is limited. Second, during the serial reconstruction of faces, Smyth et al. (2005, Experiment 2) found a non-significant difference between partial articulatory suppression (i.e. articulatory suppression during the presentation phase only) and full articulatory suppression (i.e. articulatory suppression throughout both the presentation phase and the recall phase).

Although Smyth et al. (2005, Experiment 2) found a main effect of articulatory suppression, crucially, a non-significant interaction between serial position and articulatory suppression was not found, i.e. the act of articulatory suppression impacted upon recall for each position equally. If the primacy component was underpinned via verbalisation one might predict greater impairment for the first serial position relative to post-primacy items. This was not found. Confidence ratings were employed as in single-probe serial position recall of olfactory stimuli in Experiment 2.1 for two reasons. First, to assess the extent to which the act of articulatory suppression impaired general response certainty (i.e. an index of task difficulty) and, second, to assess the extent to which any detriment to confidence induced by articulatory suppression disproportionately impacted serial position 1. Such a finding might indicate that verbalisation has a greater facilitative effect on early list items, suggesting a strategy of verbal labelling and rehearsal.

Method.

Participants. Twenty-four (3 males and 21 females: mean age 19 years and 1 month) Cardiff University volunteer Psychology undergraduates participated in exchange for course credit. None had participated in the previous Chapter 4 experiments.

Materials. The stimuli were as described for Experiment 2.2a.

Design. The design was as described for Experiment 2.2a with the exception that during half the trials participants performed articulatory suppression throughout the presentation phase. In the other half of trials participants performed the presentation phase in silence.

Procedure. The procedure was as described for Experiment 2.2a with the exception that in half of the trials participants repeated the word "the" 2-3 times per second out loud during the presentation phase. At the commencement of each trial participants were informed if the trial was an articulatory suppression or quiet trial. As in Experiments 2.1(a-c), participants provided a confidence rating following each answer with respect to the degree of certainty that the response was correct.

Results

Non-Standardised Serial Position Recall and Response Bias Serial Position Analysis

Figure 2.20a shows the mean percentage correct recall as a function of serial position for the quiet and articulatory suppression conditions. A 2-factor (2x4) within-subjects ANOVA was computed where the first factor represents the articulatory suppression condition (quiet versus articulatory suppression) and the second factor represents serial position (1-4). A main effect of articulatory suppression was found, $F(1,23)=59.83$, $MSe=0.84$ (mean correct recall of the articulatory suppression condition = 64.58%, mean correct recall of the quiet condition = 85.00%) and main effect of serial position, $F(3,69)=12.23$, $MSe=0.78$. Crucially, a significant interaction between articulatory suppression and serial position was also found, $F(3,69)=2.87$, $MSe=0.78$.

As demonstrated in Experiments 2.1-2.3, an examination of response frequency for each serial position revealed a response bias at serial position 2 following both the quiet and articulatory suppression conditions; this is demonstrated in Figure 2.20b. A single-factor within-subjects ANOVA with four levels was computed on the response frequency data for both the quiet and articulatory suppression condition.

Quiet: A borderline main effect of serial position was found, $F(3,69)=2.67$, $MSe=2.03$, p=.05.

Articulatory Suppression: A main effect of serial position was found, $F(3,69)=4.84$, $MSe=4.26$. Further analysis (Newman Keuls) revealed that responses for serial position 2 were significantly more frequent than positions 1, 3 and 4.

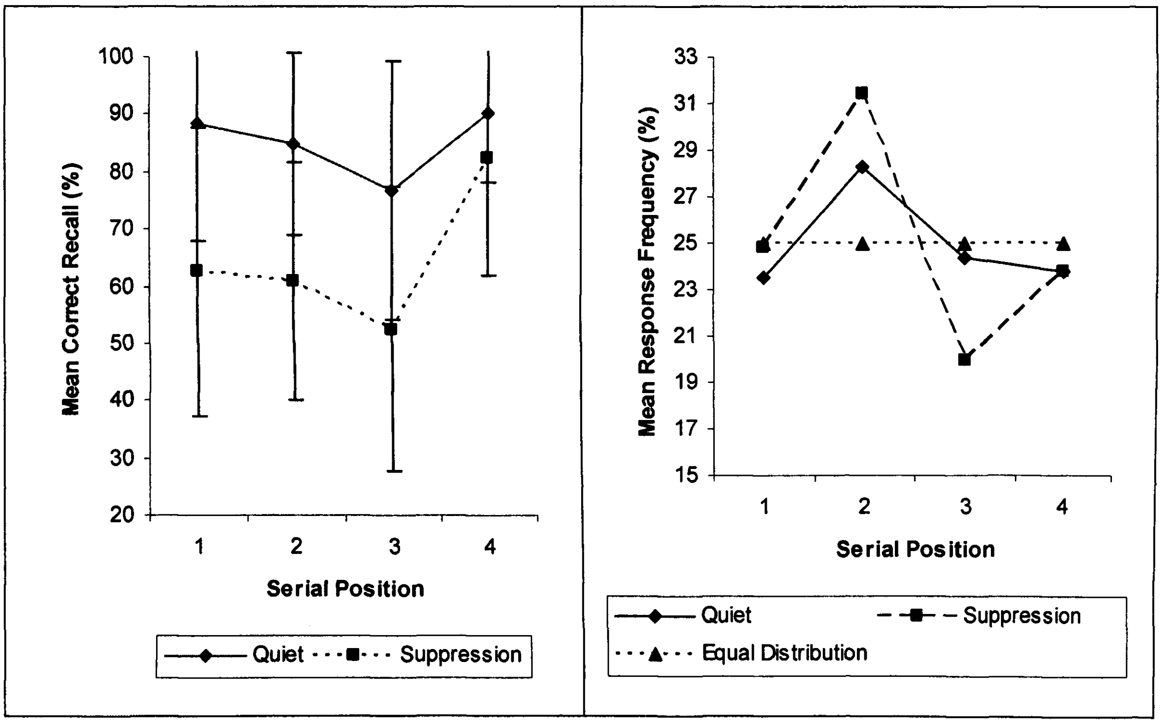


Figure 2.20(a-b): Mean percentage correct recall (a) and mean percentage response frequency (b) as a function of serial position for the silent and articulatory suppression conditions. In Figure 2.26a error bars denote 1 standard deviation. In Figure 2.26b an

equivalent distribution of responses across serial positions is depicted by the dotted line

Corrected Recall Serial Position Analysis

As in Experiments 2.1-2.3 the data were corrected for the response bias employing the equation described by Kerr et al. (1998) and is demonstrated in Figure 2.21. The corrected data were analysed using a 2-factor (2x4) within-subjects ANOVA, where the first factor represents the articulatory suppression manipulation (articulatory suppression versus quiet) and the second factor represents serial position (1-4). A significant main effect of articulatory suppression was found, $F(1,23)=53.80$, $MSe=0.07$ (mean corrected recall of the quiet condition = 0.76; mean corrected recall of the articulatory suppression condition = 0.48). A significant main effect of serial position was also reported, $F(3,69)=32.91$, $MSe=0.03$. Importantly, a significant interaction between serial position and articulatory suppression was found, $F(3,69)=5.05$, $MSe=0.03$.

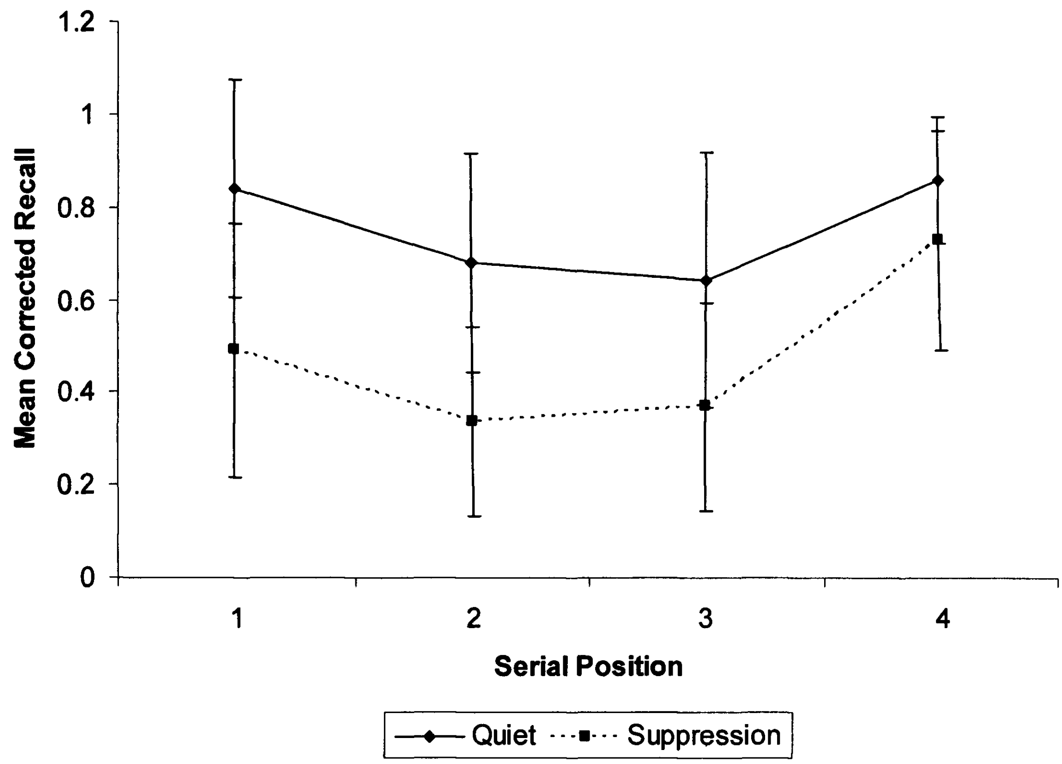


Figure 2.21: Mean corrected recall for the silent and articulatory suppression conditions following correction for response bias as a function of serial position. Error bars denote 1 standard deviation.

Further analysis of the interaction (Newman Keuls) revealed that the act of articulatory suppression significantly impaired recall at all positions in the sequence except serial position 4. When compared to the quiet condition, recall in the articulatory suppression condition was significantly poorer at positions 1, 2 and 3 but not position 4. The finding indicates that the recency component reported for single-probe serial recall of unfamiliar-faces is not underpinned, or even facilitated, by verbalisation. In the quiet condition, recall at positions 1 and 4 was significantly greater than that of positions 2 and 3. No differences between the terminal positions were found, indicating the presence of equivalent primacy and recency components. In the articulatory suppression condition, although recall at position 1 was significantly greater than that of positions 2 and 3, recall at position 4 was significantly greater than that of positions 1, 2 and 3. The finding indicates that the act of articulatory suppression had attenuated the primacy component to a far greater extent than that of recency.

Trend Analysis

Trend analysis was conducted on the corrected data for the quiet and articulatory suppression conditions.

Quiet: A significant quadratic component, $F(1,23)=38.64$, $MSe=0.02$, and a non-significant linear component, $F<1$, was found.

Articulatory Suppression: Both a significant quadratic, $F(1,23)=34.65$, $MSe=0.05$, and a significant linear component was found.

Primacy and Recency Analysis

Quiet: Corrected recall at serial position 1 (mean corrected recall = 0.84) was significantly greater than that of the mean of positions 2-3 (mean corrected recall = 0.66), $t(23)=4.78$, $p<.05$. Corrected recall at serial position 4 (mean corrected recall = 0.86) was significantly greater than that of the mean of positions 2-3, $t(23)=4.93$, $p<.05$.

Articulatory Suppression: Corrected recall at serial position 1 (mean corrected recall = 0.49) was significantly greater than that of the mean of positions 2-3 (mean corrected recall = 0.35), $t(23)=4.78$, $p<.05$. Corrected recall at serial position 4 (mean corrected recall = 0.72) was significantly greater than that of the mean of positions 2-3 $t(23)=6.92$, $p<.05$.

Confidence Rating Analysis

Consistent with the main effect of articulatory suppression, analysis of confidence ratings demonstrates that participants were significantly more confident of their responses in the quiet (mean confidence rating=4.16) compared to the articulatory suppression condition (mean confidence rating=3.20), $t(23)=9.79$, $p<.05$. Consistent with confidence ratings produced for odours (Experiment 2.1a-c), participants displayed insight into the accuracy of their responses. In the quiet condition, confidence ratings were significantly higher for correct (mean confidence rating = 4.29) relative to incorrect (mean confidence rating = 3.31) answers, $t(19)=5.58$, $p<.05$. [It should be noted that this comparison was only possible with 20 participants as 4 participants correctly responded to all trials in the quiet condition.] Similarly, in the articulatory suppression condition, confidence ratings were significantly higher for correct (mean confidence rating=3.59) compared to incorrect responses (mean confidence rating=2.53), $t(23)=6.62$, $p<.05$.

If the previously observed primacy component for single-probe serial recall of unfamiliar-faces was underpinned via verbalisation, one might predict an interaction between articulatory suppression group and serial position with respect to confidence ratings. That is, following articulatory suppression the confidence ratings fall to a greater extent at the primacy component of the function. A 2-factor (2x4) within-subjects ANOVA was computed where the first factor represents the articulatory suppression condition (quiet versus articulatory suppression) and the second factor represents serial position (1-4). A main effect of articulatory suppression condition was observed, $F(1,23)=12.34$, $MSe=7.02$, but crucially a non-significant interaction was found between articulatory suppression condition and serial position ($F<1$). A primacy-recency dissociation was not, therefore, apparent with respect to the effect of articulatory suppression on confidence ratings. This finding is inconsistent with the dissociating effect of articulatory suppression on recall levels between the primacy and recency components.

Due to the lack of erroneous responses, confidence ratings were only analysed for correct responses of the quiet and articulatory suppression conditions (confidence data is demonstrated in Figure 2.28a-b). A single-factor ANOVA with four levels was computed on the correct responses for the quiet and articulatory suppression conditions and revealed a significant main effect of serial position for both the quiet, $F(3,22)=10.65$, $MSe=0.19$, and articulatory suppression, $F(3,21)=6.68$, $MSe=0.53$, conditions (the groups comprised of 23 and 22 participants respectively due to some participants providing no correct answers for at least one serial position). In both these conditions further analysis (Newman Keuls) revealed that confidence ratings for serial position 4 were significantly greater than that of ratings for positions 1-3. Similar to the confidence ratings for 4-odour sequences, confidence ratings for correct responses appear to demonstrate single-item recency.

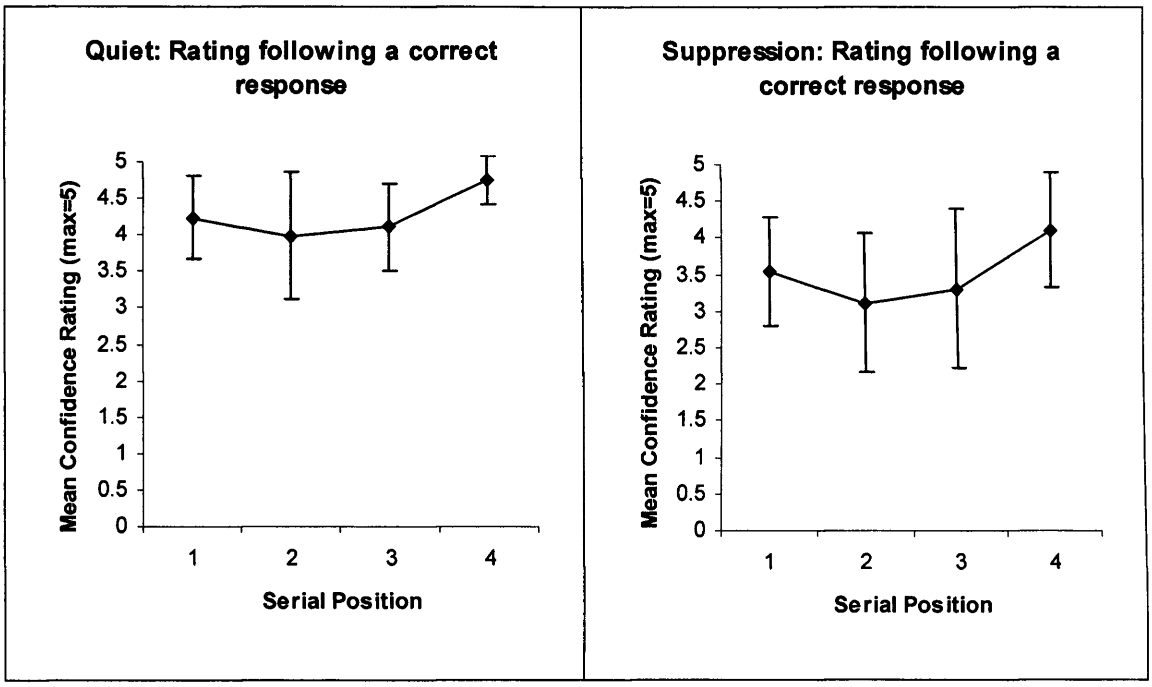


Figure 2.22(a-b): Mean confidence ratings for serial positions 1-4 following correct responses in the quiet (a) and articulatory suppression conditions (b).

Experiment 2.4: Discussion

Experiment 2.4 demonstrates that although the primacy component is attenuated following the employment of articulatory suppression during the presentation phase, a significant primacy effect remains. The finding indicates that verbal labelling has a facilitative role in the presence of primacy, although the first item benefit is not uniquely dependent upon verbal labelling and subsequent rehearsal. It should be emphasised that the facilitative effect of verbalisation does not seem to extend to the final serial position; articulatory suppression resulted in a 0.42 proportional fall in accuracy of position 1 compared to 0.15 of position 4. This finding indicates that different mechanisms may facilitate the primacy and recency component for single-probe serial recall of unfamiliar-faces.

In summary, the primacy disparity between unfamiliar-faces and odours/pure-tones is not an artefact of participants labelling and subsequently rehearsing verbal labels. This finding suggests qualitative differences between the memory of unfamiliar faces and the memory of odours and pure-tones.

Chapter 4: Discussion

In Chapter 4 the ability of participants to recall the order of items within a sequence was investigated by employment of the single-probe serial recall paradigm. Participants were presented with a sequence of 4-, 5- and 6-items. In Experiment 2.1(a-c) odours were employed, in Experiment 2.2(a-c) unfamiliar-faces were employed and in Experiment 2.3(a-c) pure-tones were employed. Each sequence was followed by a test probe from the previous sequence and the participant was required to state the position of that odour within the previous sequence.

Response Bias/Error Distribution

Consistent with Kerr et al. (1998), a response bias was observed for the single-probe serial position recall task. For odours and unfamiliar-faces this bias was apparent for earlier list items. Following single-probe serial position recall for pure-tones the bias was apparent for later list items. Response biases for different sections of the sequences demonstrated by odours and unfamiliar-faces compared to that of pure-tones, provides some evidence that different mechanisms/processes underpin performance of the task for pure-tones.

However, despite the cross-modal differences in response distribution, erroneous responses for odours, unfamiliar-faces and pure-tones were most frequently allocated to adjacent serial positions (see Appendix 4 for a more detailed analysis of response distributions). This trend for allocation errors is consistent with the analysis conducted by Smyth et al. (2005) following serial order reconstruction of unfamiliar-faces. This finding demonstrates cross-modal similarities between the memory processes undertaken for order. Specifically, it suggests that items are stored with a relative, rather than absolute, positional code. For example, if participants were associating a specific item with an absolute position (e.g. this particular odour is linked to serial position 3) one might predict an equal distribution across the remaining serial positions for incorrect responses, as if the associative link between that odour and a specific position has eroded, no other clues are available of the positional origins. However, if the item is stored along a contextual spectrum (e.g. the activation gradient described in Page and Norris', 1998, Primacy Model), decay or blurring of the item might increase the difficulty by which the exact position of the item can be recalled but still maintain a vague blurred region on that spectrum from which the item originated. Such a mechanism might predict a greater frequency of erroneous response allocated to adjacent serial positions.

Evidence for coding of position along a relative dimension is supported by Henson (1999) who found that intrusion errors across lists of different lengths were relative to the position of the item in the previous sequence (i.e. equivalent proportional distance from the end of the sequence) rather than a transposition for the absolute serial position (i.e. an identical number of positions from the end). This demonstrated that items are stored relative to start-end markers rather than stored as absolute positions in the sequence.

Corrected Recall Functions for Odours, Unfamiliar-Faces and Pure-Tones

Following a correction for the response bias, qualitatively different serial position effects were reported for odours, unfamiliar-faces and pure-tones. For odours, an absence of serial position effects was observed across list lengths (Experiment 2.1a-c). A bowed serial position function was observed for unfamiliar-faces (Experiment 2.2a-c). Furthermore, the primacy component observed for unfamiliar-faces was shown not to be reliant upon verbalisation/rehearsal (Experiment 2.4). In contrast, single-probe serial position recall of pure-tones produced recency but not primacy. The three qualitatively different serial position functions contradict the proposal by Ward et al. (2000) that the serial position function is task dependent, as the same task, applied to three different stimuli types, produced qualitatively different functions.

The flat serial position function observed for odours is consistent with the conceptualisation of odours as unitary entities impervious from interference (e.g. Chobor, 1992; Engen and Ross, 1973). Under such a conceptualisation, the position of odours is recalled at an equivalent level, as each odour is stored as a unique event. This idea that odours are resistant to interference is consistent with the failure to find a correlation between number of items intervening between presentation and test and recall. A significant correlation was found neither following the present paradigm nor 2AFC recognition in Experiment 1.1b. However, if odours are encoded as unitary perceptual events one might predict flat serial position effects following backward testing in Experiment 1.1. This was not found.

The bowed serial position function produced following single-probe serial position recall of unfamiliar-faces (Experiment 2.2a-c) is inconsistent with Kerr et al. (1998) who found only recency. However, the observation of primacy was found not to be dependent on verbalisation/rehearsal (Experiment 2.4). It remains, therefore, unclear as to why different serial position functions were produced to that of Kerr et al. (1998).

Single-probe serial position recall of pure-tones produced recency but not primacy. Such a finding replicates the strong recency found following backward 2AFC recognition testing with pure-tones (Experiment 1.4) and is consistent with the existence of a short-term auditory-specific store (e.g. PAS, Crowder and Morton, 1969, analogous to Phillips and Christie's, 1977, duplex theory). This fragile short-term echoic store holds auditory information for a short period until displaced by another auditory event. Under this account the terminal item is stored within the highly accurate PAS, but storage is fragile, such that recall is impaired by a suffix. Following the single-probe serial recall paradigm, the terminal item is tested without any items intervening, therefore, allowing a strong match between the test probe and the item held within PAS. If an amodal duplex store was employed, one might predict equivalent levels of recency cross-modally when scores were transformed. Instead, recency is absent for odours and significantly greater for pure-tones compared to that of unfamiliar-faces. The findings suggest that different mechanisms may underpin the recency component, or at least an additional auditory-specific facilitative process may promote pure-tone recency.

The task, therefore, produced three qualitatively different serial position functions; an absence of serial position effects for odours, primacy and recency for unfamiliar-faces and recency but not primacy for pure-tones. The cross-modal serial position function differences were not an artefact of reduced recall rates for olfactory stimuli as the 4-odour, 5-pure-tone and 6-unfamiliar face sequences produced broadly equivalent performance levels (mean recall of odours = 60%; mean recall of pure-tones = 58%; mean recall of unfamiliar-faces = 56%), yet produced an absence of serial position effects, recency but no primacy and a bowed function, respectively. As in Chapter 3, nor can the cross-modal differences be explained in terms of differences in stimulus exposure time; items were all presented for 1000ms followed by a 1000ms ISI in all experiments.

Modularity

The findings are consistent with studies that argued for modularity in sensory memory (e.g. Andrade and Donaldson, in press; Guérard and Tremblay, under review), i.e. the observation of incongruent functions across the three modalities, when presentation procedures are uniform, indicates that the stimuli are being stored by different mechanisms. Andrade and Donaldson (in press) found that olfactory and visual memories were differentially impaired by olfactory and verbal distraction respectively. Similarly, verbal suppression was found to exclusively impair verbal serial recall and finger-tapping was observed to selectively impair spatial serial recall (Guérard and Tremblay, under review). Andrade and Donaldson (in press) proposed that a dedicated olfactory subsystem of working memory exists analogous to the visuo-spatial scratchpad and phonological loop.

An alternative explanation of the cross-modal differences relates to the overall distinctiveness of the stimuli. Although presentation times were equivalent across modalities, the extent to which the items within each sequence differed was not controlled. For example, the magnitude of recency may be mediated by the extent to which the terminal item can be differentiated from pre-recency items. Although intuitively one might predict that similarity may affect the serial position function quantitatively but not qualitatively (see Smyth et al., 2005), it is possible that characteristics of the stimuli specific to the modality may selectively affect the function. Therefore, stimuli-specific characteristics may produce the differing functions rather than separate systems/mechanisms. Such a hypothesis is very difficult to test, as it necessitates that the same stimuli can be applied to different modalities (e.g. the same words can be presented visually and aurally). Such an interpretation is more consistent with a perceptual organisation approach to memory (e.g. Jones et al. 2007), which does not necessarily rely upon separate memorial modules. Under such an account, it is the ability to organise the stimuli into sequences that governs memory performance.

Modelling of Order Memory

Numerous models have been formulated to account for verbal serial order memory. Although designed specifically to account for verbal memory, these models have also been applied to non-verbal functions, specifically for serial order reconstruction and 2AFC relative recency tasks (see Avons et al., 2004). Application of these models to the present functions has mixed implications. This is particularly apparent for models that employ the first item in the sequence as a marker (e.g. Henson's, 1998, Start-End Model) or where the first item receives the highest activation level (e.g. Primacy Model, Page and Norris, 1998). These models are consistent with the primacy observed for single-probe serial recall of unfamiliar-faces but are contradicted by the absence of primacy found for both odours and pure-tones. The absence of recency for the olfactory data is inconsistent with the prediction of most models. For example, at immediate testing, a temporal distinctiveness approach (e.g. Neath, 1993) might predict superior recall of the terminal item, as (1) the ratio between ISI and retention interval is equivalent and (2) no items intervene between presentation and test.

Summary

Experiments 2.1-2.4 have demonstrated qualitatively different serial position functions following single-probe serial recall for sequences of odours, unfamiliar-faces and pure-tones. These differences were observed despite consistent exposure times, ISIs and sequence-lengths across stimulus type. Despite the absence of serial position effects, olfactory recall was found to be above chance, demonstrating that participants possess the ability to associate an odour with a context. This supports the finding that participants can perform the 2AFC relative recency task (White and Treisman, 1997) but demonstrated qualitatively different functions following the absence of recency. Furthermore, Experiments 2.1 and 2.2 also provided some evidence that recognition and recall paradigms produce qualitatively different serial position functions (consistent with the claim of Ward et al., 2005). Both odour and face stimuli produced qualitatively different functions in the 2AFC recognition paradigm of Chapter 3 compared to their single-probe serial position recall functions displayed in Chapter 4. Qualitatively different serial position functions across stimuli types for the single-probe serial recall task suggest that different memorial mechanisms/strategies underpinned memory across the three stimuli types. Qualitatively different functions is consistent with a modularity account of memory such as the working memory account (e.g. Baddeley and Hitch, 1974), whereby separate stimuli-specific systems operate. A qualitatively different olfactory function supports the presence of an additional olfactory module in working memory (Andrade and Donaldson, in press).

Key Findings

Application of odours, unfamiliar-faces and pure-tones to the identical single-probe serial position recall task has produced qualitatively different functions for the three stimuli. Odours produced no serial position effects, unfamiliar-faces revealed recency and primacy, whereas pure-tones produced primacy but not recency. The presence of primacy for unfamiliar-faces was found not to be due to verbal labelling and subsequent rehearsal. The findings indicate qualitatively different cross-modal memory processes/systems.

CHAPTER 5: MODIFIED-RECONSTRUCTION

Introduction

Overview

Chapter 5 proposes and tests a modified version of the serial order reconstruction paradigm. The introduction to Chapter 5 initially describes the serial order reconstruction task and reports the serial position function characteristic of this paradigm. It is proposed that the serial order reconstruction paradigm is restricted to visual stimuli thereby negating any cross-modal comparison. A new paradigm applicable to all stimuli modalities, termed modified-reconstruction, is described. The modified-reconstruction paradigm is trialled and compared with serial order reconstruction in Experiments 3.1 and 3.2. This new paradigm is then applied to olfactory, visual and auditory stimuli (Experiments 3.3-3.5), with a serial position function cross-modal comparison.

Serial Order Reconstruction

In Chapter 4 the single-probe serial position recall paradigm was investigated. In this paradigm a single test item is presented per trial. For a sequence of 6-items, therefore, six trials are required to obtain a score for each position in the sequence. In contrast, paradigms exist in which all positions are tested within each trial. With such a design, data is collected with fewer trials but at the expense of order effects. The following section reviews the multiple test item paradigms applied to hard-to-name stimuli, specifically, the serial order reconstruction task.

An established method by which serial order position effects have been assessed is via free recall of verbal stimuli. In this paradigm a sequence of verbal stimuli is presented to the participant. At test, the participant is required to recall as many items from the sequence as possible in any order. The free recall of verbal stimuli has consistently produced a bowed serial position function, that is, exhibiting both primacy and recency components (e.g. Craik, 1968; Ellis and Hope, 1968; Glanzer and Cunitz, 1966). The primacy component of the serial position function has traditionally been attributed to verbal rehearsal (Rundus, 1971), whereas recency is argued to be an underpinned by a separate primary memory (Craik, 1968).

The free recall paradigm, however, is unsuitable for application to non-verbal stimuli. In order for free recall to occur, verbal labels must first be assigned to the non-verbal stimuli. Following the employment of verbal labels it is impossible to empirically differentiate the extent to which the observed serial position functions are characteristic of the non-verbal perceptual stimuli or a characteristic of the verbal representation of those stimuli. The paradigm is, therefore, inappropriate for adequate cross-modal serial position function comparisons.

Serial order memory of non-verbal stimuli has, therefore, been investigated via the serial order reconstruction paradigm (e.g. Avons, 1998; Smyth et al., 2005). Within this paradigm, a sequence of items is presented followed, at test, by simultaneous re-presentation of all previous sequence items. The participant is required to select each item in the order of original presentation. In essence, the participant reconstructs the order of the items. Ward et al. (2005) argued that the reconstruction of serial order task is characterised by a bowed serial position function, exhibiting both primacy and recency components. They presented participants with sequences of 4, 6 and 8 unfamiliar faces (Experiment 1) and sequences of 4, 5 and 6 non-words (Experiment 3), with each item presented for 1500ms followed by a 500ms ISI. At test, the sequence items were represented simultaneously on a computer screen and participants were required to click on the items in the order of original presentation, therefore, reconstructing the order. Enhanced recall was reported for the first and terminal item in the sequence regardless of both list length and modality of presentation. Avons and Mason (1999) reported the same pattern of findings following serial order reconstruction of abstract block patterns (Experiment 1).

The bowed functions reported by both Ward et al. (2005) and Avons and Mason (1999) are consistent with other reconstruction studies. For instance, Smyth et al. (2005) presented participants with sequences of 3, 4, 5 and 6 unfamiliar faces, followed by serial order reconstruction at test. Smyth et al. (2005) reported both primacy and recency with curvature more pronounced for longer sequence lengths. Importantly, this study showed no interaction between serial position and articulatory suppression (Experiment 2) suggesting that the serial position effects, specifically the primacy component, were not underpinned by verbal encoding/rehearsal strategies.

Similarly, Avons (1998) presented participants with a sequence of 3, 4, 5 and 6 visual matrices. Reconstruction of serial order produced a bowed serial position for all sequence lengths. The pattern was replicated following articulatory suppression (Experiment 2), although articulatory suppression was found to have a greater impairment on performance than a finger-tapping task (Experiment 3). Avons (1998) argued, therefore, that verbal labelling/rehearsal contributes to serial order memory to a limited degree. Importantly, Avons (1998) showed no interaction between serial position and articulatory suppression, indicating that the serial position effects, and crucially the primacy component of the function, were not dependent upon verbalisation. The performance discrepancy between Experiments 2 and 3 might, therefore, be a product of task difficulty whereby an articulatory suppression task produces greater cognitive demands than a finger-tapping task.

The potential role of verbal labelling/rehearsal on order memory highlighted by Avons (1998) can be removed via the study of non-human animal populations. Specifically, the extent to which verbalisation underpins the primacy component can be investigated by the employment of non-human animals. For instance, Buchanan, Gill, and Braggio (1981) trained a single chimpanzee (Lana) to free recall lists of 1-8 Yerkish symbols. The methodology comprised a serial order reconstruction-free recall hybrid task. Following sequential presentation of the symbols, these were re-presented on the keyboard in front of Lana, and she was required to press the symbols presented in the previous sequence. However, additional symbols that were not presented in the previous list were on the keyboard, therefore, the task differed from the serial order reconstruction task. Primacy and terminal item recency was observed on lists of 7 and 8 symbols. The experiment, therefore, demonstrates primacy for the free recall of visual stimuli in a non-verbal subject, thereby suggesting that the primacy component is not always underpinned via verbalisation. Since Lana could not verbalise the stimuli it seems unlikely that the presence of primacy could be explained by verbal rehearsal. However, it should be noted that this is a single subject study who experienced extensive training in Yerkish symbols.

Reconstruction of serial order for spatial locations of both visual and auditory stimuli has demonstrated congruency with that for visual item reconstruction. For example, Parmentier and Jones (2000) presented participants with a sequence of 7 bursts of white noise, each presented from a different spatial location. Following presentation of the sequence, participants were given a diagrammatic representation on the computer screen of the position of the speakers producing the sounds. Participants were required to click on each picture of a speaker to reproduce in the order of original presentation. Both primacy and recency components was reported (see also, Parmentier, Maybery, and Jones, 2004, Experiment 1), and this function was robust qualitatively (if not quantitatively) following a 10s retention interval (Experiment 2).

In addition, reconstruction of serial order of the spatial location of dots has been investigated (Farrand, Parmentier, and Jones, 2001; Jones et al., 1995). Participants were presented with a sequence of 4-, 7- and 10-dots (only 7-dot sequences in Farrand et al., 2001). During the retrieval stage all dots were simultaneously represented in their original positions of presentation and participants were required to mark the position on the screen where each item had been located. Consistent with reconstruction of spatial positions of auditory stimuli (Parmentier and Jones, 2000; Parmentier et al., 2004), both studies reported a bowed function.

Smyth and Scholey (1996) investigated reconstruction of the spatial positions of black squares within a 3x3 matrix. In the presentation phase, 7 different squares within the matrix turned black in sequence. At test, the participant had to indicate which squares on the 3x3 matrix turned black in the previous sequence and use the touch screen to select these squares in the order in which they were presented in the preceding sequence. In Experiment 1, Smyth and Scholey (1996) observed fewer errors for the terminal items. Primacy and recency was attributed to first and terminal items not being "exchanged with other items on either side. That is, the serial position curve appears because the first and terminal items of a sequence present fewer error opportunities than do central items" (pg. 166). Specifically, the terminal items only have items in the list to one side, thereby restricting erroneous responses to one direction. If one assumes that errors are more prevalent for adjacent serial positions (Smyth et al., 2005), the probability of recalling a terminal item in an erroneous position is, therefore, reduced. This is contrary to non-terminal items where positional errors can be made on either side. Consistent with this interpretation, Smyth and Scholey (1996) found that the most common errors involved changes in serial position between adjacent items. Experiment 2 provided further support using a sequence recognition task. Participants were presented with two sequences (one immediately following the other) of 6-spatial items presented visually and had to decide if the sequences were the same or different. When different, the spatial location of a pair of items within the sequence was transposed. A greater number of errors were observed when the transposed pair comprised adjacent items within the sequence. The functions reported in Experiment 1 were qualitatively equivalent with reconstruction of other stimuli, prompting Smyth and Scholey to conclude that "positional information is dealt with in a similar way across domains" (pg. 176). Such an interpretation supports a uni-modal account of memory, suggesting at least that different stimuli are processed via analogous mechanisms.

In summary, the serial order reconstruction paradigm permits the application of non-verbal stimuli to a task in which all positions are probed in every trial. The task does not, therefore, rely upon verbal labels and is characterised by both primacy and recency.

The Qualitative Effect of Task and Stimuli Type on the Serial Position Function

The proposed distinction (Ward et al., 2005) between the serial position function produced for serial order reconstruction (a recollection based task, characterised by a bowed function) and 2AFC recognition (a familiarity based task, characterised by single-item recency) is consistent with the reported neurological dissociation between familiarity and recollection (e.g. Brown and Aggleton, 2001). The 2AFC recognition task can be performed either via a familiarity judgment of the two items in the test pair or via recollection of one of the test items being previously presented in the sequence (Mandler, 1980). However, reconstruction necessitates explicit recollection of the item in order to recall the serial position of that item within the sequence.

One can argue that Chapters 3 and 4 (2AFC recognition and single-probe serial position recall, respectively) of the current thesis have provided some support for the familiarity-recollection function disparity. For the 2AFC recognition task (a familiarity-based task) both odours and unfamiliar-faces produced recency but not primacy. In the single-probe serial recall task (necessitating recollection) odours produced a flat function and unfamiliar-faces produced a function with both primacy and recency respectively. That is, qualitatively different functions were produced for a familiarity-based task and a recollection-based task. However, it is important to note that single-item recency was observed for both 2AFC recognition and single-probe serial recall of pure-tones. That is, qualitatively equivalent functions were produced for familiarity and recollection-based tasks with auditory stimuli. However, Chapter 4 clearly contradicted the proposition by Ward et al. (2005) that the serial position function is task rather than stimuli dependent. Here, the single-probe serial recall paradigm was applied to odours, unfamiliar-faces and pure tones, revealing a flat function, a bowed function and a function exhibiting single-item recency, respectively. Therefore, despite identical tasks, different modalities produced qualitatively different functions.

Limitations of Cross-Modal Comparisons with the Serial Order Reconstruction Paradigm

As previously detailed, Ward et al. (2005) proposed that the serial position function is task rather than stimuli dependent. This finding was formulated following qualitatively equivalent serial position functions produced for serial order reconstruction of unfamiliar-faces and nonwords (in which a bowed function exhibiting both primacy and recency was found). Furthermore, qualitatively equivalent functions were produced following application of unfamiliar-faces and nonwords to the 2AFC recognition paradigm (both producing single-item recency). Ward et al. (2005) argued that since both non-verbal (unfamiliar-faces) and verbal (nonwords) stimuli produced qualitatively equivalent functions, the serial position function is not altered qualitatively by the stimuli.

The Ward et al. (2005) study illustrated functional equivalence between visually presented nonwords and unfamiliar-faces. However, the study does not investigate the extent to which this function is robust across other non-visual modalities. An alternative hypothesis is, therefore, that the functional equivalence reported may be characteristic of visual memory (irrespective as to whether verbal or non-verbal) but not extended to other modalities. However, the reconstruction of serial order paradigm precludes this alternative hypothesis from being empirically tested. The reconstruction of serial order requires that, the sequence items are simultaneously represented at test and the participant indicates the order in which the items were originally presented. Such a manipulation is only possible for visual and, arguably, tactile stimuli. For instance, a participant cannot smell/hear simultaneous presentation of items and differentiate between them. Since the serial order reconstruction task prohibits cross-modal comparison, a modified paradigm was developed.

The Modified-Reconstruction Paradigm

In order to investigate cross-modal equivalence in the reconstruction of serial order, a modified-reconstruction paradigm was devised. In this paradigm items are presented individually in a sequence during the presentation phase consistent with serial order reconstruction. However, at test each item is re-presented individually/sequentially, and the participant is required to state the serial position of each item individually. Items are re-presented in the original order of presentation (forward testing procedure), in the reverse order of original presentation (backward testing procedure) or in a control order of presentation that was neither forward nor backward. The forward testing procedure is argued to be the closest replication of the serial order reconstruction task, since participants are required to recall the items in the original order of presentation. However, unlike serial order reconstruction participants are naïve with respect to the direction of recall.

The modified-reconstruction paradigm differs to the serial order reconstruction task in three ways. First, the two paradigms are contradictory with respect to the direction of cueing between item and order. In serial order reconstruction, the participant knows the order in which the items are to be recall and is instructed to indicate each item in order of original presentation. Therefore, the participant knows the position that is being currently tested but is searching the problem space for an item that was in that temporal context. Conversely, in the modified-reconstruction paradigm the participant is given an item and has to indicate the position. Therefore, they know the item but are required to recall the temporal context in which that item occurred. Second, at test, each item is presented individually in the modified-reconstruction paradigm but simultaneously in the serial order reconstruction paradigm. Simultaneous presentation may promote a different recall strategy because participants are able to compare multiple items prior to recalling serial position. In the modified-reconstruction paradigm there is no opportunity for multiple item comparisons. A third difference concerns the time elapsed between initial presentation of the items and their re-presentation at test. The time elapsed between original presentation and representation at test is far greater for many of the items in the modified-reconstruction paradigm. For instance, in the conventional serial order reconstruction task the participant is presented with all list items simultaneously at test. The terminal sequence item, therefore, is presented last in the presentation phase and then immediately at test. However, in the forward modified-reconstruction task, the terminal sequence item is only presented after each of the previous sequence items have been individually re-presented.

Although the forward modified-reconstruction procedure has already been identified as the closest approximation to serial order reconstruction, it is important to note the other testing procedures employed within the modified-reconstruction paradigm. Whilst serial order reconstruction only requires forward recall, the modified-reconstruction paradigm incorporates three different recall directions; forwards, backwards and control. The implementation of the three directions of test should inhibit learning of test order on any given trial. Conrad (1965) proposed that backward recall of a list necessitates a more cognitively taxing strategy resulting in an increase in errors. Conrad (1965) proposed that participants employ a strategy whereby items are originally recovered in the original forward order even though recalling in the reverse order. The participant is proposed to then scan to the end of the list, recall the terminal list item and then suppress that item once recalled. The process is then repeated for the penultimate item, which is subsequently suppressed. This procedure is repeated until all items have been recalled. Backward recall is, therefore, more cognitively taxing since once originally recalled in the forward order, the participant must store this order and work backwards through the list. The process, therefore, takes longer than forward recall thus increasing the opportunity for trace decay.

Li and Lewandowsky (1995) concurred that backward recall is often inferior to forward recall but proposed distinct retrieval processes for forward and backward recall. They demonstrated that backward recall, unlike forward recall, is immune to the detrimental effect of inter-item distracter tasks leading them to conclude that different retrieval processes underpin forward and backward recall. Expressly, Li and Lewandowsky (1995) proposed that forward recall is underpinned by asymmetrical inter-item associations, whilst backward recall relies upon visuo-spatial representations of the learnt material. This retrieval distinction was supported by the double dissociation finding: forward recall was disrupted whenever items were separated during the presentation phase by a distracter task, whereas backward recall was impaired when the visual processing of the study items was altered. This retrieval process disparity is supported by the finding that, unlike the forward serial recall facilitation observed, backward recall does not benefit from high word frequency (Hulme, Roodenrys, Schweickert, Brown, Martin and Stuart, 1997).

Nevertheless, it should be noted that Farrand and Jones (1996) found no difference between backward and forward recall when the items were re-presented at test and the task necessitated only memory of order. This was found for auditory-verbal, visuo-verbal and (nonverbal) spatial stimuli. However, when memory for both item and order information was required (i.e. serial recall), Farrand and Jones (1996) found that the superiority for forward recall was restored. Farrand and Jones (1996), therefore, argued that symmetry in inter-item association exists. Furthermore, the fact that direction of recall did not interact with modality of presentation was taken as additional evidence contrary to spatial strategies underpinning reverse recall (as proposed by Li and Lewandowsky, 1995).

The control testing procedure allows an assessment into some of the strategies/mechanisms underpinning serial recall. For example, is primacy and/or recency an artefact of the first/last item being tested first/last? Does the first and/or terminal item(s) recalled from the sequence have a performance advantage irrespective of being a terminal item in the original sequence? The control order procedure is similar to the testing procedure described by Greene et al. (1998). In this experiment a sequence of 8 words was presented at learning. At test each of the previous words was represented individually. Participants were required to type the position 1-8 (without repeating positions) for each of the test probes until all items had been presented. The order of word representation at test was randomised yet still produced a bowed function for words (Experiment 1) and sums (Experiment 2).

The present set of experiments was designed to compare modified-reconstruction and serial order reconstruction tasks for unfamiliar-faces in order to determine the degree of cross paradigm concordance. Once established, odours, unfamiliar-faces and pure-tones are applied to the modified-reconstruction paradigm. Additionally, the present set of experiments investigated the proposition by Ward et al. (2005) that modality does not qualitatively alter the serial position function. If this proposition is correct, qualitatively equivalent functions should be found for odours, unfamiliar-faces and pure-tones.

Experiment 3.1

Prior to comparisons between olfactory and face stimuli in the modified-reconstruction of serial order, it is first necessary to establish functional equivalence between the serial order reconstruction task and the modified-reconstruction task. Experiment 3.1, therefore, broadly replicated the serial order reconstruction methodology employed for visual stimuli (e.g. Avons, 1998; Smyth et al, 2005; Ward et al, 2005). The serial order reconstruction task traditionally produces a bowed serial position function.

Method

Participants. Twenty-four (9 males and 15 females: mean age 21 years 5 months) Cardiff University volunteer undergraduates from a variety of disciplines participated. Each received a £3.00 honorarium upon completion of the study.

Materials. The stimuli set was as described for Experiment 1.2. Sixty-three unfamiliar faces were employed for the experimental trials and 12 were employed for practice trials.

Design. A single factor within-subjects design was adopted. Participants were each presented with 18 trials each comprising a sequence of 7 unfamiliar-faces. The presentation order of the 18 trials within the experiment was randomised for each participant. Each face was employed twice in the experiment.

Procedure. The procedure closely followed the reconstruction paradigm employed by Ward et al. (2005) and Smyth et al. (2005). Participants sat approximately 50cm from the computer screen and were instructed to remember the order of a 7-face sequence in preparation for an immediate test. Two practice trials were provided. Each trial began with a message on the screen instructing the participant to "press any key when ready to begin". Once the participant had responded the screen went blank for a period of 1000ms. This was followed immediately by a sequence of 7 faces. For all sequences the faces were presented individually in the centre of the screen for 750 ms followed by an ISI of 500 ms. Following presentation of the seventh face the screen displayed the message "test faces". This served as the cue for participants to turn over the page in their answer booklet and commence recall. The seven previously presented faces were presented in a circular array in the centre of the page. The positioning of the faces in the answer booklet, with respect to the original position within the sequence, was randomised across trials.

Participants reconstructed the original order of face presentation by writing 1-7 on each face in the answer booklet. Participants were instructed to write the positions in the order of original presentation (e.g. choose the face that they believed to be at the beginning of the sequence first and write '1'; and the item that they believed to be seventh chosen last). Participants were told that they could not correct a response once it had been made nor could a serial position be repeated within a trial. If participants were uncertain about the position of a particular face they were instructed to guess. When a position had been allocated to each of the seven test faces the participant was instructed to press any key. The screen then displayed the message "press any key when ready to begin". The participant was told to rest for as long as necessary before commencement of the next trial. The experimental procedure lasted approximately 20 minutes.

Results and Discussion

Serial Position Analysis

Figure 3.1 shows the mean percentage correct recall at each of the seven serial positions. Recall accuracy is high for the first position in the sequence and gradually declines to the fourth position where performance levels off. Recall accuracy then improves for the terminal face in the sequence. A single factor within-subjects ANOVA revealed a main effect of serial position, $F(6,138)=30.69$, $MSe=4.23$.

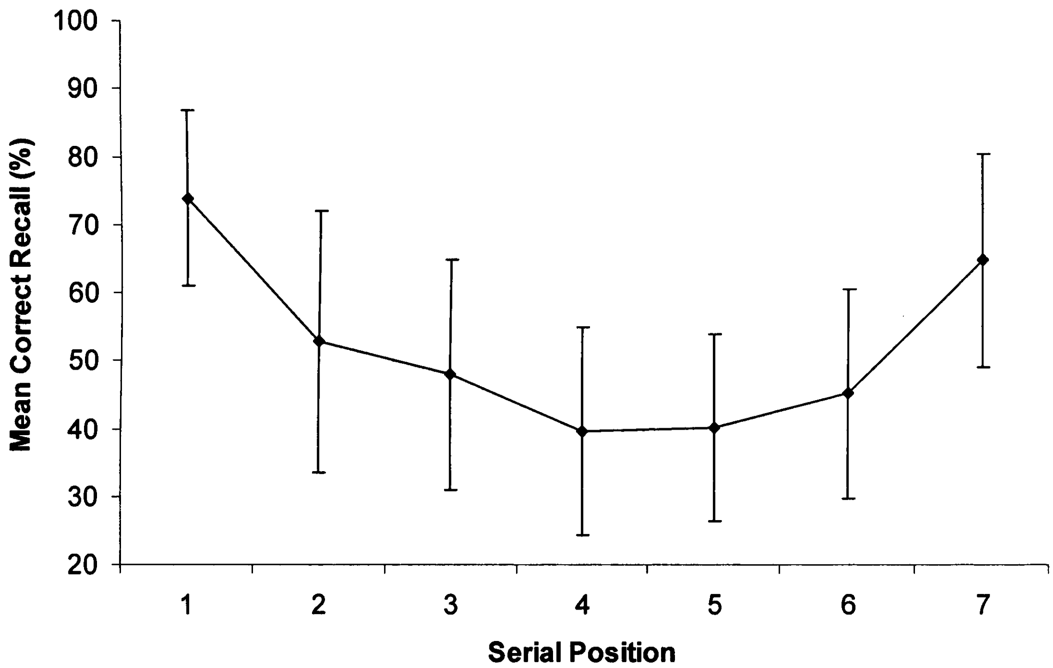


Figure 3.1: Mean percentage correct recall as a function of serial position. Error bars demonstrate the standard deviation.

Further analysis (Newman Keuls) revealed that recall accuracy for the first face in the sequence was significantly greater than that at all other serial positions. Recall accuracy for the terminal serial position was significantly greater than that at positions 2, 3, 4, 5 and 6. Recall accuracy for serial position 2 was significantly greater than that for both serial positions 4 and 5.

Trend Analysis

The enhanced recall accuracy for the first and terminal positions relative to the other positions is supported by a trend analysis. This revealed both a significant quadratic ($F(1,23)=67.94$, $MSe=10.01$) and linear component.

Response Distribution

As in Chapter 5 the distribution of erroneous responses was analysed and are demonstrated in Figure 3.2. A single-factor within-subjects ANOVA with 6 levels was computed on the displacement data and revealed a main effect of displacement distance, ($F(5,23)=37.55$, $MSe=0.30$. Further analysis (Newman Keuls) revealed that displacements of one serial position were significantly greater than displacements of 2, 3, 4, 5 or 6 positions. Furthermore, displacements of 2 serial positions were significantly more frequent than displacements of 3, 4, 5 or 6 positions. This trend was replicated for 3 item displacements, which were found to be significantly more frequent than displacements of 4, 5 and 6 position. This pattern of findings is consistent to that reported by both Smyth et al. (2005) and Smyth and Scholey (1996), in showing that erroneous responses are more frequently attributed to adjacent serial positions.

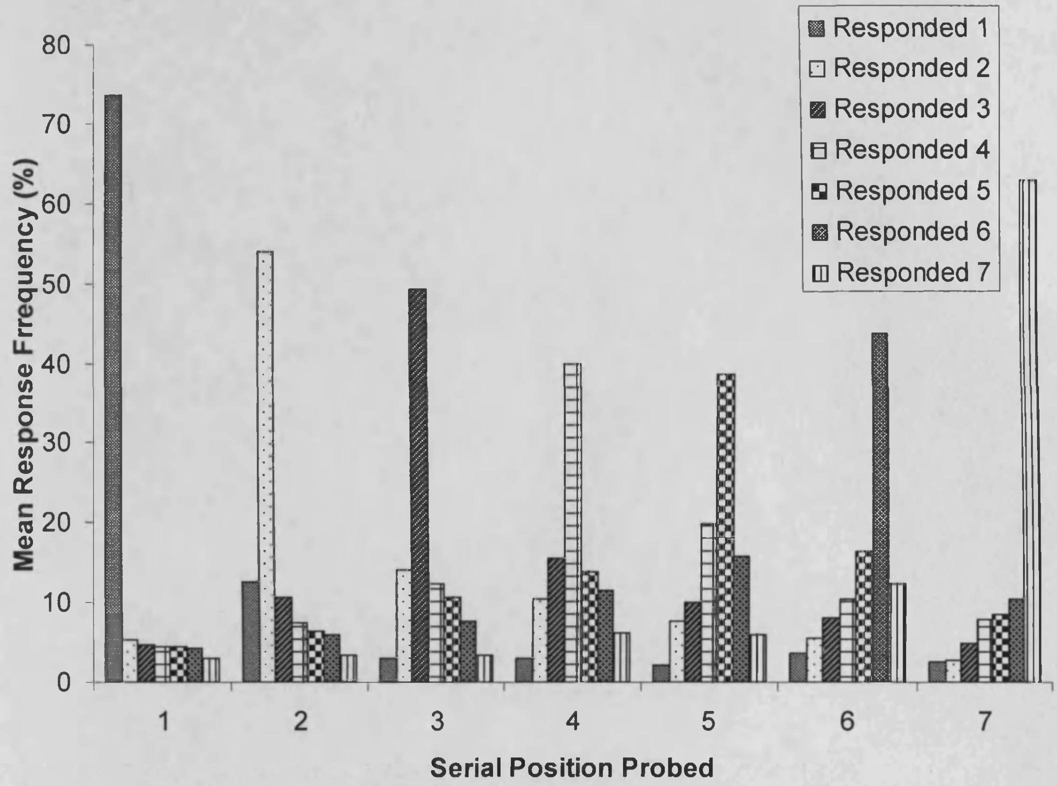


Figure 3.2: Mean percentage response frequency for each serial position (1-7) as a function of serial position.

The responses distribution analysis supports the premise that participants possess a vague representation with respect to the position of items within the sequence. If an item was associated with an absolute position within the sequence, it follows that erroneous responses should be equally distributed across the remaining positions. However, a steady decline in response frequency is found as temporal distance increases. This suggests that temporal memory of the item is stored relationally to a particular area of the sequence. This trend is consistent with the distribution demonstrated in Chapter 4 following single-probe serial recall.

Experiment 3.2

Consistent with previous research (e.g. Avons, 1998; Smyth et al, 2005; Ward et al, 2005), Experiment 3.1 replicated the bowed serial position function for reconstruction of serial order for unfamiliar-faces within a seven-item sequence. However, as previously described, this methodology cannot be applied to olfactory stimuli since simultaneous presentation at test is not possible. Reconstruction of serial order for odours must, therefore, be presented individually rather than simultaneously. In order to validate a comparison between olfactory stimuli and visual stimuli, it is first necessary to demonstrate that modified-reconstruction for faces produces a qualitatively equivalent function to that demonstrated for reconstruction of faces in Experiment 3.1. Therefore, in Experiment 3.2 participants received the same presentation phase as the first experiment and at test received each of the sequence faces again. However, at test, the faces were represented in sequence and the participant was required to state the position of each face within the previous sequence.

If forward modified-reconstruction for unfamiliar-faces produces a qualitatively equivalent function to that for serial order reconstruction (Experiment 3.1) one might predict a bowed function with both primacy and recency components.

Method

Participants. Twenty-four (2 male and 22 female: mean age 19 years and 11 months) Cardiff University volunteer Psychology undergraduates participated in exchange for course credit. None had participated in Experiments 3.1.

Materials. The stimuli were identical to those employed in Experiment 3.1.

Design. A 3x7 within-subjects factorial design was adopted. The first factor represents the testing procedure (forward versus backwards versus control) and the second factor represents the serial position (1-7). The testing procedure (forward, backward and control) was randomised throughout the 18 trials, and included the proviso that the same testing procedure was employed on no more than two successive trials. The experiment was divided into three six-trial blocks with each block containing two trials testing each testing procedure. The ordering of trials of presentation within each block was randomised by the Sup Lab program. Each face was employed twice in the experiment, with the second presentation of the face in a sequence containing a different set of faces.

Procedure. The procedure was a modified version of the serial order reconstruction paradigm reported by Avons (1998), Smyth et al. (2005), Ward et al. (2005) and Experiment 3.1. In these studies a sequence of visual stimuli was presented in the centre of a computer screen. Following the sequence, all items were re-presented simultaneously and the participant was required to reconstruct the original sequence by selecting each item in the order of original presentation. Once a choice had been made the item disappeared and the selection could not be altered.

The presentation phase was identical to that of Experiment 3.1. Following the presentation phase, a message appeared on the screen for 1000 ms informing the participant that the test phase was about to commence. Each face was then re-presented and the participant was required to write down the serial position of the test face in the previous sequence. The test face remained on the screen until the participant had recalled a position and pressed any key for the next test face. Participants were instructed not to change their responses and not to repeat the same serial position response within a trial. If uncertain, participants were instructed to guess. Once the seventh face had been responded to the screen displayed the message "press any key when ready to begin". The participant was told to rest for as long as necessary before commencement of the next trial.

In the forward testing procedure the first test probe was the face presented first in the previous sequence. The participant was required to respond "1", "2", "3", "4", "5", "6" or "7". This procedure was then repeated for the next test probe. This test item was the face presented second in the previous sequence. This pattern of testing continued until each face from the previous sequence had been tested in the order of original presentation. The backward testing procedure followed that described for the forward testing procedure, with the exception that the sequence of the test probe faces tracked backward through the sequence previously presented. Thus, the first probe face was the face presented last in the previous sequence. In the control testing procedure the faces were tested in a constant order that was neither forward nor backward. The third face from the previous sequence was tested initially, followed by the sixth, first, seventh, fourth, second and fifth.

Results and Discussion

Serial Position Analysis

Figure 3.3 shows the mean percentage correct recall for each serial position in forward, backward and control testing procedures. This demonstrates enhanced accuracy for the first and terminal items in the sequence irrespective of testing procedure. A 2-factor (3x7) within-subjects ANOVA was computed, where the first factor represents testing procedure (forward, backward or control) and the second factor representing serial position (1-7). A significant main effect of testing procedure was reported, $F(2,46)=57.10$, $MSe=1.66$; forward mean correct recall=73.71%, backward mean correct recall=64.38%, control mean correct recall=48.91%. Additionally a main effect of serial position was also found, $F(6,138)=30.12$, $MSe=1.23$. Both main effects were modified by a significant interaction between testing procedure and serial position, $F(12,276)=3.32$, $MSe=0.91$.

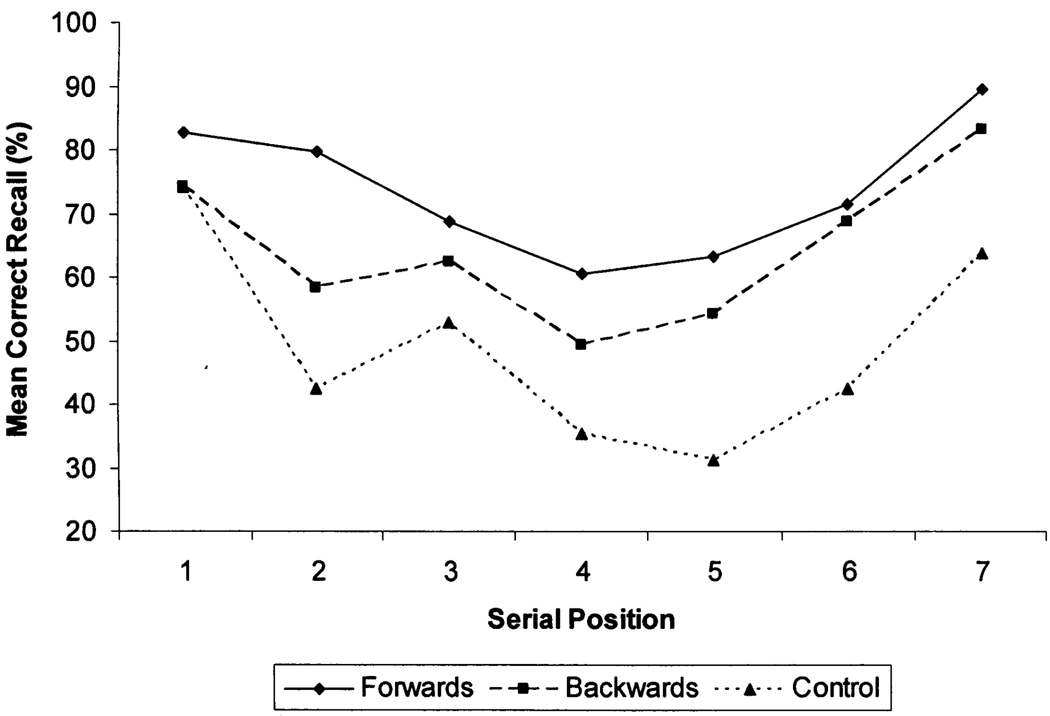


Figure 3.3: Mean percentage correct recall following the forward, backward and control testing procedures as a function of serial position.[7]

[7] In order not to overly complicate the figures, error bars have been omitted for all modified-reconstruction experiments. Standard deviations can be found in Appendix 5.

Further analysis (Newman Keuls) revealed that overall performance was significantly better following the forward testing procedure than that of either the backward or control testing procedures. Serial position recall accuracy was also found to be significantly higher following the backward testing procedure compared to that of the control testing procedure. Following the forward testing procedure, recall accuracy for position 7 was significantly greater than that for positions 3, 4, 5 and 6. Recall at serial position 1 was significantly greater than that at serial positions 3, 4 and 5. Recall at serial position 2 was significantly greater than that at serial positions 4 and 5. Following the backward testing procedure recall at serial position 7 was significantly greater than that at serial positions 2, 3, 4, 5 and 6. Recall at serial position 1 was significantly greater than that for positions 2, 4 and 5. And recall at serial position 6 was significantly greater than that at serial positions 4 and 5. Finally, following the control testing procedure recall of both positions 1 and 7 are significantly greater than that at serial positions 2, 3, 4, 5 and 6. Recall at serial position 3 was significantly greater than that at serial positions 4 and 5.

The serial position analysis provides evidence that both primacy and recency are present for the forward, backward and control testing procedure. Following the control testing procedure, a recall advantage was observed for serial position 3 indicating that the first item tested exhibits a recall advantage.

Trend Analysis

Trend analysis was performed on the three testing procedures. The forward testing procedure revealed a significant quadratic component, $F(1,23)=34.24$, $MSe=1.75$, and a non-significant linear trend, $F<1$. The backward testing procedure revealed both a significant quadratic, $F(1,23)=34.10$, $MSe=1.75$, $p<.05$, and linear component. The control testing procedure also revealed both a significant quadratic, $F(1,23)=41.49$, $MSe=2.19$, $p<.05$ and linear component. The significant quadratic components are consistent with the superior recall reported for the first and terminal items in the serial position analysis.

Response Distribution

As in Experiment 3.1, the response distributions for each serial position were examined.

The Forward Testing Procedure: Response distributions following the forward testing procedure are depicted in Figure 3.4. A single-factor ANOVA with 6 levels was computed on the displacement scores and revealed a main effect of displacement distance, $F(5,23)=28.21$, $MSe=0.03$. Further analysis (Newman Keuls) revealed that displacements of one serial position were significantly more frequent than that for displacements of 2, 3, 4, 5 and 6 positions. Additionally, displacements of two serial positions were significantly more frequent than that for 4, 5 or 6 positions. The findings demonstrate similar displacement trends to those reported in Experiment 3.1.

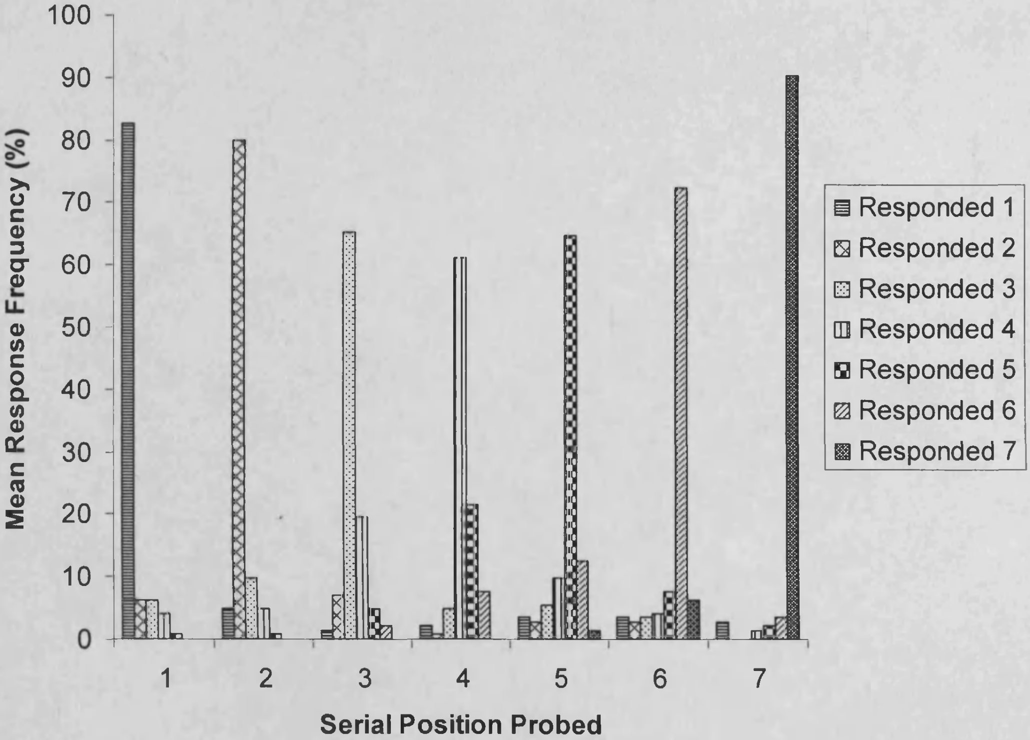


Figure 3.4: Response distribution at serial positions 1-7 following the forward testing procedure and as a function of serial position.

The Backward Testing Procedure: Response distributions following the backward testing procedure are depicted in Figure 3.5 A single-factor ANOVA with 6 levels was computed on displacement scores and revealed a main effect of displacement distance, $F(5,23)=11.36$, $MSe=0.07$. Further analysis (Newman Keuls) revealed that displacements of one serial position were significantly more frequent than that of displacements of 2, 3, 4, 5 and 6 positions.

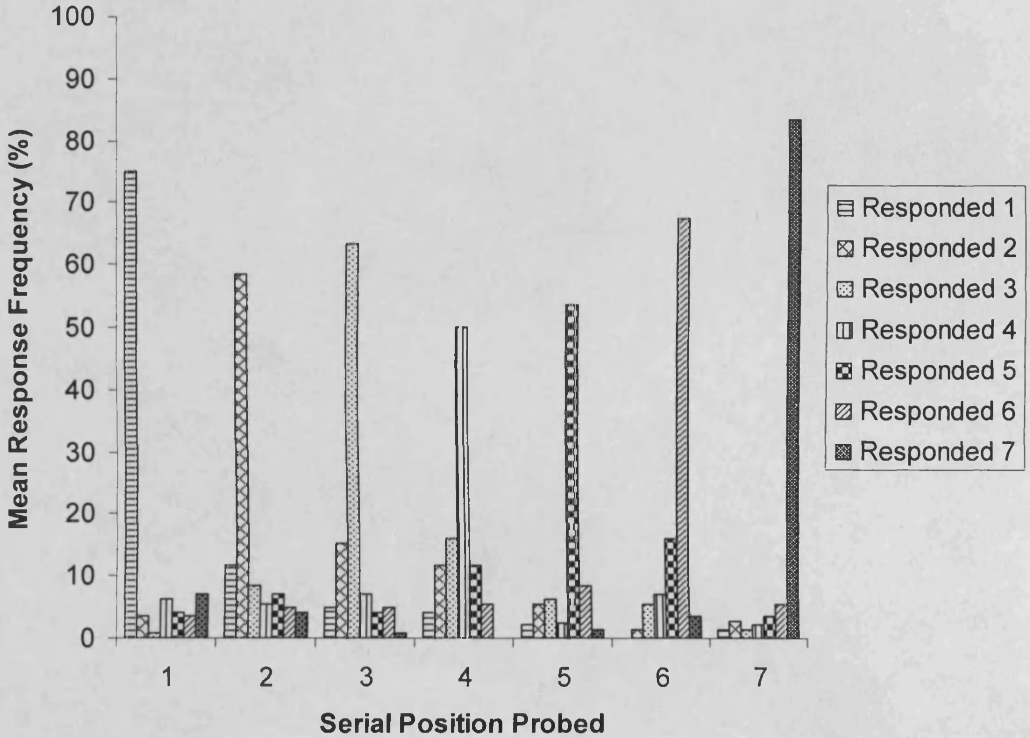


Figure 3.5: Response distribution at serial positions 1-7 following the backward testing procedure and as a function of serial position.

The Control Testing Procedure: Response distributions following the control testing procedure are depicted in Figure 3.6. A single-factor ANOVA with 6 levels was computed on displacement scores and revealed a main effect of displacement distance, $F(5,23)=48.50$, $MSe=0.05$. Further analysis (Newman Keuls) revealed that displacements of one serial position were significantly more frequent than that of 2, 3, 4, 5 or 6 position displacements. Displacements of two positions were significantly more frequent than that of 3, 4, 5 or 6 position displacements. Furthermore, both 3- and 4- item displacements were significantly more frequent than that of 6-item transpositions.

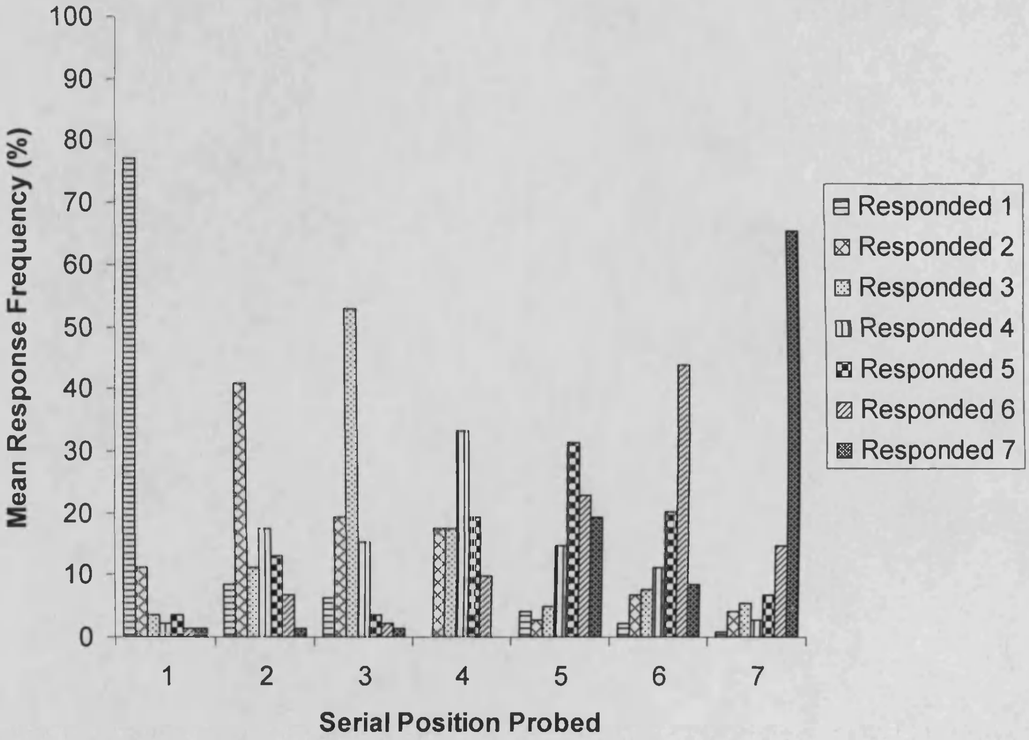


Figure 3.6: Response distribution at serial positions 1-7 following the control testing procedure and as a function of serial position.

Learning of Testing Order

Since the forward, backward and control testing procedures were repeated throughout the experiment, it is possible that participants learned the order of the testing procedures. Learning over the course of the experiment should be reflected by improved performance. This possibility was examined via a paired *t*-test comparing performance for the first half of the experiment (mean accuracy = 62.17%) with performance for the second half (mean accuracy = 64.02%) and revealed a non-significant difference, $t<1$. This suggests that, despite repeated presentation of the testing procedures, participants were not learning the order of these procedures.

Analysis of Control Testing Procedure[8]

The forward, backward and control testing procedures produce bowed serial position functions. The results for the control testing procedure demonstrate that the presence of primacy and recency is not dependent upon those terminal items in the sequence being tested first and last respectively. An interesting observation with respect to the control testing procedure concerns the heightened recall levels for serial position 3. This third item benefit is observed following neither the forward or backward testing procedure. This observation indicates that the advantage is a product of testing procedure. This is important because the control testing procedure order was the same for each control trial.

The third item benefit is demonstrated following the third item being always tested first for the control testing procedure trials. One possible explanation of this benefit is that participants learned the order of test and, therefore, learned that in a proportion of the trials the third item was probed first at test. This possibility was examined in a pilot study (see Appendix 3, Experiment 1) in which participants performed modified-reconstruction of faces following forward, control and randomised testing procedures (demonstrated in Figure 3.7a-c). In the randomised condition, participants were tested in a different order on each randomised trial, wherein each serial position in the sequence was probed an equal number of times across the positions at recall. Despite this manipulation, when performance was plotted based upon the order in which items were represented at test (rather than serial position per se) a benefit was still observed for the first item. This trend, therefore, indicates that the benefit observed for serial position 3 following the control testing procedure is not an artefact of participants learning the order of test, but rather, reflects an inherent advantage for the item tested first.

[8] Following the analysis of the control testing procedure in Experiment 3.2, analysis of control trials are omitted in future modified-reconstruction experiments. The procedure is intended merely to prevent participants from learning the order at test. The forward and, to a lesser extent, the backward trials are of theoretical importance. For more detail see Statistical Methodology (Chapter 2).

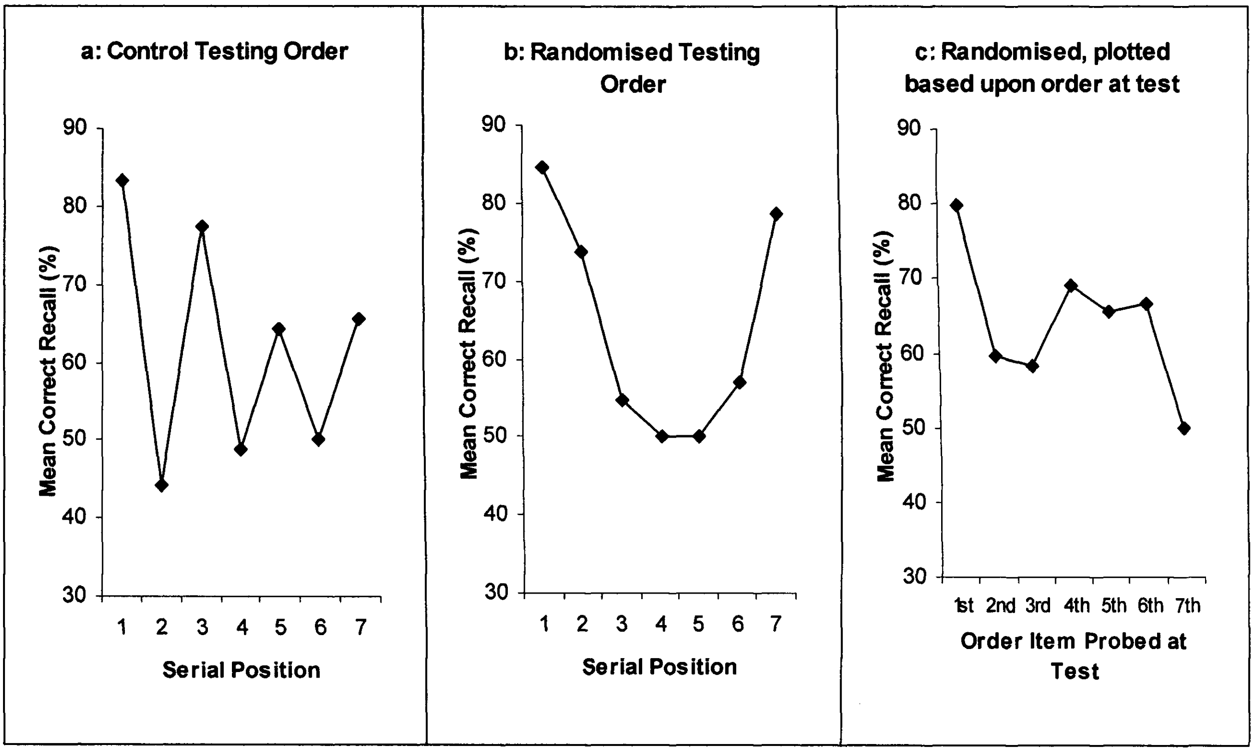


Figure 3.7(a-c): Mean percentage correct recall following the control testing procedure (a) and the randomised testing procedure (b) as a function of serial position. Mean correct serial position recall is additionally shown for the randomised testing procedure wherein accuracy is re-plotted as a function of order that items were probed at test (c.).

The origins of the benefit for the first-tested item are beyond the scope of the present pilot experiment. However, interference from subsequent test items appears a plausible explanation. For instance, Lewandowsky et al. (2006) demonstrated that output interference in serial recall qualitatively influenced the serial position function. The finding suggests that (1) the presence of primacy is facilitated by the first item in the sequence being tested earliest; however, (2) primacy is not solely dependent upon the benefit of initial testing as primacy still develops when not probed initially (Figure 3.7a and b). Furthermore, these data imply some degree of mechanistic dissociation between the origins of the primacy and recency components. Following forward testing, the primacy is facilitated by the benefits associated with being tested first, whereas recency develops in the absence of similar benefit for the last tested item.

Alternatively, the first-item benefit might be explained via methodological constraints of the modified-reconstruction task. In this task, accurate recall at serial positions following the first-tested item is reliant upon previous accuracy. For example, if position 3 is erroneously assigned to a test item before the probe for position 3 is presented, the participant cannot thereafter accurately respond to that item when subsequently tested. This is because the position 3 response has already been employed. The advantage for the first-tested item may, therefore, be due to recall for that item being a pure measure of recall uncontaminated by previous performance. That is, accurate recall of the first-tested item is not reliant upon any previous correct responses.

However, it should be noted that in the small-scale study described earlier (see Appendix 3, Experiment 1), primacy was apparent following the randomised testing procedure. In that pilot study, positions 1-7 were tested first on an equal number of times. The primacy component following forward modified-reconstruction for faces cannot, therefore, be uniquely explained in terms of this methodological advantage.

Importantly, this methodological restriction of performance for items tested after the first test item is not confined to the modified-reconstruction paradigm but illustrates another similarity with the serial order reconstruction task. In the serial order reconstruction task, once a participant has assigned an item to a serial position neither that item nor that serial position can be reused within the trial. During recall therefore, early errors in the reconstruction process predict later errors. That is, if a participant erroneously recalls one item as the first serial position in the sequence, it translates that the participant will also be incorrect when the actual position for that item is tested, as that item has already been employed. Similar constraints between the serial order reconstruction and forward modified-reconstruction tasks provide further validity for cross-paradigm comparisons.

Comparison of Modified-Reconstruction and Serial Order Reconstruction

The forward testing procedure is the closest replication of the serial order reconstruction task, as both tasks require items to be recalled in the same order. The forward testing procedure from the modified-reconstruction paradigm (Experiment 3.2) was, therefore, compared to the serial order reconstruction task (Experiment 3.1).

Mean percentage recall correct and mean correct Z-score recall for the two tasks is demonstrated in Figures 3.8a and 3.8b, respectively. Standardised recall scores were compared in a 2-factor (2x7) mixed-design ANOVA where the between-subjects factor represents task (forward modified-reconstruction and serial order reconstruction) and the within-subjects factor represents serial position. The main effect of test type was non-significant, $F<1$. The main effect of serial position was significant, $F(6,46)=39.37$, $MSe=2.56$, together with a significant interaction, $F(6,276)=3.03$, $MSe=0.40$, between these factors.

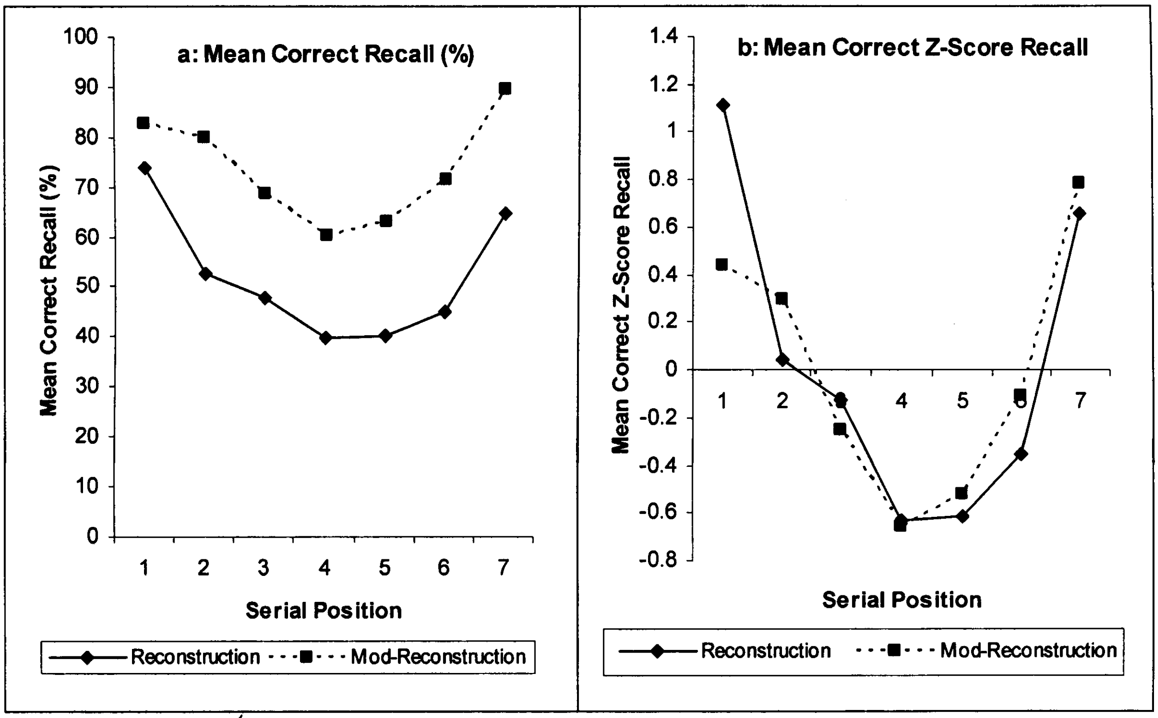


Figure 3.8(a-b): Mean percentage correct recall (a) and mean correct Z-score recall s (b) following the modified-reconstruction and serial order reconstruction paradigms as a function of serial position.

Figure 3.8b suggests that the significant interaction between serial position and testing procedure is underpinned by enhanced primacy in the reconstruction paradigm relative to that of the modified-reconstruction task. However, this hypothesis is not supported by further analysis (Newman Keuls), which failed to reveal any significant differences across the two testing paradigms at each of the seven serial positions. Figure 3.8b does, however, demonstrate that the two functions map very closely.

Experiment 3.3

The serial position functions for the modified-reconstruction paradigm and the serial order reconstruction task have been shown to produce qualitatively similar functions. Primacy is enhanced following the serial order reconstruction paradigm but the remaining six serial positions closely match. Furthermore, additional consistencies are found across paradigms for the error distributions: both showing that erroneous responses are most frequently allocated to adjacent serial positions.

In Experiment 3.3, the modified-reconstruction task was applied to odours. Sequence length was reduced to five odours following a pilot study (n=24, see Appendix 3, Experiment 2) in which modified-reconstruction of 6-odour sequences produced low overall performance levels (correct mean = 35.17%) relative to that of unfamiliar-faces in Experiment 3.2 (mean correct recall = 62.33%).

If forward modified-reconstruction of odours produces a qualitatively equivalent function to that for unfamiliar-faces (Experiment 3.2) one might predict a bowed serial position function demonstrating both primacy and recency.

Method.

Participants. Twenty-four (3 male and 21 female: mean age 20 years and 6 months, 22 non smokers) Cardiff University volunteer Psychology undergraduates participated in exchange for course credit. None had participated in Experiments 3.1 and 3.2. Participants suffering from a cold or blocked nose were excluded.

Materials. 75 odours were selected at random from the 120 employed odours described in Experiment 1.1.

Design. A 3x5 within-subjects factorial design was adopted in which a series of single serial position recall probes followed presentation of the sequence (modified-reconstruction paradigm). The first factor represents the testing procedure (forward versus backwards versus control) and the second factor represents serial position (1-5). The testing procedure (forward, backward and control) was randomised throughout the 18 trials and included the proviso that the same testing procedure was employed on no more than two successive trials. The experiment was divided into six three-trial blocks, wherein each block contained a trial testing each testing procedure (forward, backward and control). The order in which blocks were presented was randomised across participants. Each trial contained a different set of odours chosen at random and each odour was presented on one occasion only.

Procedure. The odour presentation procedure followed closely that reported by both Reed (2000), Miles and Hodder (2005) and Experiments 1.1a-b. The testing procedure was similar to that described in Experiment 3.2. Participants were tested individually in a well-ventilated, soundproofed laboratory and sat facing the experimenter with a fan blowing across their face. In order to minimise visual cues, the participant was instructed to fixate on a red spot located on the table 30cm in front of them throughout the trials. For each trial the participant was presented with a sequence of 5-odours. Each odour was presented over a wooden screen located 40cm in front of the participant and held under the nose of the participant for a period of 3000 ms. The participant was instructed to inhale deeply through both nostrils for the duration of each odour presentation. The odour was then replaced behind the screen during which time the participant exhaled. There was an ISI of approximately 2000 ms after which the next odour was presented. This procedure continued to the presentation of the fifth odour

A retention interval of approximately 3000 ms followed presentation of the fifth odour during which the participant was informed that the test phase was commencing. As described in Experiment 3.2 each of the sequence items were represented at test in a forward, backward or control testing procedure (in the control testing procedure the fourth odour was tested initially, followed by the fifth, first, third and finally the second item). Each odour was represented for 3000 ms followed by a 2000 ms ISI. Identical to Experiment 3.2, once each test odour had been presented, the participant was instructed to write down the position in the sequence in which the odour had appeared.

Results and Discussion

Serial Position Analysis

Figure 3.9 shows the mean percentage correct recall at each serial position in the forward and backward testing procedures. A 2-factor (2x5) within-subjects ANOVA was computed where the first factor represents the testing procedure (forward versus backwards) and the second factor represents serial position (1-5). A null effect of testing procedure was found, F=1.53 (forward mean correct recall=43.00%; backward mean correct recall=37.50%) and a significant main effect of serial position, $F(4,92) = 5.04$, $MSe = 0.85$. The interaction was non-significant, $F<1$.

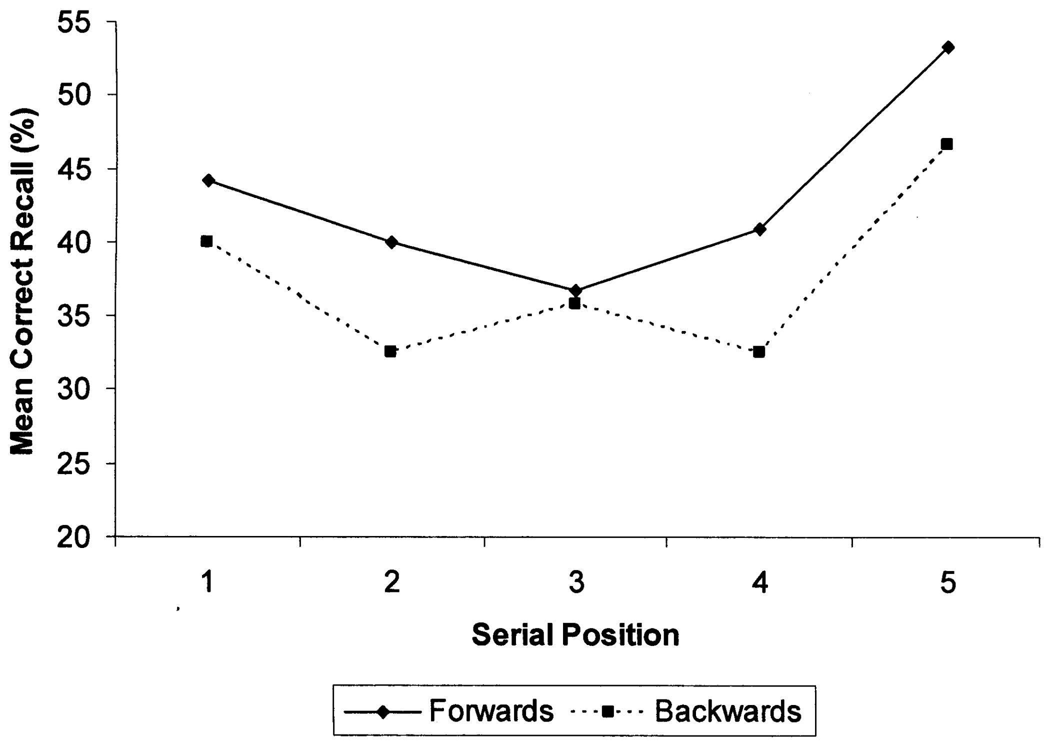


Figure 3.9: Mean percentage correct recall following the forward and backward testing procedure and as a function of serial position.

Further analysis (Newman Keuls) of the main effect at serial position revealed that recall at serial position 5 was significantly greater than that at serial positions 1-4.

Trend Analysis

Trend analyses were conducted on the forward and backward testing procedures. For the forward testing procedure a significant quadratic component, $F(1,23)=6.99$, $MSe=1.02$, and a non-significant linear component, $F=1.35$, were found. For the backward testing procedure both significant quadratic component, $F(1,23)=6.50$, $MSe=0.89$ and non-significant linear component, $F=1.10$, were found.

The serial position and trend analysis indicate that there is some curvature within the forward testing procedure function. This is demonstrated by the significant quadratic component. However, further analysis of the main effect of serial position (Newman Keuls) revealed that the curvature is more pronounced at the recency component as recall at serial position 5 is significantly greater than that at serial positions 1-4.

Distribution of Responses

As in Experiments 3.1 and 3.2, the response distribution of each serial position was examined.

The Forward Testing Procedure: Response distributions following the forward testing procedure are depicted in Figure 3.10. A single-factor ANOVA with 4 levels was computed on the displacement scores and revealed a main effect of displacement distance, ($F(3,23)=5.95$, $MSe=0.23$). Further analysis (Newman Keuls) revealed that adjacent displacements were significantly more frequent than that of displacements of 2, 3 or 4 positions.

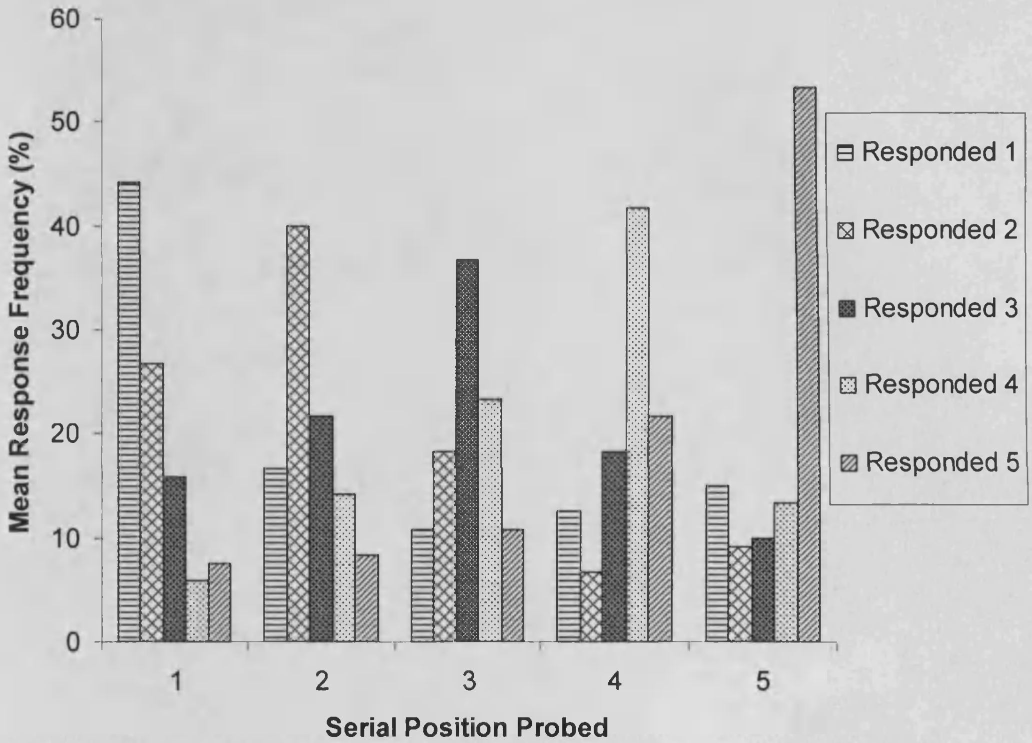


Figure 3.10: Mean percentage response frequency for each serial position following the forward testing procedure as a function of serial position.

Both the backward and control testing procedures produced similar distributions of erroneous responses, i.e. incorrect responses were more frequently allocated to adjacent serial positions. Response distributions for the backward testing procedure can be found in Appendix 4.

Learning of Testing and Olfactory Fatigue Analysis

As in Experiment 3.2 (modified-reconstruction of unfamiliar-faces) the possibility that participants were learning the order of test presentation was examined. Recall for the first 20% of the experiment (trials 1-3; mean correct recall = 40.28%) and the final 20% of the experiment (trials 13-15; mean correct recall = 34.44%) was compared and found to be non-significant, $t = 1.40$. The first and last 20% were analysed to include an equal number of trials from each testing procedure (forwards, backwards and control). If participants were learning the order of test one might predict higher recall accuracy for the latter trials. This was not found.

Additionally, this analysis permits the possibility of olfactory fatigue to be assessed. If the olfactory system became fatigued due to multiple odour presentations one might predict reduced recall accuracy for the latter trials. This was not found and replicates the absence of olfactory fatigue found in Experiments 1.1 and 2.1 (2AFC recognition and single-probe serial position recall, respectively). The finding further supports the claim that participants are able to receive a large number of trials (in Experiment 3.3, 18 trials; 180 odour presentations) without a sensory fatigue-induced performance decrement. Such a finding further substantiates the inability of Miles and Hodder (2005) to replicate the olfactory fatigue reported by Reed (2000). Moreover, the finding further generalises the absence of olfactory fatigue to the modified-reconstruction paradigm.

Comparison across Experiment 3.1, 3.2 and 3.3: Visual and Olfactory Stimuli

A comparison across the Experiments 3.1 (serial order reconstruction of unfamiliar-faces), 3.2 (forward modified-reconstruction of unfamiliar-faces) and 3.3 (forward modified-reconstruction of odours) was performed. Forward modified-reconstruction is the closest replication of the serial order reconstruction task and was, therefore, employed in the comparison. In order to compare the modified-reconstruction for odours to the serial order reconstruction and modified-reconstruction for unfamiliar-faces, two serial positions must be collapsed, since the odour experiment employs 5-odour sequences and the unfamiliar-face studies employs 7-face sequences. In the unfamiliar-face studies, serial positions 2 and 3 were collapsed as were positions 5 and 6. Figure 3.11(a) demonstrates mean percentage correct recall for the collapsed data across experiments.

Recall levels differed for the three experiments (serial order reconstruction of unfamiliar-faces = 52.02%; forward modified-reconstruction of unfamiliar-faces = 73.71%; forward modified-reconstruction of odours = 43%) and were consequently standardised to assess the qualitative function differences. Standardised *Z*-scores for the three experiments are demonstrated in Figure 3.11(b). A 2-factor (3x5) mixed ANOVA was conducted on the standardised data where the between-subjects factor represents experiment (serial order reconstruction of unfamiliar-faces, forward modified-reconstruction of unfamiliar-faces and forward modified-reconstruction of odours) and the within-subjects factor represents serial position (1-5). A null effect of task was found, $F<1$, and main effect of serial position, $F(4,276)=38.61$, $MSe=0.47$. Crucially, a significant interaction between serial position and task was found, $F(8,276)=5.49$, $MSe=0.47$, indicating that qualitatively different functions were produced. However, these qualitative differences did not prove robust since further analysis of the interaction (Newman Keuls) revealed no recall differences between experiments at each serial position.

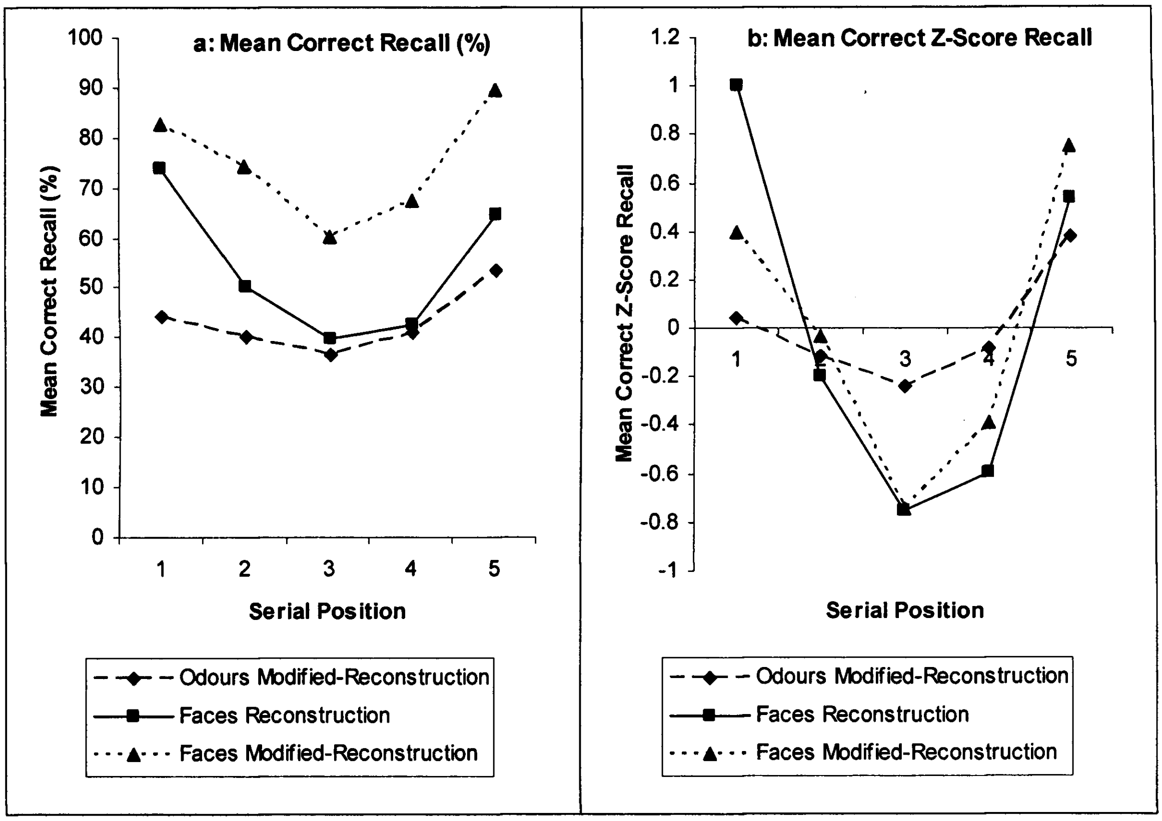


Figure 3.11(a-b): Mean percentage correct recall (Figure 3.11a) and mean correct *Z*-score recall (Figure 3.11b) following reconstruction for faces and forward modified-reconstruction for odours and faces and as a function of serial position. For the face stimuli positions 2 and 3 plus positions 5 and 6 have been collapsed to produce a 5-item function.

Primacy and Recency Analysis

A further analysis of primacy and recency was conducted upon the serial position function for the standardised data following the collapsed serial order reconstruction of unfamiliar-faces data, the collapsed forward modified-reconstruction of unfamiliar-faces data and the forward modified-reconstruction of odours data. This analysis is described in the Statistical Methodology section (Chapter 2)

Serial order reconstruction of unfamiliar-faces: Mean standardised correct *Z*-score recall at serial position 1 (mean correct recall=1.00) was significantly greater than the mean standardised correct *Z*-score recall at serial positions 2-4 (mean correct recall=-0.51), $t(23)=10.01, p<.05$. Mean standardised correct *Z*-score recall at serial position 5 (mean correct recall=0.54) was significantly greater than the mean standardised correct *Z*-score recall at serial positions 2-4, $t(23)=6.16, p<.05$.

Forward modified-reconstruction of unfamiliar-faces: Mean standardised correct *Z*-score recall at serial position 1 (mean correct recall=0.40) was significantly greater than the mean standardised correct *Z*-score recall at serial positions 2-4 (mean correct recall=-0.38), $t(23)=3.34, p<.05$. Mean standardised correct *Z*-score recall at serial position 5 (mean correct recall=0.75) was significantly greater than the mean standardised correct *Z*-score recall at serial positions 2-4, $t(23)=7.91, p<.05$.

Forward modified-reconstruction of odours: A non-significant difference was found between mean standardised correct *Z*-score recall at serial position 1 (mean correct recall=0.04) was and the mean standardised correct *Z*-score recall at serial positions 2-4 (mean correct recall=-0.14), $t<1$. Mean standardised correct *Z*-score recall at serial position 5 (mean correct recall=0.38) was significantly greater than the mean standardised correct *Z*-score recall at serial positions 2-4, $t(23)=3.07$, p<.05.

The primacy and recency analyses demonstrate qualitatively different serial position functions. Forward modified-reconstruction for odours produced recency and an absence of primacy, whereas both unfamiliar-face tasks demonstrated both primacy and recency. These trends indicate evidence of modularity for reconstruction of serial order, such that different stimuli produce qualitatively diverse functions despite task equivalence. The finding contradicts the proposed serial position task dependency (e.g. Ward et al., 2005), which suggests that the type of task qualitatively determines the function irrespective of the type of stimuli employed.

However, there is an alternative explanation for the observed cross-modal disparity. Since overall performance levels were far higher for face stimuli it is possible that the absence of statistically significant primacy reported for olfactory stimuli was an artefact of low performance levels. Overall performance for forward modified-reconstruction of a 5-odour sequence was 38.16%, possibly precluding the development of primacy and recency. If recall performance levels at some positions within the sequence are at a level predicted by chance, curvature of the function will be less pronounced. In such an instance, increased overall performance may promote the development of observable primacy. The possibility was examined in a pilot study (see Appendix 3, Experiment 3), in which the methodology described for Experiment 3.3 was replicated. Sequences of 4 odours were employed and revealed equivalent trends to those observed for the 5-odour sequence, despite overall performance levels rising to 45.89%. More importantly, for the forward testing procedure, recall levels increased from 44.17% in Experiment 3.3 to 50%. The primacy and recency analysis of this pilot study revealed a non-significant difference between recall at serial position 1 (mean recall = 50%) and recall of the mean of serial positions 2 and 3 (mean recall = 47.57%), $t<1$. Recall at serial position 4 (mean recall = 61.81%) was significantly greater than the mean of serial positions 2 and 3, $t(23)=4.04$, $p<.05$. On the basis of these findings it is unlikely that the absence of primacy in Experiment 3.3 was an artefact of low overall recall levels obscuring the first item recall benefit.

As previously described the modified-reconstruction paradigm differs functionally from the serial order reconstruction paradigm. A substantive difference during positional recall concerns the comparison between positional information for other sequence items. In the serial order reconstruction task the participant is re-exposed to the sequence items simultaneously at test and is, therefore, able to make cross-item comparisons between positional information of all sequence items prior to recall. However, in the modified-reconstruction task, these items are presented individually/sequentially at recall, therefore, negating any comparison with other sequence items. It is possible that the observed absence of primacy for modified-reconstruction of odours is an artefact of the inability to compare sequence items during the recall stage. Furthermore, following longer exposure times for odours it is possible that olfactory traces experienced increased decay in the interval between presentation and test.

This possibility was investigated in a pilot study (n=24; see Appendix 3, Experiment 4) in which participants were given the sequence items en masse at test and permitted to smell each odour from the sequence as many times as they felt was necessary prior to giving a position response.[9] There are three important caveats to the methodology of this pilot study. First, although participants were able to compare sequence items at test this cannot be performed simultaneously as each item must be perceived individually. In the serial order reconstruction task, participants can simultaneously view the sequence items and compare the items. Second, when participants are presented with the sequence items at test, there is no control over which odour the participant is re-exposed to first. Intuitively, the order in which the participant inhales the odours at test might have an influence on memory for the position of that item (i.e. if the terminal sequence item is smelt first at test one would predict a greater likelihood of correct positional recall due to an absence of intervening/interfering items). Third, large individual differences may exist between participants regarding the duration of time employed during odour re-exposure at test and the time for which each odour is smelt at test prior to a decision. These variables could impact the level of interference, temporal distinctiveness and strength of memorial traces, all potentially influencing performance patterns.

Notwithstanding these methodological reservations, a qualitatively equivalent function was found to that reported following forward modified-reconstruction of odours (Experiment 3.3). A non-significant difference was found between recall at serial position 1 (mean correct recall = 55%) and recall of the mean of serial positions 2-3 (mean correct recall = 50.63%), t=1.50. In contrast, recall of serial position 4 (mean recall correct =62.08%) was significantly greater than that of the mean of serial positions 2-3, $t(23)=3.56$ $p<.05$. The finding suggests that the absence of primacy for forward modified-reconstruction of odours was not due to an inability to compare

[9] This methodology was recommended by an anonymous reviewer.

items at test. This finding also indicates that recency is robust across a range of task demands (i.e. receiving items en masse or sequentially at test and sequence length).

Intervening Items Analysis

In Chapters 3 and 4 (2AFC recognition and single-probe serial position recall, respectively), the extent to which the number of items intervening between presentation and test correlated with recognition/recall accuracy was assessed. Number of items intervening between presentation and test was found to be a poor predictor of single-probe serial recall. In the modified-reconstruction paradigm all sequence items are re-presented at test. This increases both the temporal interval between presentation and test and the potential cumulative interference. One might predict, therefore, that the number of items intervening between presentation and test impacts recall accuracy.

Item recall scores were collapsed across testing procedures for Experiments 3.2 (modified-reconstruction of unfamiliar-faces) and 3.3 (modified-reconstruction of odours). It was proposed that as number of items intervening between presentation and test increases, then performance should decrease (either via temporal interval-induced trace decay or interference from other items), i.e. a significant negative correlation is predicted. Following serial order reconstruction of unfamiliar faces a non-significant positive correlation was observed (R=0.3; p=.51). Observation of the scatterplot (see Figure 3.12a) shows that the failure to demonstrate a negative correlation was not an artefact of strong primacy, as recall generally improves following an increase in the number of items intervening between presentation and test. Following the modified-reconstruction task employing unfamiliar-faces (see Figure 3.12b), a non-significant weak positive correlation was observed (R=0.05; p=.83). Olfactory modified-reconstruction was more consistent with the hypothesis (see Figure 3.12c), demonstrating a non-significant negative correlation (R=-0.42; p=.12). However, the findings indicate that serial order reconstruction/modified-reconstruction performance is not determined by the number of items intervening between presentation and test.

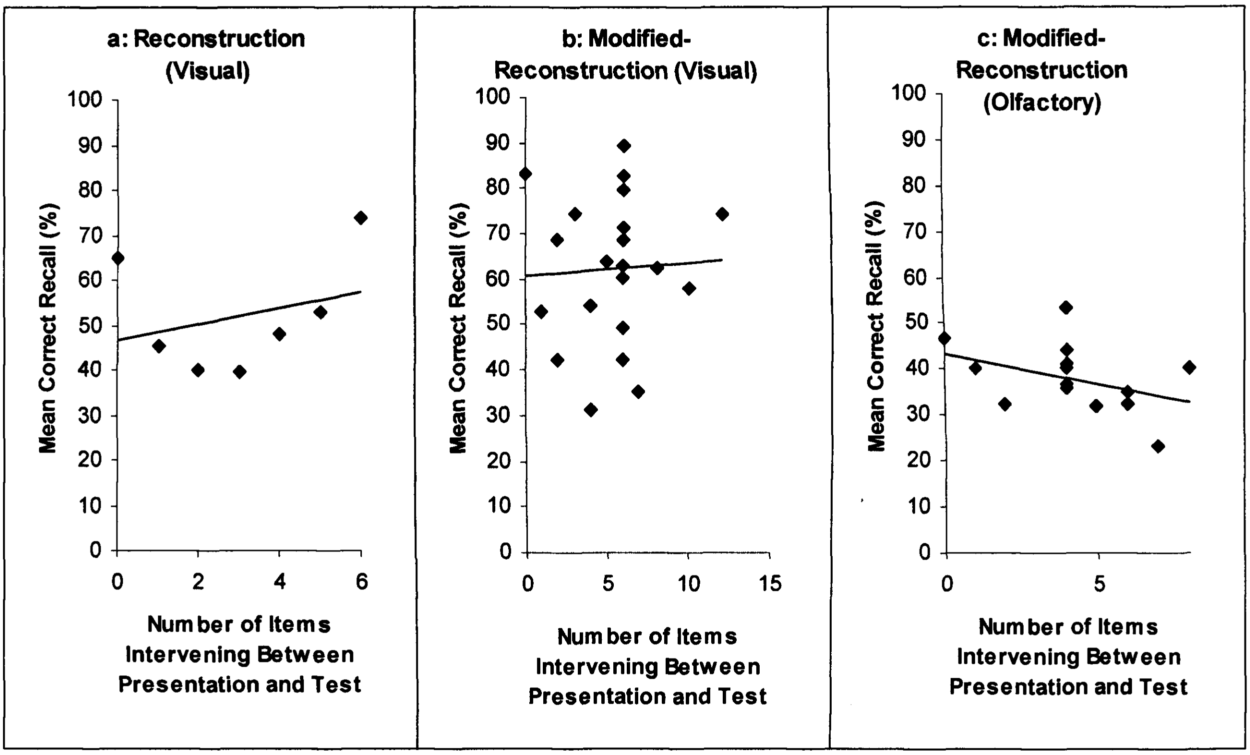


Figure 3.12(a-c): Mean percentage correct recall following serial order reconstruction of unfamiliar-faces (a: Experiment 3.1), modified-reconstruction of unfamiliar-faces (b: Experiment 3.2) and modified-reconstruction of odours (c: Experiment 3.3) and as a function of the number of items intervening between presentation and test. The trend line indicates the line of best fit.

Experiment 3.4

Forward modified-reconstruction of odours demonstrated a qualitatively different serial position curve compared to that for the visual domain. However, there is a caveat to the interpretation that odours and unfamiliar-faces produce qualitatively different serial position functions. The caveat is premised on the important methodological differences existing between the odour and face modified-reconstruction paradigms. In the unfamiliar-face experiment (Experiment 3.2) sequences of 7 unfamiliar-faces were employed, each presented for 750 ms with a 500 ms ISI. However, modified-reconstruction for odours (Experiment 3.3) employed sequences of 5-odours, each presented for 3000 ms with a 2000 ms ISI.

These methodological differences created disparities with respect to both absolute presentation times and, perhaps more importantly, the ratio between presentation times and ISIs. These presentation differences, as described previously, were adopted to limit ceiling effects for the face stimuli and prevent floor effects for the olfactory stimuli. However, these methodological differences might arguably account for the cross-modal differences observed. To directly assess that hypothesis, the following study compared modified-reconstruction performance for both odours and unfamiliar-faces employing identical sequence lengths, presentation times and ISIs. The experiment examined directly the possibility that the cross-modal differences might be explained uniquely in terms of methodological differences. If qualitatively different functions are produced for unfamiliar-faces and odours one might predict a significant interaction between stimuli (odours or unfamiliar-faces) and serial position.

Method.

Participants. Twenty-four (6 males, 18 females: mean age = 22 years 5 months, of which 22 were non-smokers) Cardiff University volunteer undergraduates from a variety of disciplines participated and each received a £6.00 honorarium upon completion of the study. None had participated in Experiments 3.1, 3.2 or 3.3.

Materials. The visual stimuli were as described for Experiment 3.1, and comprised 54 unfamiliar-faces employed for experimental trials and 6 employed for a practice trial. The olfactory stimuli were as described for Experiment 3.3, and comprised 54 odours employed for experimental trials and 6 for a practice trial.

Design. A 2x3x6 within-subjects factorial design was adopted in which a series of single serial-position recall probes followed presentation of the sequence (modified-reconstruction paradigm) for both visual and olfactory stimuli. The first factor refers to the modality of stimuli (visual versus olfactory). The second factor concerns the testing procedure (forward versus backwards versus control). The third factor refers to the serial position (1-6). Participants performed the task on consecutive days receiving either visual or olfactory stimuli. Modality of presentation was counterbalanced across days. The testing procedure (forward, backward and control) was randomised throughout the 18 trials on each day, and included the proviso that the same testing procedure was employed on no more than two successive trials. For both days the experiment was divided into three six-trial blocks, wherein each block contained two trials at each testing procedure. The ordering of trials within each block was randomised for both the faces and the odours. Each face and each odour was employed twice in the experiment.

Procedure. The procedure for visual and olfactory modified-reconstruction was as described for Experiment 3.2 and Experiment 3.3 respectively, with the exceptions that each sequence comprised 6-items and each item was presented for 1000 ms followed by a 1000 ms ISI. Due to an increase in sequence length the control testing procedure differed with respect to order, such that the fifth item from the previous sequence was tested initially, followed by the third, first, sixth, second and the fourth item probed last.

Results

Serial Position Analysis

Figure 3.13a shows the mean percentage correct recall at each serial position for the forward and backward testing procedures for the olfactory stimuli. Figure 3.13b shows the mean percentage correct recall at each serial position for the forward and backward testing procedure for the visual stimuli.

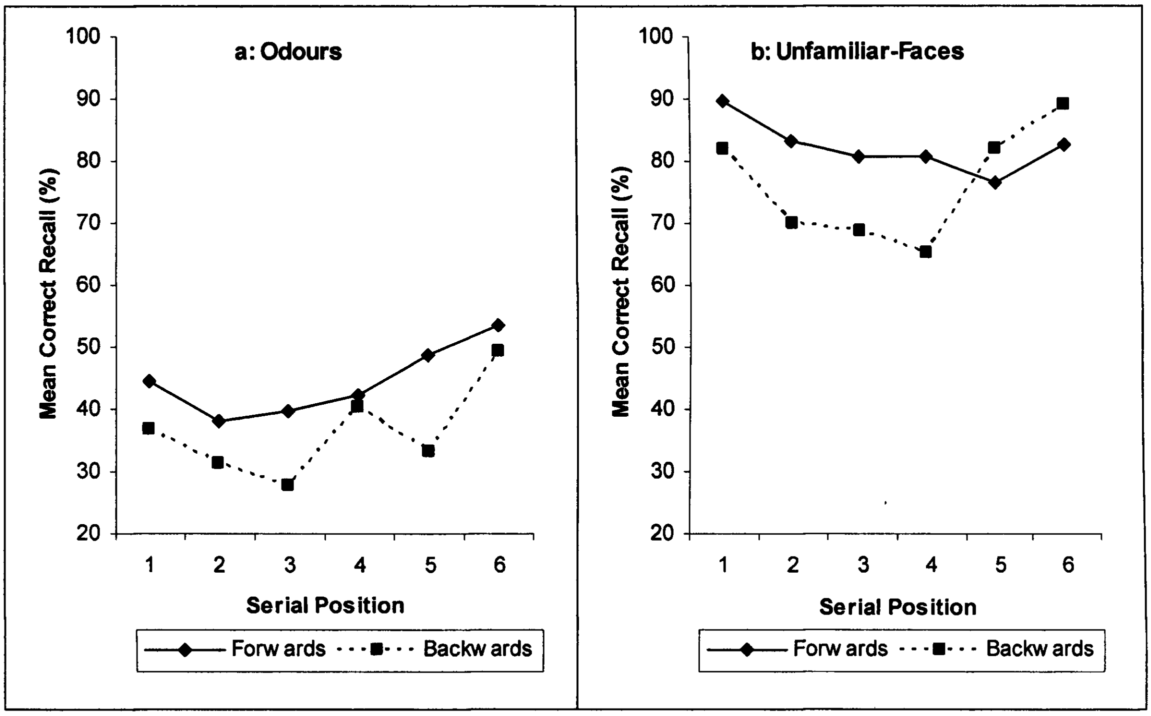


Figure 3.13(a-b): Mean percentage correct recall for odours (a) and unfamiliar-faces (b) following the forward and backward testing procedure and as a function of serial position.

To assess the extent to which forward modified-reconstruction of odours and unfamiliar-faces produced qualitatively equivalent functions, scores were standardised to *Z*-scores (olfactory mean correct recall = 44.41%; unfamiliar-faces mean correct recall = 82.18%). Mean correct recall and mean correct *Z*-score recall for the forward modified-reconstruction of odours and unfamiliar-faces is demonstrated in Figure 3.14(a-b). A 2-factor (2x6) within-subjects ANOVA was computed on the standardised data where the first factor represents modality of stimuli (olfactory and visual) and the second factor represents serial position (1-6). A null effect of modality was found, $F<1$, and a main effect of serial position, $F(5,115)=2.88$, $MSe=0.40$. Importantly, a significant interaction between modality and serial position was found, $F(5,115)=2.94$, $MSe=0.50$, indicating that the olfactory and visual functions differ qualitatively.

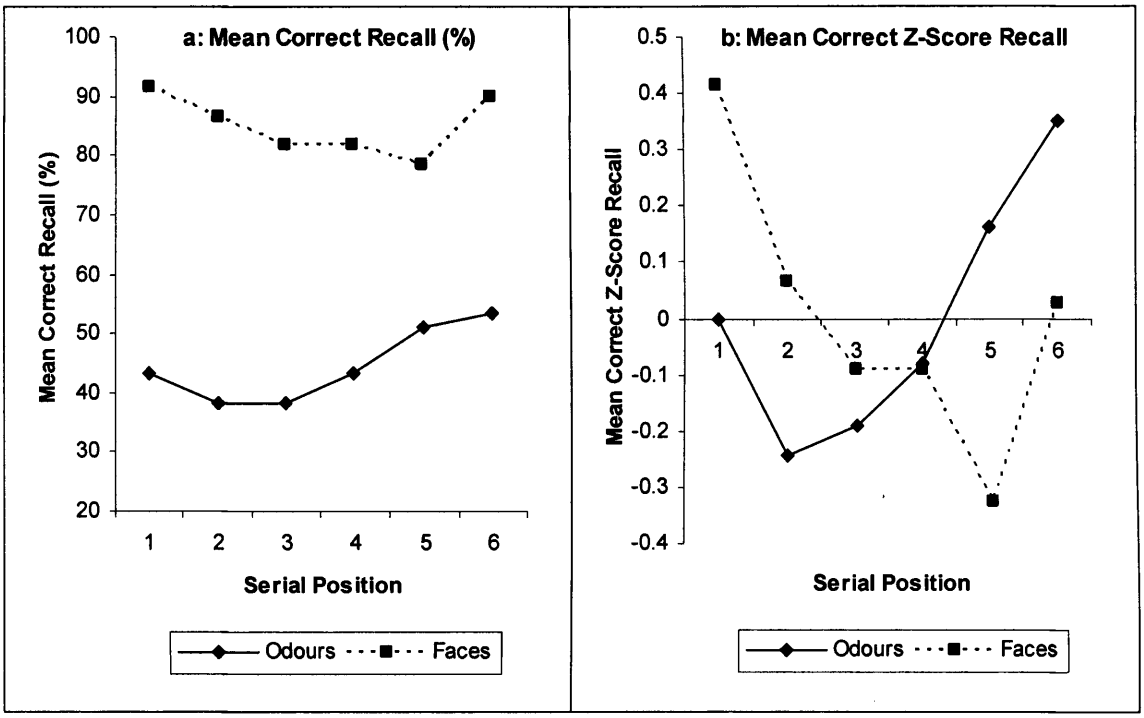


Figure 3.14(a-b): Mean percentage correct recall (a) and mean correct Z-score recall (b) for olfactory and visual stimuli following the forward testing procedure and as a function of serial position.

Further analysis of the interaction (Newman Keuls) revealed that for the olfactory stimuli, recall for serial position 6 was significantly greater than that for positions 2 and 3. For the visual stimuli, recall for serial position 1 was significantly greater than that for positions 3, 4 and 5. At each level of serial position, no significant differences were found between olfactory and visual stimuli.

Trend Analysis

Trend analysis was conducted for the olfactory and visual stimuli on the forward testing procedure only to assess the extent to which the forward testing procedure functions differed.

> **Odours:** A borderline significant quadratic component, $F(1,23)=3.52$, $MSe=1.64$, $p=.07$, and a borderline significant linear component were found, $F(1,23)=3.92$, $MSe=1.97$, $p=.06$.

Unfamiliar-Faces: A borderline significant quadratic component, F=(1,23)=4.09, MSe=0.81, p=.06, and a significant linear component were found, $F(1,23)$=7.54, MSe=0.51.

Primacy and Recency Analysis

A further analysis of primacy and recency was conducted upon the serial position functions following forward modified-reconstruction of odours and unfamiliar-faces. This analysis is described in the statistical methodology section.

Odours: A non-significant difference was found between mean recall at serial position 1 (mean correct recall = 44.44%) and recall of mean of serial positions 2-5 (mean correct recall = 42.14%), t<1. In contrast, recall at serial position 6 (mean correct recall = 53.47%) was significantly greater than the mean recall of serial positions 2-5, $t(23)$=2.23, p<.05.

Unfamiliar Faces: Recall at serial position 1 (mean correct recall = 89.58%) was significantly greater than the mean recall of serial positions 2-5 (mean correct recall = 80.21%), $t(23)$=3.26, p<.05. In contrast, a non-significant difference was found between recall at serial position 6 (mean correct recall = 82.64%) and recall of mean of serial positions 2-5, t<1.

In general, the analyses are consistent in showing that forward modified-reconstruction for odours and unfamiliar-faces produced qualitatively different functions. A significant interaction between modality and serial position was found and this difference is further substantiated by the primacy/recency analysis. The primacy/recency analysis indicates a double dissociation between odours and unfamiliar-faces: odours produced recency in the absence of primacy, conversely, unfamiliar-faces produced primacy in the absence of recency.

Response Distribution

The distribution of responses was compared between forward modified-reconstruction for odours and unfamiliar-faces and is demonstrated in Figure 3.15(a-b).

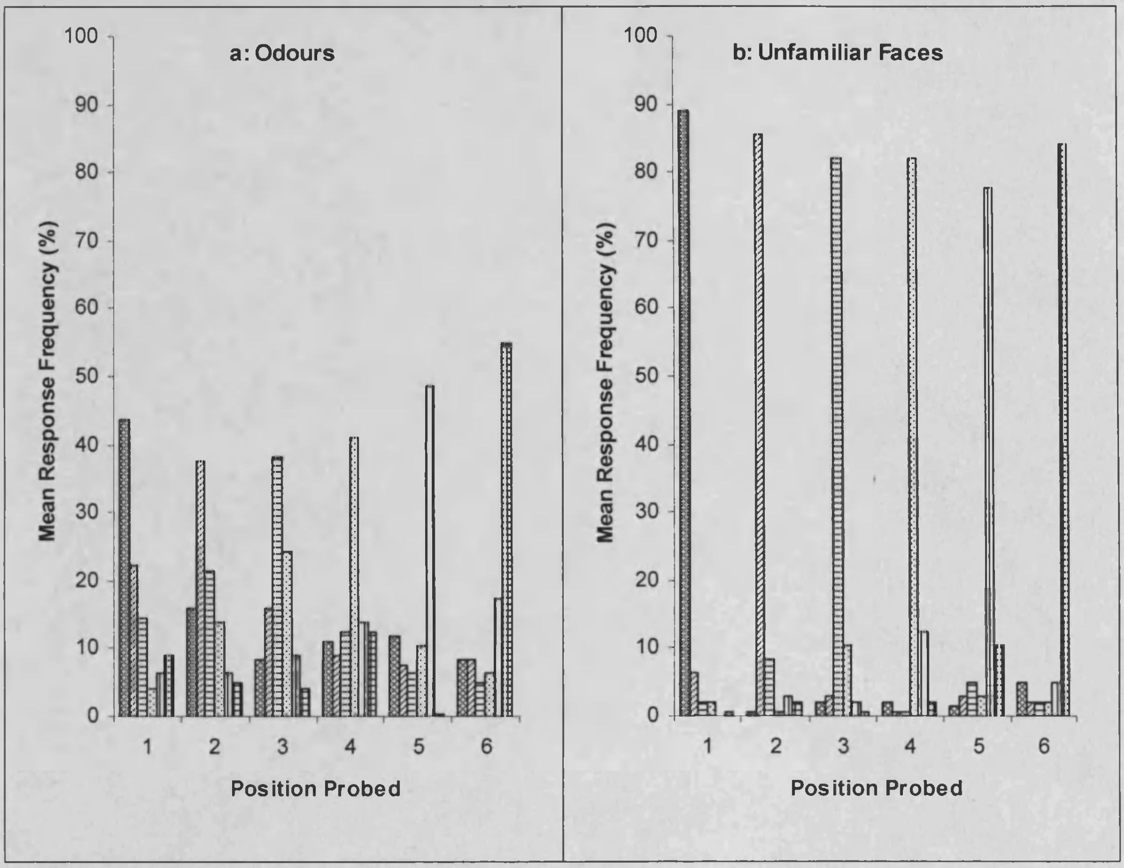


Figure 3.15(a-b): Mean response frequency of each serial position for odours (a) and unfamiliar-faces (b) following forward modified-reconstruction and as a function of serial position.

A single-factor (1x5) within-subjects ANOVA was computed on the displacement distance of erroneous responses (i.e. the extent to which an incorrect response was displaced 1, 2, 3, 4 or 5 positions).

Odours: The ANOVA revealed a main effect of displacement distance, $F(4,92)=11.84$, $MSe=0.15$. Further analysis (Newman Keuls) revealed that displacements of one serial position were significantly more frequent than that of 2, 3 or 4 position displacements.

Unfamiliar-Faces: The ANOVA revealed a main effect of displacement distance, $F(4,92)=7.42$, $MSe=0.04$. Further analysis (Newman Keuls) revealed that displacements of one serial position were significantly more frequent than that of 2, 3 or 4 position displacements.

The analysis of response distributions has demonstrated that both odours and unfamiliar-faces produce analogous error distributions. More specifically, for both modalities an erroneous response is most frequently allocated to adjacent serial positions. This is found despite qualitatively different functions produced for forward modified-reconstruction of odours and unfamiliar-faces.

Intervening Items Analysis

An intervening items analysis was performed to assess the extent to which interference may account for the differences observed between the olfactory and visual functions. Scores were collapsed across testing procedures and are demonstrated for odours and unfamiliar-faces in Figure 3.16a and 3.16b, respectively. A small non-significant negative correlation was found for both the visual (R=-0.12; p=.63) and the olfactory data (R=-0.21; p=.39). The absence of correlations demonstrates that the number of items intervening between presentation and test does not reliably determine the serial position function for either olfactory or visual modified-reconstruction tasks.

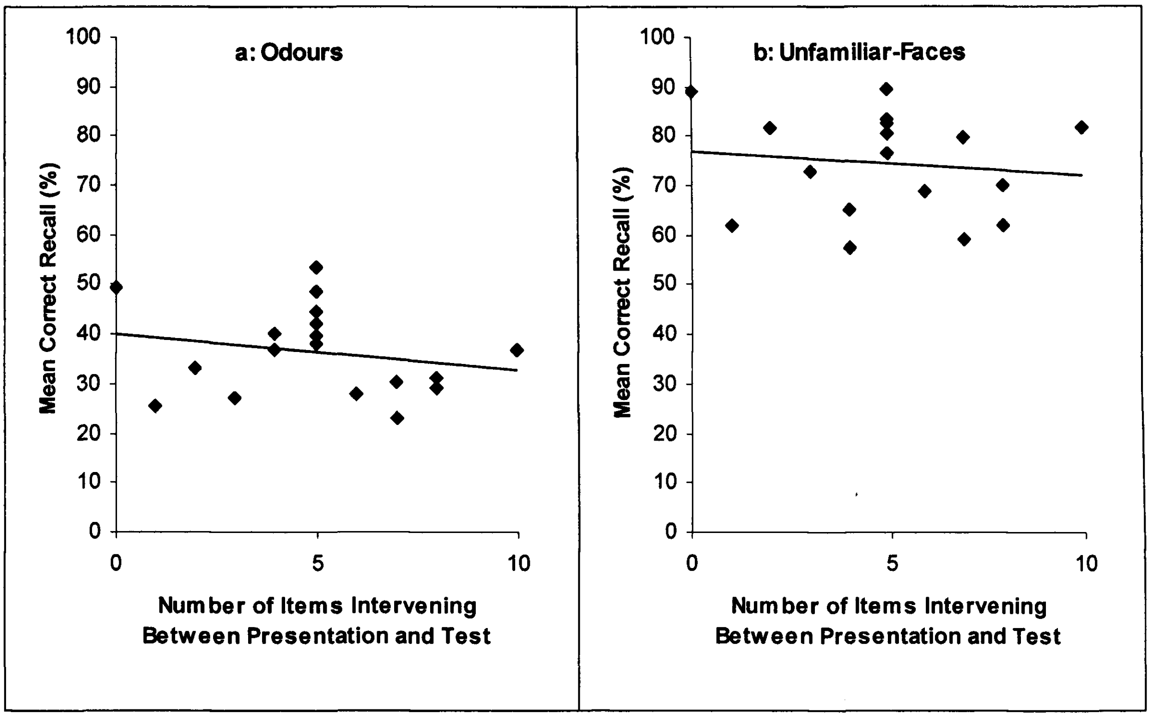


Figure 3.16(a-b): Mean percentage correct recall following modified-reconstruction of odours (a) and unfamiliar-faces (b) as a function of the number of items intervening between presentation and test. The trend line indicates the line of best fit.

Discussion

Experiment 3.4 employed identical exposure and ISIs for both the olfactory and visual stimuli, and yet, once more, obtained qualitatively different functions for forward modified-reconstruction. Recall data for the forward modified-reconstruction task produced recency but not primacy for odours and primacy but not recency for unfamiliar-faces. One might argue that the functional dissociation between odours and unfamiliar-faces suggests modularity. That is, odours and unfamiliar-faces are processed/stored by different mnemonics/systems.

The function produced for forward modified-reconstruction of unfamiliar-faces in the present experiment differs qualitatively to that produced for forward modified-reconstruction of unfamiliar-faces in Experiment 3.2. In the present study only primacy was observed, whereas in Experiment 3.2 both primacy and recency were reported. Why the different presentation times in Experiment 3.4 (1000 ms on, 1000 ms ISI) compared to Experiment 3.2 (750 ms on, 500 ms ISI) should result in recency attenuation is unresolved. It may be related to trace decay because an increased temporal delay between original presentation and test of the terminal sequence item exists for the current experiment. However, such suggestions are merely speculative. The finding raises concerns with respect to the reliability of the bowed function produced for forward modified-reconstruction of unfamiliar-faces. However, it should be noted that a bowed function exhibiting both primacy and recency is replicated for forward modified-reconstruction of unfamiliar-faces on two further occasions in Chapter 6 (Experiment 4.1).

Even if the absence of recency for unfamiliar-faces in the present experiment is viewed as anomalous data, the function (either primacy and recency or just primacy) remains qualitatively different to the recency only function demonstrated for odours. The effect of increasing both stimulus presentation times and ISIs on the unfamiliar-face function is an interesting finding but is beyond the scope of the present thesis. Further work is required to investigate the precise impact of presentation time. Nevertheless, it should be noted that a reduction in stimuli presentation time for odours (3000 ms in Experiment 3.3 to 1000 ms in Experiment 3.4) did not qualitatively alter the olfactory serial position function.

Odours and unfamiliar-faces produced analogous error distributions, i.e. erroneous responses were most frequently allocated to adjacent serial positions. This distribution of errors is consistent with the serial order reconstruction of unfamiliar-faces (Smyth et al., 2005). Interestingly, this cross-stimuli error distribution consistency in the present experiment is found despite qualitatively different functions following forward modified-reconstruction. This suggests that there are some similarities between how the order of olfactory and visual stimuli are stored. Specifically, for both types of stimuli, participants store the position of items in a relative rather than an absolute positional code.

Experiment 3.5a-d

As described earlier, the serial order reconstruction task is a paradigm restricted to visual (and arguably tactile stimuli). Parmentier and Jones (2000) and Parmentier et al. (2004) investigated serial order reconstruction for white noise bursts. The authors reported functional equivalence with other stimuli, e.g. abstract matrices. However, rather than reconstruction of auditory stimuli, the task relied upon a visual representation of the spatial domain. At test, participants received a visual representation of the spatial domain and were required to indicate the order in which each speaker in the spatial representation produced a white noise burst. Task execution was, therefore, characteristic of both visual and spatial modalities rather than the auditory memory per se because participants were reconstructing the spatial order of auditory events.

If a pure measure of auditory order memory is sought the serial order reconstruction task is unsuitable. This is because auditory items cannot be simultaneously re-presented at test. As previously discussed, the modified-reconstruction paradigm is a more appropriate paradigm by which cross-modal consistency can be explored. Similar to the reconstruction task, forward modified-reconstruction necessitates order recall of all items within the sequence and, unlike a multiple single probe serial recall paradigm, induces the same suppression of alternatives once a position has been responded/employed.

In Experiment 3.5(a-d) sequences of 4, 5, 6 and 7 pure-tones were applied to the modified-reconstruction task to assess (1) the extent to which the functions for these auditory sequences are qualitatively equivalent to those observed for other modalities and (2) the extent to which the functions are consistent across sequence lengths as demonstrated for serial order reconstruction of unfamiliar faces (Ward et al., 2005). If forward modified-reconstruction for pure-tones produces a qualitatively equivalent function to that for unfamiliar-faces, one might predict a bowed function exhibiting both primacy and recency. Alternatively, if the serial position function is qualitatively equivalent to that for odours one might predict recency but no primacy.

Method

Participants. There were twenty-four participants in each experiment. All were Cardiff University undergraduate volunteers from a variety of disciplines. All reported normal hearing and participated in exchange for £3.00 honorarium. Participants were restricted from participating in more than one of the four experiments. Details of the participants are:

Experiment 3.5a (4-pure-tone sequences): 3 males and 21 females (mean age 20 years and 6 months).

Experiment 3.5b (5-pure-tone sequences): 3 males and 21 females (mean age 21 years and 8 months).

Experiment 3.5c (6-pure-tone sequences): 4 males and 20 females (mean age 21 years and 2 months).

Experiment 3.5d (7-pure-tone sequences): 5 males and 19 females (mean age 21 years and 4 months).

Materials. The pure tones employed were as described for Experiment 1.3. In Experiment 3.5a a sample of 36 pure tones was employed (range of 300-1529Hz). In Experiment 3.5b a sample of 45 pure tones was employed (range of 300-1529Hz). In Experiment 3.5c a stimulus set of 54 tones was employed ranging in frequency from 300-3090 Hz. In Experiment 3.5d a stimulus set of 42 tones was employed ranging in frequency from 300Hz-1823Hz. Pure-tones were presented via headphones at75dB.

In Experiment 3.5a experimental tones were divided into 4 groups of 9 pure tones based upon chronological frequency, i.e. the first 9 tones became group 1. Similarly, experimental tones were divided into 5 groups of 9 pure tones in Experiment 3.5b, 6 groups of 9 pure tones in Experiment 3.5c and 7 groups of 6 pure tones in Experiment 3.5d. Each sequence then comprised one tone taken from each of the four groups, and included the additional constraint that any item within a sequence should not be within 4.5% Hz of another sequence item, i.e. stimulus set items that are adjacent in terms of frequency were not employed in the same sequence. The order of pure-tones within each sequence was organised so that a strategy based upon ascending or descending frequency levels was not possible.

Design. The design closely following previous modified-reconstruction experiments (Experiments 3.2-3.4). Participants were presented with18 trials and there were six trials for each of the forward, backward and control testing procedures, with the proviso that 2 or more consecutive trials were not of the same testing procedure. Experiments 3.5(a-d) differed with respect to sequence length (4-, 5-, 6- and 7-pure tone sequences, respectively).

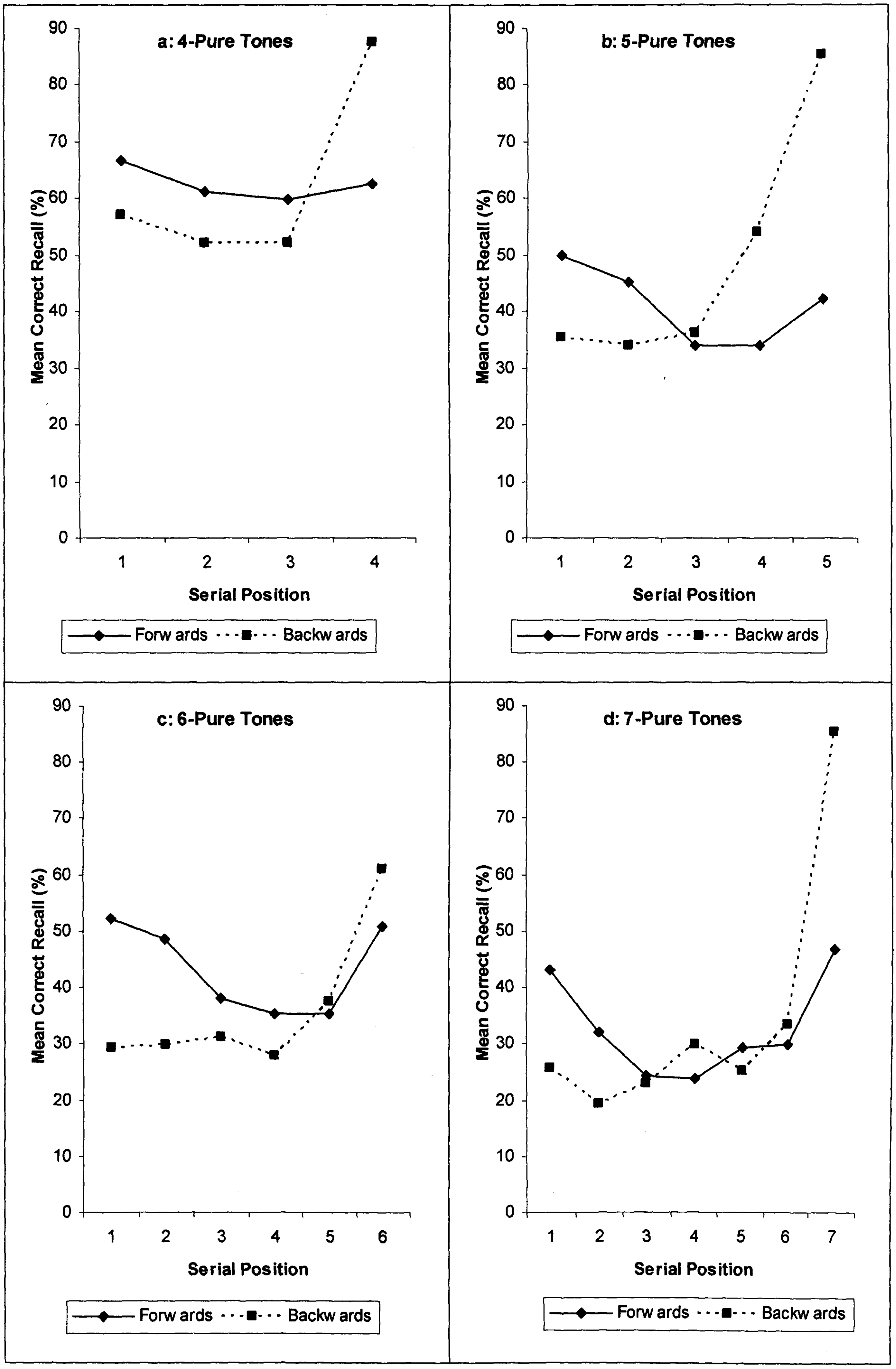
In Experiments 3.5a, 3.5b and 3.5c each pure tone was presented in two separate sequences; one in each half of the experiment. Tones presented in the same sequence in the first half of the experiment were presented in separate sequences in the second half of the experiment. In Experiment 3.5d each pure tone was presented in three separate sequences; one in each third of the experiment.

Procedure. The procedure followed closely that described for other modified-reconstruction experiments (Experiments 3.2-3.4). Each pure tone was presented for 500 ms followed by a 500 ms ISI. At test the pure tone were represented either in a forwards, backwards or control testing procedure.

Results

Serial Position Analysis

Figure 3.17(a-d) demonstrates the mean percentage correct recall following the forward and backward testing procedures for sequences of 4-, 5-, 6- and 7-pure tones.



a: 4-Pure Tones
b: 5-Pure Tones
c: 6-Pure Tones
d: 7-Pure Tones
Mean Correct Recall (%)
Serial Position
Forwards
Backwards

Figure 3.17(a-d): Mean percentage correct recall following modified-reconstruction of 4- (a), 5- (b), 6- (c) and 7- (d) pure-tones for the forward and backward testing procedures as a function of serial position.

Separate 2-factor within-subjects ANOVAs were conducted on the data for each of the four experiments. The first factor represents the testing procedure (forward or backward) and the second factor represents serial position.

4-Pure Tone Sequences: there was a null effect of testing procedure, $F<1$, (forward mean correct recall = 62.5%, backward mean correct recall = 62.15%) and a significant main effect of serial position, $F(3,69)= 16.71$, $MSe=0.81$. In addition a significant interaction was found between testing procedure and serial position, $F(3,69)=21.39$, $MSe=0.58$. Further analysis of the interaction (Newman Keuls) revealed that for the forward testing procedure there were no significant differences between recall at serial positions. For the backward testing procedure recall at serial position 4 was significantly greater than that at serial positions 1, 2 and 3. Comparisons across the forward and backward testing procedures revealed that the backward testing procedure was superior to that of the forward testing procedure at serial position 4.

5-Pure Tone Sequences: there was a main effect of testing procedure, $F(1,23)=6.09$, $MSe=2.22$, (forward mean correct recall = 41.11%; backward mean correct recall = 49.03%) and a significant main effect of serial position, $F(4,92)= 23.62$, $MSe=0.90$. In addition a significant interaction was found between testing procedure and serial position, $F(4,92)=21.39$, $MSe=1.38$. Further analysis of the interaction (Newman Keuls) revealed that for the forward testing procedure recall at serial position 1 was significantly greater than that at serial positions 3 and 4. Recall at serial position 2 was significantly greater than that at serial position 4. For the backward testing procedure recall at serial position 5 was significantly greater than that at serial positions 1, 2, 3 and 4. Comparisons across the forward and backward testing procedures revealed that the backward testing procedure was superior to that of the forward testing procedure at both serial positions 4 and 5.

6-Pure Tone Sequences: there was a borderline main effect of testing procedure, $F(1,23)=3.91$, $MSe=3.53$, $p=.06$, (forward mean correct recall = 43.40%; backward mean correct recall = 36.11%) and a significant main effect of serial position, $F(5,115)= 11.72$, $MSe=1.08$. In addition a significant interaction was found between testing procedure and serial position, $F(5,115)=5.22$, $MSe=1.29$. Further analysis of the interaction (Newman Keuls) revealed that for the forward testing procedure recall at serial positions 1, 2 and 6 was significantly greater than that at serial positions 3, 4 and 5. For the backward testing procedure recall at serial position 6 was significantly greater than that at serial positions 1, 2, 3, 4 and 5. Comparisons across the forward and backward testing procedures revealed that the forward testing procedure was superior to that of the backward testing procedure at both serial positions 1 and 2.

7-Pure Tone Sequences: there was a null effect of testing procedure, $F<1$, (forward mean correct recall = 32.64%; backward mean correct recall = 34.52%) and a significant main effect of serial position, $F(6,138)= 41.33$, $MSe=0.91$. In addition a significant interaction was found between testing procedure and serial position, $F(6,138)=17.82$, $MSe=0.81$. Further analysis of the interaction (Newman Keuls) revealed that for the forward testing procedure recall at serial positions 1 and 7 was significantly greater than that at serial positions 2, 3, 4, 5 and 6. For the backward testing procedure recall at serial position 7 was significantly greater than that at serial positions 1, 2, 3, 4, 5 and 6. Recall at serial position 6 was significantly greater than that at serial position 2. Comparisons across the forward and backward testing procedures revealed that the backward testing procedure was superior to that of the forward testing procedure at serial position 7.

Trend Analysis

Trend analyses were conducted to further assess the extent of similarity for serial position functions at each sequence length.

4-Pure Tones: For the forward testing procedure a non-significant quadratic, F=2.56, and a non-significant linear components, F=1.02, were found. For the backward testing procedure both significant quadratic, $F(1,23)$=25.62, MSe=1.37 and significant linear components were found.

5-Pure Tones: For the forward testing procedure significant quadratic, $F(1,23)$=10.81, MSe=0.80, and borderline significant linear components were found. For the backward testing procedure both significant quadratic, $F(1,23)$=38.07, MSe= 1.07 and significant linear components were found.

6-Pure Tones: For the forward testing procedure significant quadratic, $F(1,23)$=7.41, MSe=1.29, and non-significant linear components were found, F=2.33. For the backward testing procedure both significant quadratic, $F(1,23)$=20.48, MSe= 1.10 and significant linear components were found.

7-Pure Tones: For the forward testing procedure significant quadratic, $F(1,23)$=45.33, MSe=0.85, and non-significant linear components were found, $F<1$. For the backward testing procedure both significant quadratic, $F(1,23)$=71.19, MSe= 1.23 and significant linear components were found.

The trend analysis indicates that for the forward modified-reconstruction paradigm a bowed serial position function is produced. A quadratic component is demonstrated for sequences of 5-, 6- and 7-pure tones but not for shorter sequences (4-pure tone lists).

Primacy and Recency Analysis

A further analysis of primacy and recency was conducted upon the serial position function following forward modified-reconstruction of the pure-tones. This analysis is described in the Statistical Methodology section (Chapter 2).

4-Pure Tones: A non-significant difference was found between mean recall at serial position 1 (mean recall = 66.67%) and the mean recall of serial positions 2-3 (mean recall = 60.42%), t=1.63. Recall at serial position 4 (mean recall =

62.50%) was non-significantly greater than that of the mean recall of serial positions 2-3, $t<1$.

5-Pure Tones: A significant difference was found between mean recall at serial position 1 (mean recall = 50.00%) and the mean recall of serial positions 2-4 (mean recall = 37.73%), $t(23)=2.89, p<.05$. Mean recall at serial position 5 (mean recall = 42.36%) was non-significantly greater than that of the mean recall of serial positions 2-4, $t=1.32$.

6-Pure Tones: A significant difference was found between mean recall at serial position 1 (mean recall = 52.08%) and the mean recall of serial positions 2-5 (mean recall = 39.41%), $t(23)=2.36, p<.05$. Mean recall at serial position 6 (mean recall = 50.63%) was significantly greater than that of the mean recall of serial positions 2-5, $t(23)=2.12, p<.05$.

7-Pure Tones: A significant difference was found between mean recall at serial position 1 (mean recall = 43.06%) and the mean recall of serial positions 2-6 (mean recall = 27.78%), $t(23)=4.12, p<.05$. Mean recall at serial position 7 (mean recall = 46.53%) was significantly greater than that of the mean recall of serial positions 2-6, $t(23)=5.63, p<.05$.

Response Distributions

A further analysis was conducted on the distribution of erroneous responses for the forward and backward testing procedure across Experiments 3.5(a-d). Consistent with previous experiments investigating single-probe serial position recall (Experiment 2.1-2.4) and reconstruction (Experiment 3.1-3.4) incorrect responses are, generally, more frequently allocated to adjacent serial positions. This analysis can be found in more detail in Appendix 4. This finding is consistent with the error analysis conducted by Smyth et al. (2005) following reconstruction of unfamiliar-faces. The finding suggests that participants represent the position of pure-tones along a continuous order dimension rather than in an absolute positional code. If participants were representing items in absolute positional terms (e.g. this item was third), one would predict that if that position could not be recalled, erroneous responses would be equally distributed across the remaining positions. However, if represented along a continuous order dimension, wherein items are represented at an approximate point along that dimension, erroneous responses would be more frequently found in the approximate region of the correct position.

Learning of Testing Order

Experiment 3.5a produced a flat serial position function for forward modified-reconstruction of 4-pure tones. Participant performance in this experiment was found to be significantly better in the final third (mean recall = 66.49%), compared to the first third (mean recall = 58.33%) of the experiment, $t(23)=2.20$, $p<.05$. The finding suggests that participants may have learned the orders associated with each testing procedure. Learning of the testing procedure orders may have induced the observed flat function. However, if participants were indeed learning the order, this learning failed to produce performance near ceiling. Since performance was not at asymptote it is evident that ceiling effects did not induce an absence of serial position effects.

To assess the extent to which participants may have been learning the order of presentation at test, an analysis comparing first and final third performance was applied to the 5-, 6- and 7-pure tone sequences.

> **5-Pure Tone Sequences**: No significant difference between recall at the first third (mean recall = 42.08%) and the last third (mean recall accuracy = 44.31%) of the experiment, $t<1$.
>
> **6-Pure Tone Sequences**: No significant difference between recall at the first third (mean recall = 40.16%) and the last third (mean recall accuracy = 35.65%) of the experiment, $t=1.51$.
>
> **7-Pure Tone Sequences**: No significant difference between recall at the first third (mean recall = 29.17%) and the last third (mean recall accuracy = 28.27%) of the experiment, $t<1$.

The non-significant differences for 5-, 6- and 7-pure tone sequences demonstrate that participants' performance did not significantly improve throughout the duration of the experiment and indicates that they were not learning the presentation of the testing procedure orders.

Discussion

Experiments 3.5(a-d) compared forward and backward recall for pure-tone sequences ranging from to 4-tones to 7-tones. The experiment demonstrated a general decrease in serial position recall accuracy as list length increased. A single factor between-subjects ANOVA with four levels was performed comparing collapsed forward modified-reconstruction scores of 4-, 5-, 6- and 7-pure tone sequences. The ANOVA revealed a main effect of list length ($F(3,92)=14.62$, $MSe=0.94$). Further analysis (Newman Keuls) revealed that recall for 4-tone lists (mean accuracy=62.50%) was significantly greater than that for 5-tone lists (mean accuracy = 41.11%), 6 (mean accuracy = 43.40%) and 7 (mean accuracy = 32.64%). No differences were observed between list lengths of 5-, 6- and 7-tones. Although non-significant, a general trend is observable whereby list length increase is inversely related to recall accuracy. The trends are broadly consistent with Ward et al. (2005) who found significant differences between list lengths of 4, 6 and 8 unfamiliar-faces (Experiment 1) and differences between 4-, 5- and 6-nonword sequences (Experiment 3) following serial order reconstruction.

Experiments 3.8(a-d) demonstrated a gradual shift in the shape of the serial position function from an absence of serial position effects for 4-tone sequences to a bowed function exhibiting strong primacy and recency for 7-tone sequences. Forward modified-reconstruction of 4-pure tones produced a statistically flat line. As list length increased to 5-pure tones primacy is observed but not recency. However, for sequences of 6- and 7-pure tone sequences both primacy and recency is observed. It remains currently unresolved as to why the bowed function is observable only for longer sequence lengths. However, it is unlikely that the bowed function is observable only for poorer accuracy levels (e.g. <50%), as both primacy and recency is reported for modified-reconstruction of unfamiliar faces (Experiment 3.2) when performance levels are at 74%.

The general finding of a bowed serial position function following forward modified-reconstruction of pure-tones is broadly consistent with that for forward modified-reconstruction of unfamiliar-faces (Experiment 3.2). Both stimuli types demonstrated primacy and recency, a finding inconsistent with the recency but no primacy demonstrated following forward modified-reconstruction of odours (Experiment 3.3 and Experiment 3.4). Indeed, when forward modified-reconstruction of 7-unfamiliar-faces (Experiment 3.2) and 7-pure-tones (Experiment 3.5d) are compared, the functions match very closely. Figure 3.18(a-b) demonstrates the mean correct recall (a) and mean Z-score standardised correct recall (b) of unfamiliar-faces and pure-tones. Following standardisation the functions closely match. This is illustrated by a non-significant interaction between serial position and modality, *F*=1.79.

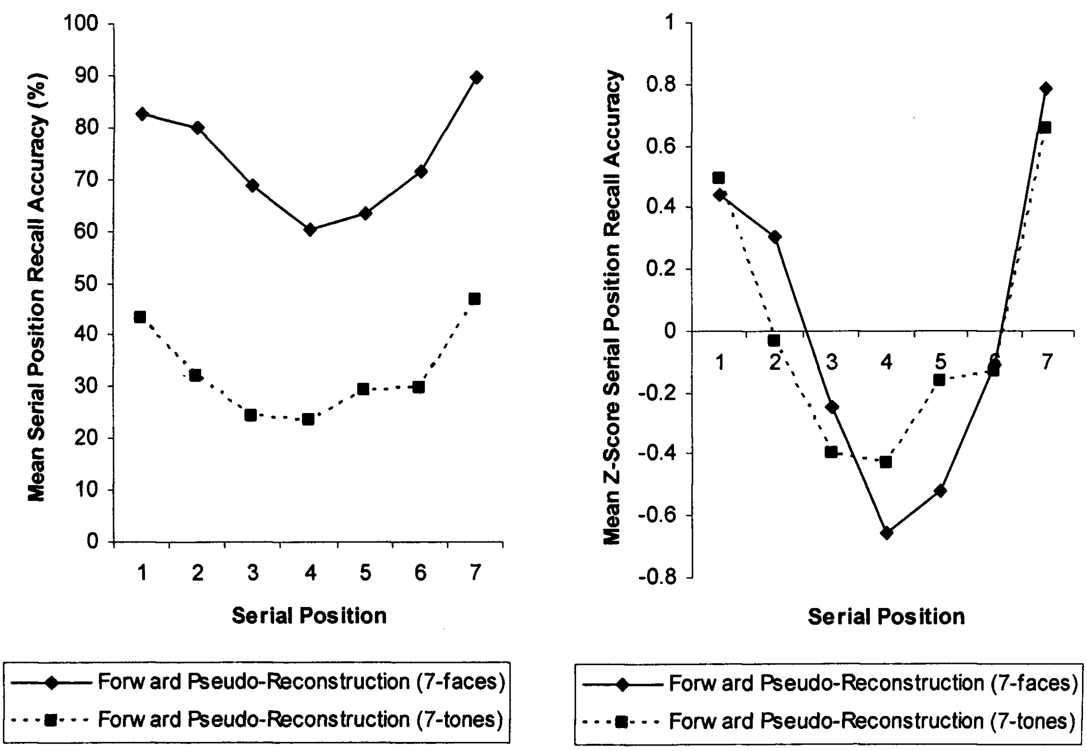


Figure 3.18(a-b): The mean correct recall (a) and mean correct Z-score recall (b) for unfamiliar-faces and pure-tones following forward modified-reconstruction as a function of serial position.

Throughout Experiments 3.5(a-d), the backward testing procedure for pure-tones has produced strong recency. This finding is consistent with both Chapter 3 (2AFC recognition) and Chapter 4 (single-probe serial position recall), where terminal item recognition and terminal item recall were highly accurate. This heightened recency is indicative of some form of auditory STS/echo conceptually analogous to PAS (e.g. Crowder and Morton, 1969). When an item is tested immediately following presentation, a highly accurate match follows between the tested item and the item held within the STS. However, when another item(s) intervenes between presentation and test, the benefit attenuates suggesting that this auditory STS has a single item capacity. Although evident in visual and olfactory modalities to varying degrees (e.g. see Experiments 1.1-1.3, 2.1-2.2 and 3.1-3.4) this recency component is accentuated for the auditory stimuli suggesting two preliminary conclusions. First, an initial cross-modal or modality analogous system promotes a benefit for items tested immediately following presentation. Second, the auditory system has an additional modality-specific mechanism/store which facilitates this terminal item benefit.

In summary, forward modified-reconstruction of pure-tones produced a bowed function consistent with unfamiliar-faces but inconsistent with odours. The finding suggests that pure-tones may be stored amodally or via analogous systems to that of unfamiliar-faces. In contrast, odours are processed separately/differently.

Chapter 5 Discussion

This series of experiments has examined serial order memory for olfactory, visual and auditory stimuli. The experiments have trialled a new methodology of measuring serial order memory termed modified-reconstruction. This paradigm has been applied to unfamiliar-face stimuli (Experiment 3.2) and has been shown to produce a serial position function qualitatively equivalent to that for the serial order reconstruction task (Experiment 3.1, see also Smyth et al., 2005; Ward et al., 2005).

The bowed serial position function observed for unfamiliar-face stimuli following both serial order reconstruction and forward modified-reconstruction was then compared to the function produced following forward modified-reconstruction of odours (Experiment 3.3). It was shown that following forward modified-reconstruction, olfactory stimuli produced a qualitatively different serial position function to that of unfamiliar-faces, demonstrating an absence of primacy for the olfactory stimuli. This difference was still observed following a replication in which odour-face list length and presentation times were identical cross-modally (Experiment 3.4). Appendix 3 Experiment 3 examined the extent to which the absence of primacy following forward modified-reconstruction for odours was due to low overall performance obscuring the observation of primacy. A replication of the modified-reconstruction for odours (Experiment 3.3) employing a reduced sequence length was found to increase overall performance in the forward testing procedure to over 50%. However, primacy remained absent (see Appendix 3, Experiment 3).

In Experiment 3.5(a-d) auditory stimuli were applied to the modified-reconstruction paradigm. Bowed serial position functions were generally observed for sequences of 4-7 pure tones, wherein curvature was accentuated for lengthened sequences (the curvature is consistent with the serial order reconstruction of the spatial position of white noise bursts, see Parmentier and Jones, 2000; Parmentier et al., 2004). The functions are broadly consistent with the unfamiliar-face functions indicating cross-stimuli consistency between unfamiliar-faces and pure-tones.

The Modified-Reconstruction Paradigm

Forward modified-reconstruction and serial order reconstruction has been demonstrated to produce qualitatively similar functions for unfamiliar-face stimuli (Experiments 3.1 and 3.2). Additionally, modified-reconstruction and serial order reconstruction of unfamiliar-faces has produced similar error distributions (also demonstrated for serial order reconstruction of unfamiliar-faces by Smyth et al., 2005). The functions differ slightly with respect to magnitude of the primacy component; more pronounced primacy is observed following serial order reconstruction. Although the function similarity does not demonstrate that the two paradigms are cognitively analogous, it is a telling finding that two separate tasks investigating serial recall of items within a sequence produced qualitatively equivalent functions.

The finding of functional similarity between serial order reconstruction and modified-reconstruction is important for future studies seeking to compare serial reconstruction of other modalities. Arguably the conventional serial order reconstruction paradigm can only be applied to visual stimuli. This is clearly evident for the aforementioned studies investigating reconstruction of facial stimuli and abstract patterns (e.g. Avons, 1998; Smyth et al, 2005; Ward et al., 2005) but is arguably also a necessary restriction for studies claiming to investigate spatial serial order reconstruction (Parmentier and Jones, 2000; Parmentier et al, 2001; Jones et al, 1995; Parmentier et al, 2004; Smyth and Scholey, 1996). Despite reconstructing the serial position of spatially presented bursts of white noise, dots and squares, these studies still rely upon a visual representation of the spatial domain at test, wherein the participant indicated the positions in the order of original presentation on a visual representation. The modified-reconstruction paradigm does not suffer from such constraints and because of this advantage can be applied to all modalities. Similar to olfactory stimuli, auditory, tactile and taste stimuli cannot be simultaneously represented at test and, therefore, cannot be applied to the serial order reconstruction paradigm. The serial order reconstruction paradigm is, therefore, an unsuitable method of comparison across modalities since performance of the task is heavily reliant upon visualisation.

In Experiments 3.2, 3.4 and 3.5b, a main effect of testing procedure (forward versus backwards) was reported for the modified-reconstruction paradigm. In Experiments 3.2 and 3.4 forward recall was superior to that of backward recall. Although only observed in two experiments, the difference is consistent with the proposal that backward recall is a more cognitively demanding task. For example, Li and Lewandowsky (1995) argued that different retrieval processes are employed for forward and backward recall. They argued that forward recall is reliant upon inter-item associations, whereas backward recall utilises visual-spatial representations. Conrad (1965) conceptualises backward recall as a more cognitively demanding adaptation of forward recall. In this strategy participants initially recall the items in forward order, recalling the terminal item and then omitting it from the set of recall candidates. This 'scan and drop' technique is then applied to the penultimate item and repeated until all items had been recalled in the reverse order. However, Experiments 3.3, 3.5a, 3.5c and 3.5d failed to report a main effect of testing procedure, suggesting that forward and backward modified-reconstruction was comparable. Such a finding is consistent with Farrand and Jones (1996) who found that forward and backward recall was equivalent following a task that required order memory only.

In the discussion of Experiment 3.2 (modified-reconstruction of unfamiliar-faces) the control testing procedure was examined. A benefit was found for the first-tested item, but this benefit was found not to be due to participants learning the order of presentation. Rather, the item that is tested first exhibits a performance advantage (see Appendix 3 Experiment 1). It is unclear what should underpin this benefit. Items may experience output interference, wherein the first recalled item is not subjected to any recall-based interference. However, the number of items intervening between presentation and test was not found to be a predictive of recall accuracy. Alternatively, the methodology may restrict performance of later items. Specifically, accurate recall of serial positions after the first-tested item are reliant on previous accuracy, i.e. if position 3 is erroneously assigned to a test item before the correct probe is presented, the participant, therefore, cannot accurately respond to that item when subsequently tested. The advantage for the item tested first is, therefore, that recall of that item is a pure measure of recall uncontaminated by previous performance.

Nevertheless, it should though be noted that in the aforementioned pilot study (see Appendix 3 Experiment 1) primacy was still reported following the randomised testing procedure. This was found despite the first sequence item not being tested first. Primacy for the forward modified-reconstruction of unfamiliar-faces cannot, therefore, be uniquely explained in terms of this methodological advantage.

Importantly, this methodological restriction of performance for items tested after the first test item is not confined to the modified-reconstruction paradigm but demonstrates another similarity with the serial order reconstruction task. In the serial order reconstruction task, sequence items are simultaneously represented at test and the participant is required to indicate the order in which the items were originally presented. If a participant has erroneously chosen an item first it will prohibit accurate serial order recall of the remainder of the sequence. This is consistent with Brown and Lamberts (2003) who argued that output effects can determine the serial position function in immediate free recall. In SIMPLE (Brown et al., 2002), a model of serial order STM, recalling the first or terminal sequence item at the beginning of recall determined the magnitude of primacy and recency, respectively.

Criticisms of the Modified-Reconstruction Paradigm

One potential criticism of the forward modified-reconstruction paradigm is that rather than conceptualised as analogous to serial order reconstruction, the task is better conceptualised as a series of single probe serial recall tests (i.e. the task employed in Kerr et al., 1998 and Chapter 4). However, clear empirical differences exist between modified-reconstruction and single serial probe recall. Although single-probe serial recall and forward modified-reconstruction for unfamiliar-faces produced both primacy and recency, this functional equivalence is not replicated for either odours or pure-tones. Single-probe serial recall of odours (Experiment 2.1) produced a flat serial position function, whereas forward modified-reconstruction of odours revealed recency (Experiment 3.3). This difference is demonstrated also for pure-tones, wherein single-probe serial recall produced recency but not primacy and forward modified-reconstruction generally produced both primacy and recency.

In response to this shift in function across the auditory single-probe and modified-reconstruction tasks (i.e. the development of primacy), one might argue that the primacy observed in the forward modified-reconstruction procedure is merely an artefact of output interference/output effects (e.g. one element underpinning primacy in the Brown et al. (2000) OSCAR model is output of items at test interfering with memory of to-be-remembered items). However, the control testing procedure (see Experiment 3.2) has shown that there is a benefit for serial position 1 even when not tested first. Moreover, the recall constraints of the modified-reconstruction paradigm indicate parallels with the serial order reconstruction task but not the single-probe serial recall task. That is, in the serial order reconstruction task, participants are required to recall all the previous list items at test, with the repetition of serial positions prohibited. Therefore, in the modified-reconstruction task, as in serial order reconstruction, recall accuracy of items tested first predicts later test accuracy (i.e. if the first test item tested is allocated to an erroneous serial position, it follows that when that position is tested it will be recalled incorrectly since the correct position has been utilised). Furthermore, in both the serial order reconstruction and modified-reconstruction tasks, suppression of response alternatives provides an additional constraint. As more responses are provided at test, the options for later test items are restricted as serial positions cannot be repeated. This suppression of response alternatives is not present in the single-probe serial recall paradigm as each trial tests a single serial position.

A further criticism of the paradigm concerns the repetition of the testing procedure orders at test. This repetition increases the likelihood that participants may learn the order at test. Specifically, at test participants receive each of the sequence items again and are instructed to state the serial position of each of the test items within the previous sequence. Over the 18 trials, each participant receives 6 trials with sequence items represented at test in the forward testing procedure, 6 trials in the backward testing procedure and 6 trials in the control testing procedure. Over the course of the experiment, participants may learn the order with which items are being represented at test. Responses may, therefore, comprise the learnt order rather than memory for the position of the sequence items.

However, the modified-reconstruction paradigm was adopted to produce a task as analogous as possible to the recognised serial order reconstruction paradigm. In the serial reconstruction task participants reconstruct original order through selecting the items in the order of original presentation. This is mirrored in the modified-reconstruction task via the forward testing procedure, wherein participants are represented with the items in the same order of original presentation. Although the same risk of order learning is not applicable to the serial order reconstruction paradigm, the paradigm is restrictive for the present thesis as it prohibits cross-modal comparison. The employment of the modified-reconstruction paradigm is, therefore, a compromise. This compromise permits cross-modal comparison but at the expense of methodological problems, specifically the risk of the learning of test order.

Nonetheless, there were attempts to limit the learning of the testing procedure orders. Trial numbers are limited to 18 (6 in each testing procedure) in order to reduce opportunities for acquiring the testing orders. Moreover, the same testing procedures occur on no more than two adjacent trials in order to limit reinforcement of those orders. Comparisons between recall accuracy at the beginning and end of the experiment are employed as an index as to the extent to which participants are learning the order at test. Only in Experiment 3.5a (modified-reconstruction of 4-pure tones) was recall accuracy found to be significantly greater at the end of the experiment. Notwithstanding the significant different, final third performance remained far from ceiling (mean correct recall = 58%), indicating that if learning did occur it was not uniform and far from efficient.

Furthermore, a pilot study (n=24; Experiment 4; Appendix 4) was conducted employing olfactory stimuli, wherein rather than modified-reconstruction, participants received all of the list items at test and were required to order them in original order of presentation. This manipulation eliminated the order at test learning effect. However, this adapted-reconstruction task has numerous other methodological problems (e.g. does it matter which item the participant experiences first when choosing? Does interference from smelling the items numerously at test impact performance? Do differences in the number of exposures and the duration of the process taken by participants influence the findings?). However, despite these problems, a qualitatively equivalent function was observed for 4-odour sequences following forward modified-reconstruction and this piloted adapted-reconstruction task. That is, for both tasks recency but not primacy was found. The finding suggests that the potential for learning of testing procedure did not qualitatively alter the serial position function.

Cross-modality functional equivalence following modified-reconstruction

The forward modified-reconstruction paradigm produced both primacy and recency for sequences of 7-unfamiliar faces (Experiments 3.2) and a similar function for sequences of 6- and 7-pure-tones (Experiment 3.5c and d). In comparison, olfactory stimuli produced recency only (Experiments 3.3). Interestingly, the failure to observe primacy replicates the recognition domain (Experiments 1.1a-b; Miles and Hodder, 2005) and other serial order paradigms (e.g. Experiments 2.1a-c; White, 1992; White and Treisman, 1997). Only Reed (2000) has demonstrated any evidence of olfactory primacy without overt verbalisation. The qualitatively different function for forward modified-reconstruction of odours is contrary to the proposal by Avons and colleagues that the serial position function is task rather than modality dependent (Avons, 1998; Ward et al., 2005). That is, by employment of the same task, the serial position function should be qualitatively analogous irrespective of the stimulus type. Ward et al. (2005) proposed this functional equivalence by comparing reconstruction of unfamiliar faces and reconstruction of non-words; both of which produced a bowed serial position function. The distinction between the stimuli was founded upon verbalisation of visual stimuli, i.e. unfamiliar faces are non-verbal stimuli and non-words are unfamiliar verbal stimuli. Chapter 5 has demonstrated that this functional equivalence for stimuli does not extend to olfactory stimuli.

It should, though, be noted that important methodological differences existed between the visual, olfactory and auditory modified-reconstruction paradigms. In the unfamiliar-face experiment (Experiment 3.2) sequences of 7 unfamiliar-faces were employed presented for 750 ms each and followed by a 500 ms ISI. However, for modified-reconstruction of odours sequences of 5-odours were employed. Each odour was presented for 3000 ms followed by a 2000 ms ISI. These methodological differences, as described previously, were adopted to limit ceiling effects for the unfamiliar-face stimuli and prevent floor effects for the olfactory stimuli. However, this manipulation creates an additional variable that arguably may account for the cross-modal differences observed. The difference is important as Miles and Hodder (2005) reported some evidence that the olfactory serial position function may be sensitive to exposure time manipulations.

This presentation confound was investigated in Experiment 3.4 wherein modified-reconstruction of sequences of 6-odours and 6-faces was compared (1000 ms item presentation time and 1000 ms ISI for both modalities). A cross-modal dissociation was found for forward modified-reconstruction, wherein odours produced recency but not primacy and unfamiliar-faces primacy but not recency. These preliminary findings suggest, therefore, that the different sequence lengths and presentation times were not the basis of the cross-modal differences. Nevertheless, it should also be noted that for pure-tones in Experiment 3.5(a-d), exposure and interval durations differed from both the unfamiliar-face and odour experiments. In these experiments, pure-tones were presented for 500 ms followed by a 500 ms ISI. Although differing in absolute terms, the ratio between presentation and test (1:1) was identical to that of Experiment 3.4. Nevertheless, these presentational differences limit cross-modal comparisons. A replication is, therefore, required employing identical cross-modal presentation times.

In the serial order reconstruction and the modified-reconstruction comparison (Experiment 3.1 and 3.2), the magnitude of the primacy component is lower following modified-reconstruction relative to that of the serial order reconstruction task. One might argue that this initial paradigm-based primacy deficiency may have obscured the observation of primacy in the olfactory study and, therefore, underpinned the cross-modal differences. However, the recency/primacy analysis revealed a significant primacy and recency component in both the serial order reconstruction of unfamiliar-faces (Experiment 3.1) and forward modified-reconstruction of unfamiliar-faces (Experiment 3.2). Therefore, despite the apparent reduction in the primacy component for the modified-reconstruction paradigm, a primacy component was still reported for the face stimuli. This primacy component was not found for odours, even following a decrease in task difficulty (see Appendix 3, Experiment 3).

One might argue that any functional cross-modal disparities observed could be an artefact of stimuli-specific characteristics rather than modality-specific memory. That is, cross-modal stimuli are processed via the same mechanism but features of the stimuli (e.g. number of feature elements, degree of similarity between other sequence items on some abstract parameter) induce apparent cross-modal differences. Such potential confounds are near impossible to control for when employing the present stimuli, as it necessitates that the characteristics of the stimuli are held constant with differences only in the modality of presentation. It is unclear how this could be achieved employing olfactory stimuli. One type of stimuli in which this can be applied to is verbal stimuli. This is explored in more detail in Chapter 6 (Experiments 4.3a-d).

Consistent with the present findings of modality-specific functional differences, neurological evidence exists of different cortical regions employed in memory of different modalities. Woodruff et al. (2005) followed the assumption that recollection involves the reinstatement of cortical activity during presentation. In this fMRI study, cortical activity was observed during the recollection of both words and pictures. Woodruff et al. (2005) demonstrated a double dissociation within the left fusiform cortex during recollection: recollected words produced a greater activity than recollected pictures in the lateral fusiform, whereas the opposite pattern of activation was observed in the anterior fusiform region.

Although potentially still operating via analogous mechanisms/strategies, evidence exists of separate systems executing serial memory of different modalities. For instance, Brock and Jarrold (2005) reported that Down's syndrome patients demonstrated a selective impairment of digit reconstruction compared to spatial reconstruction. This effect was found not to be an artefact of impaired hearing or poor number knowledge as a digit search task enabled the exclusion of participants impaired on those dimensions. The finding indicated that stimuli are not coded amodally in serial recall tasks and that equivalent functions reported for different modalities are an artefact of analogous mechanisms and/or strategies. Additionally, Frankish (1989) has reported modality-specific grouping effects in immediate free recall of 9-digit sequences. Temporal grouping was found to produce marked changes in the distribution of errors over serial positions of auditory but not visual stimuli. Moreover, any recall facilitation experienced by temporal grouping reached asymptote following a 0.25s interval for auditory stimuli, whereas visual stimuli experienced a progressive improvement across all serial positions as the interval was lengthened.

Forward modified-reconstruction of 7-unfamiliar-faces and 7-pure-tones was shown to produce qualitatively equivalent functions. The extent to which these stimuli were processed amodally was investigated further in two pilot studies (Appendix 3, Experiments 6-7) that employed mixed modality lists (i.e. both unfamiliar-faces and pure-tones). Modified-reconstruction was performed for 6-item mixed lists. It was proposed that if the stimuli are processed separately two modality-specific serial position functions should be produced (i.e. two mini-curves). This was not found. However, these experiments are extremely speculative and methodologically problematic.

Impact on models of serial order memory

The bowed serial position function reported for the modified-reconstruction of unfamiliar-faces is consistent with models of verbal serial order memory that predict both primacy and recency. However, recency in the absence of primacy following forward modified-reconstruction of olfactory stimuli contradicts the models and is particularly difficult to reconcile with models that utilise first item recall as a basis for subsequent item recall. For instance, the Primacy Model (Page and Norris, 1998) involves a primacy gradient wherein the first item elicits highest activation. The position of subsequent sequence items is represented relationally along a single dimension based upon first item activation levels. This primacy gradient is argued to produce primacy, wherein highest activation elicits superior recall of that first item. It seems intuitive, therefore, that accurate recall for post-primacy list items should be inferior to recall for the first item since there is a relationship of unilateral reliance. Yet despite this, significant primacy was not observed in the olfactory modified-reconstruction experiments (Experiment 3.3-3.4 and Appendix Experiments 2-3) or in the odour adapted-reconstruction task (Appendix Experiment 4).

Similarly, in Henson's (1998) Start-End model, the terminal items are employed as markers from which a 2-dimensional positional code is derived for each sequence item. Since the first item is employed as an anchor enabling recall of middle sequence items, one might again intuitively predict greater recall of the first item relative to non-terminal items. However, it is important to note that these models were designed specifically to account for verbal serial order recall and, therefore, might not be expected to account for non-verbal serial position functions.

The Absence of Primacy following Forward Modified-Reconstruction of Odours

Recency and an absence of primacy following forward modified-reconstruction of odours is a particularly anomalous finding given the presence of both primacy and recency for unfamiliar-faces and pure-tones. It seems unclear on a theoretical level why primacy should be absent. One possible explanation is that memory traces of the list items interfere with each other eradicating primacy. However, if this were occurring one might predict a flat serial position function wherein performance is at chance. This was not found. Furthermore, the terminal item following the forward testing procedure has the greatest amount of cumulative interference (i.e. the largest amount of odours is presented before presentation at learning and before test; although the number of items intervening between presentation and test is equivalent across positions). On this conceptualisation of interference (i.e. interference = total number of items presented prior to test), cumulative interference increases as a function of serial position and, therefore, one would predict a linear function demonstrating a recall decline as a function of serial position, i.e negative recency. This was not found.

A distinctiveness-based account (e.g. Nairne, Neath, Serra, and Byun, 1997) is equally incompatible with the primacy absence for odours (see Experiments 3.3-3.4 and Appendix Experiments 2-4). From a distinctiveness perspective, one might predict that the first sequence item exhibits greatest salience as the participant inhales a sequence of strong odours. The shift in perception from baseline (no odours) to initial strong odour is a particularly salient one. This might result in increased distinctiveness for that first odour, due to increased salience. However, the shift between first strong odour and second strong odour would presumably be less prominent, as participants habituate to the novelty of strong olfactory stimuli. Therefore, if distinctiveness habituation decreases (either linearly or exponentially) as a function of serial position, one would predict primacy and either an absence of recency or negative recency. This function was not found.

An account based on olfactory trace decay (although Lewandowsky et al., 2004, have argued that time is not important in determining the serial position function) is again unable to account for the observed trends. If the memory trace of each odour decayed at an equivalent rate one might predict a flat function for the forward testing procedure, or even negative recency (due to test phase being temporally longer than that of the presentation phase). If memory trace decay is related to time elapsed, one might predict recall accuracy to decline as a function of serial position. However, the opposite is observed.

The finding of recency following the forward modified-reconstruction may also not be accommodated in terms of a STM store/olfactory echo (e.g. the duplex conceptualisation, Phillips and Christie, 1977). The terminal item is only tested following the testing of each of the pre-recency items, therefore, numerous items intervene between presentation and test. Under a duplex-type STS conceptualisation, the terminal item needs to be immediately re-presented at test in order for a highly accurate match to occur between the item held within the STS and test item. If items intervene between presentation and test, these items displace the previous to-be-remembered item from the STS negating any memory facilitation. In Experiment 3.3 for example, recency is observed following forward modified-reconstruction of 5-odours despite 4-test odours separating initial presentation of the terminal list item and test of that item. Any information in the STS regarding the terminal list item is overwritten or dissipated. The finding of recency, therefore, cannot be explained in terms of a highly fragile STS. If such a store were able to operate despite the presentation of 4-interveing items (i.e. it had a capacity of 6-items), then it would be able to store all sequence items between the point of original presentation and test and, therefore, the items should be recalled to an equivalent level. However, this flat serial position function was not observed. Currently, the absence of primacy following forward modified-reconstruction of odours remains unresolved.

Key Findings

In summary, forward modified-reconstruction of unfamiliar-faces and pure-tones produced a bowed serial position function consistent with serial order reconstruction of visual stimuli (Smyth et al., 2005; Ward et al., 2005). In contrast, qualitatively different function has been produced for olfactory stimuli indicating some degree of modularity in the memory of odour order.

CHAPTER 6:
THE ROLE OF VERBALISATION IN MODIFIED-RECONSTRUCTION

Introduction

Overview

Chapter 6 investigates the role of verbalisation in the modified-reconstruction serial position function. The chapter initially investigates the extent to which the disparity at the primacy component of the serial position function observed between modified-reconstruction of unfamiliar-faces and odours is an artefact of labelling (Experiment 4.1-4.2). More specifically, are participants labelling the unfamiliar-faces and rehearsing sub-vocally. These studies investigate the serial position functions for modified-reconstruction of odours and unfamiliar-faces following the restriction of verbalisation via articulatory suppression. Conversely, Experiment 4.3 encourages verbalisation through the employment of nonwords. The study assesses whether the presence of opportunities in which to verbally rehearse list items qualitatively changes the serial position function.

Rationale for the Restriction of Verbal Labelling

In Chapter 5 forward modified-reconstruction for odours, unfamiliar-faces and pure-tones was investigated. For accurate cross-modal comparison, it is important to demonstrate that the tasks were assessing order memory for that particular modality rather than a verbal representation of those stimuli. If participants were recoding the stimuli into verbal code, the reported serial position function would be characteristic of verbal rather than visual/olfactory/auditory memory, invalidating cross modality comparison. To minimise this possibility hard-to-name stimuli were employed in Chapter 5.

The Role of Verbalisation in Memory

The limited role of verbalisation in olfactory memory is supported by the findings of Miles and Hodder (2005) and Reed (2000), who reported a marginal effect of articulatory suppression and failed to find a significant interaction between articulatory suppression and serial position in a 2AFC recognition task. Furthermore, the role of verbal labelling in serial order reconstruction of unfamiliar-faces has been shown to be facilitative but not fundamental. Smyth et al. (2005) failed to report an interaction between articulatory suppression and serial position, concluding that "serial position effects found with unfamiliar faces are not based on verbal encoding strategies" (pg. 909).

Nevertheless, Avons and Mason (1999) argued that the use of hard-to-name stimuli does not necessarily preclude the use of verbal labels. "Indeed it is not clear that there are any perceptually discriminable stimuli for which verbal labels cannot be generated. Hence if there is a strong motivation for using verbal descriptions, the potential for their use exists… An extreme view would be that subjects remember the serial order of visual stimuli by labelling components of the stimuli and retaining the order of the labels" (pg.220). Avons and Mason (1999) found that concurrent articulatory suppression had a significantly greater impairment on serial order reconstruction of abstract patterns than concurrent finger-tapping (Experiment 1). They argued this to be evidence of some verbal encoding of the stimuli and, therefore, that "concurrent articulatory suppression discourages the use of such processes and hence decreases performance" (pg. 220). However, it is not clear if articulatory suppression and finger-tapping differ on task difficulty and, therefore, the extent to which this observed difference in performance impairment is merely an artefact of cognitive load discrepancies.

Additionally, Avons and Mason (1999) reported a main effect of visual similarity (Experiments 1 and 4) providing evidence of visual encoding of the stimuli. In Experiment 4, Avons and Mason (1999) trained participants to identify the abstract block patterns, despite the familiarisation process, an effect of visual similarity was still found. The finding indicated that the (visual similarity induced) errors must originate in memory, rather than in discrimination between the patterns. Additionally, it is unlikely that a phonological code underpins the visual similarity effect as an interaction between articulatory suppression and visual similarity was not found.

In Experiments 4.1-4.3, the role of verbalisation in the modified-reconstruction task is examined in more detail.

Experiment 4.1

Experiments 3.2-3.4 indicated that qualitatively different serial position functions are produced for forward modified-reconstruction of odours and unfamiliar-faces. Specifically, primacy is present for modified-reconstruction of unfamiliar-faces but absent following forward modified-reconstruction of odours. Rundus (1971) conceptualised primacy in verbal memory as an artefact of frequent rehearsal of the earlier list items. One possible explanation for the observed cross-modal disparity is that participants assigned verbal labels (albeit arbitrarily) to the unfamiliar-faces and rehearsed these verbal labels sub-vocally.

In Experiment 4.1 this possibility is examined directly. One method by which the role of verbal labelling can be investigated is via that of articulatory suppression (as performed for single-probe serial recall of unfamiliar-faces in Experiment 2.4). Baddeley (e.g. 1997) has argued for the existence of modality-specific slave-systems that operate independently. It is proposed that the verbal component can be disabled by articulation of an irrelevant item, "preventing it (the phonological loop) from being employed either to maintain material already in the phonological store, or convert visual material into a phonological code" (Baddeley, 1997, pg. 58). It is claimed that the articulation induced decrement does not simply reflect an attentional deficit because (1) finger-tapping, a task assumed to produce similar attentional demands, does not impair STM of verbal stimuli (Baddeley, Lewis, and Vallar, 1984a). Furthermore, (2) clinical patient PV, who is argued not to have the verbal slave system, is unimpaired following articulatory suppression (Vallar and Baddeley, 1984a). The finding suggests that the act of articulatory suppression will only impair STM when disrupting operation of the articulatory loop (see also Smyth et al., 2005).

The following experiment investigated the extent to which verbal labelling of the unfamiliar-face stimuli underpinned the primacy component following forward modified-reconstruction of unfamiliar-faces. Experiment 4.1 replicated the methodology of modified-reconstruction of 7-unfamiliar-faces in Experiment 3.2, and included the exception that during the presentation phase, participants undertook articulatory suppression (repetition of the word "the"). As in Experiment 2.4, articulatory suppression was undertaken at presentation only for two reasons. First, prevention of sub-vocal rehearsal is only required during encoding. Second, during the serial reconstruction of faces, Smyth et al. (2005, Experiment 2) found a non-significant difference between articulatory suppression during the presentation phase only and articulatory suppression throughout both the presentation phase and the test phase.

Smyth et al. (2005, Experiment 2) found a main effect of articulatory suppression, but crucially, a non-significant interaction between serial position and articulatory suppression. That is, the act of articulatory suppression impaired recall equally across all serial positions. If the primacy component was underpinned via verbalisation one might predict a greater decrement to the first serial position relative to post-primacy items. This was not found. Furthermore, Smyth et al. (2005) found that the effect of visual similarity was impervious to articulatory suppression, indicating that the task was reliant upon visual, rather than verbal, coding.

Despite the evidence suggesting that attentional demands do not underpin the articulatory suppression induced decrement, Baddeley (1997) states that "it is, nonetheless, always wise in studies of articulatory suppression to include a finger-tapping condition to control for any general attentional effects on performance" (pg. 58). Therefore, in Experiment 4.1 an additional between-subjects finger-tapping condition was included whereby participants were instructed to tap the index finger of their non-dominant hand 2-3 times per second during the presentation phase of each trial whilst items are presented at presentation. A between-subjects methodology was employed as it was mooted that following repetition of the testing orders, participants may learn the order of testing procedures if exposed to a large number of trials. However, it was conceived that this design is a less sensitive measure, such that any cross-task differences might be potentially driven via individual differences.

As reported in Smyth et al. a non-significant interaction between serial position and presentation condition (articulatory suppression, finger-tapping and quiet) suggests that verbal labelling does not underpin the primacy component. A significant interaction suggests that verbal labelling determines the serial position function.

Method

Participants. Forty-eight (6 male and 42 female: mean age 20 years and 6 months) Cardiff University volunteer Psychology undergraduates participated in exchange for course credit. None had participated in the Chapter 5 experiments.

Materials. The unfamiliar-face stimuli were identical to those employed in Experiment 3.2.

Design. The design was identical to that in Experiment 3.2 with the exception that one group performed articulatory suppression during the presentation phase and another group performed a finger-tapping task during the presentation phase.

Procedure. The procedure was identical to Experiment 3.2 with the exception that participants in the articulatory suppression condition were instructed to repeat the word "the" throughout the presentation phase in each trial. Throughout the presentation phase participants were instructed to articulate "the" at a rate of 2-3 times per second and participants in the finger-tapping condition were instructed to tap the index finger of their non-dominant hand on the table at a rate of 2-3 times per second.

Results

Serial Position Analysis

Figure 4.1(a-b) demonstrates the mean correct recall for unfamiliar-faces following the forward and backward modified-reconstruction testing procedures for the articulatory suppression (a) and finger -tapping condition (b).

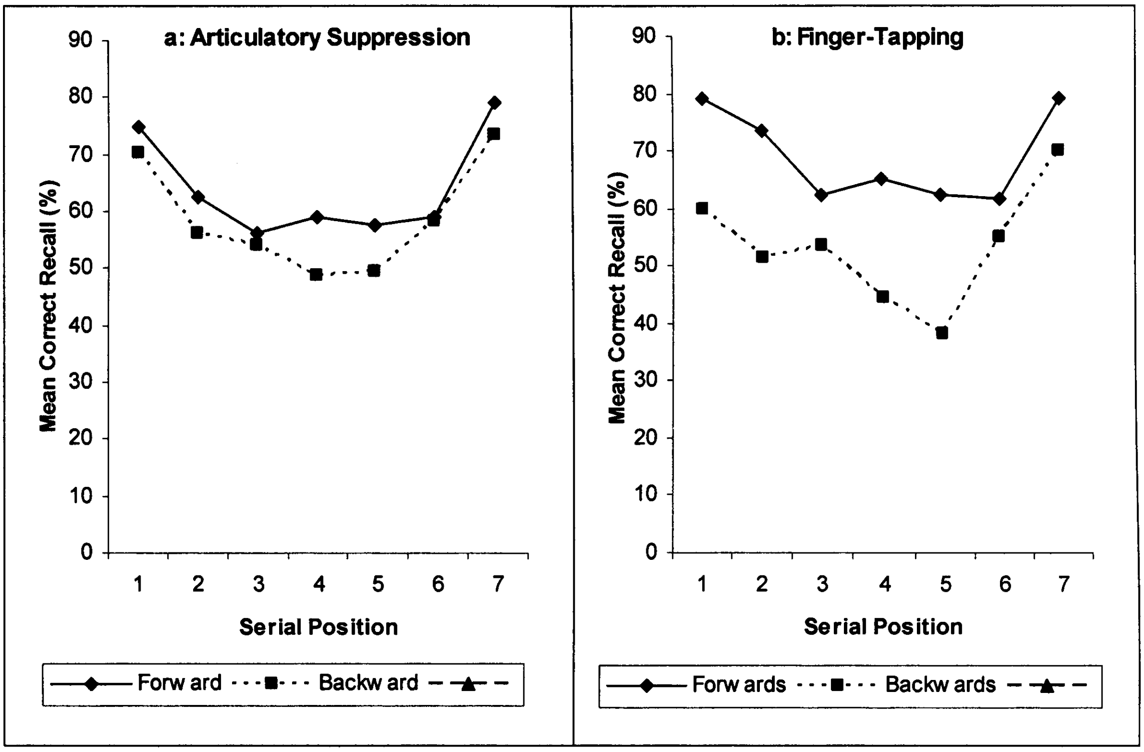


Figure 4.1(a-b): Mean percentage correct recall for the articulatory suppression (a) and finger-tapping conditions (b) following the forward and backward modified-reconstruction testing procedures and as a function of serial position.

Forward modified-reconstruction for unfamiliar-faces following articulatory suppression and finger-tapping in the current experiment was compared with forward modified-reconstruction for unfamiliar-faces in Experiment 3.2. This is demonstrated in Figure 4.2. A 2-factor (3x7) mixed ANOVA was computed where the between-subjects factor represents manipulation at the presentation phase (articulatory suppression versus finger-tapping versus non-articulatory suppression) and the within-subjects factor represents serial position (1-7). A null effect of condition at presentation phase was found, $F<1$, and a main effect of serial position, $F(6,69)=27.13$, $MSe=0.77$. Crucially, the interaction between the manipulation at presentation and serial position was non-significant, $F<1$. This demonstrates that neither articulatory suppression nor finger-tapping qualitatively changed the serial position function.

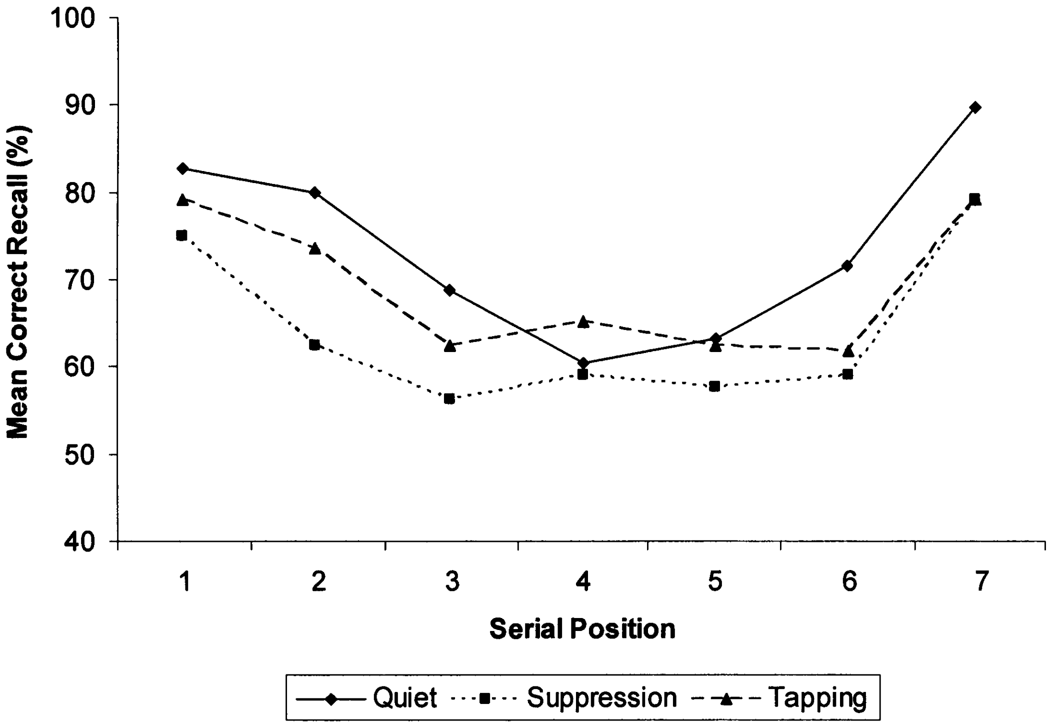


Figure 4.2: Mean percentage correct recall for the forward modified-reconstruction testing procedure following articulatory suppression (Experiment 4.1), finger-tapping (Experiment 4.1) and non-articulatory suppression (Experiment 3.2) and as a function of serial position.

Trend Analysis

Trend analyses were conducted to assess further the extent to which the serial position functions for forward modified-reconstruction were similar following non-articulatory suppression, articulatory suppression and finger-taping during the presentation phase.

Quiet during presentation phase (Experiment 3.2): A significant quadratic, $F(1,23)=34.24$, $MSe=1.75$, and a non-significant linear component was found, $F<1$.

Articulatory suppression during presentation phase (Experiment 4.1): A significant quadratic, $F(1,23)=26.36$, $MSe=1.45$, and a non-significant linear component was found, $F<1$.

Finger-tapping during presentation phase (Experiment 4.1): A significant quadratic, $F(1,23)=18.26$, $MSe=1.36$, and a non-significant linear component was found, $F=1.57$.

The quiet, articulatory suppression and finger-tapping conditions were shown to produce equivalent trend components. The three conditions revealed a significant quadratic but non-significant linear function, characteristic of a bowed serial position function.

Primacy and Recency Analysis

A further analysis of primacy and recency was conducted upon the serial position function following forward modified-reconstruction of unfamiliar-faces. This analysis is described in the Statistical Methodology section (Chapter 2).

Quiet during presentation phase: Recall at serial position 1 (mean recall = 82.64%) was significantly greater than the mean of positions 2-6 (mean recall = 68.75%), $t(23)=7.76$, $p<.05$. Recall at serial position 7 (mean recall = 89.58%) was significantly greater than the mean of positions 2-6, $t(23)=3.11$, $P<0.05$.

Articulatory suppression during presentation phase: Recall at serial position 1 (mean recall = 75%) was significantly greater than the mean of positions 2-6 (mean recall = 58.89%), $t(23)=4.15$, $p<.05$. Recall at serial position 7 (mean recall = 79.17%) was significantly greater than the mean of positions 2-6, $t(23)=5.32$, $p<.05$.

Finger-tapping during presentation phase: Recall at serial position 1 (mean recall = 79.17%) was significantly greater than the mean of positions 2-6 (mean recall = 65.14%), $t(23)=4.26$, $p<.05$. Recall at serial position 7 (mean recall = 79.17%) was significantly greater than the mean of positions 2-6, $t(23)=3.44$, $p<.05$.

This additional analysis demonstrated that both primacy and recency was present following forward modified-reconstruction of unfamiliar-faces employing quiet, articulatory suppression and finger-tapping during the presentation phase.

Discussion

Experiment 4.1 demonstrates that neither concurrent articulatory suppression nor concurrent finger-tapping impair forward modified-reconstruction performance. The finding, therefore, indicates that the primacy disparity reported between forward modified-reconstruction of odours (Experiment 3.3) and of unfamiliar-faces (Experiment 3.2) was not underpinned by verbal labelling of the faces and subsequent rehearsal of those labels. On one level this finding is consistent with Smyth et al. (2005) who reported no interaction between articulatory suppression and serial position for serial order reconstruction of unfamiliar-faces. That is, the serial position function was not qualitatively altered by articulatory suppression. More specifically, the finding suggested that primacy was not underpinned via verbal labelling of the faces.

However, the Smyth et al. (2005) findings contradict the present findings with respect to the main effect of articulatory suppression. Smyth et al. (2005) found that articulatory suppresison impaired serial order reconstruction of unfamiliar faces to a significantly greater extent than did concurrent finger-tapping. In Experiment 4.1, mean recall following the forward testing procedure in the articulatory suppression condition was 64% compared to that of 69% in the finger-tapping and 74% in the quiet condition (Experiment 3.2). Mean recall in Smyth et al. was approximately 57% for the articulatory suppression condition, 63% for the finger-tapping condition and 66% for the quiet condition. The impact of articulatory suppression is quantitatively similar across studies. However, reduced recall levels in Smyth et al. signify that the proportional impact of articulatory suppression in Smyth et al. is greater.

There are two possible reasons as to why the present experiment did not replicate the main effect of articulatory suppression found by Smyth et al. (2005). First, with respect to comparisons with the present experiment, the articulatory suppression task differed in complexity, potentially mediating the presence of the effect. In Smyth et al. (2005) participants repeated the words "one, two, three, four" at a rate of three words per second. Conversely, in the present experiment participants repeated a single word, "the", 2-3 times per second. It is plausible that the changing state of the concurrent articulatory suppression task made greater demands upon the central executive than the current articulatory suppression task. Indeed, the present findings appear more in line the with the working memory conceptualisation; a task that is argued not to necessitate verbal processing unimpaired by simultaneous operations within the phonological component.

Second, it is unclear the extent to which the greater detrimental effect of articulatory suppression, compared to finger-tapping reported by Smyth et al. (2005, Experiment 1), is due to the reliance upon verbal coding being disrupted or if the two concurrent tasks differ in complexity. In Smyth et al. (2005) the concurrent articulatory suppression task, as previously described, changed in state. In contrast, it is unclear in Smyth et al. the extent to which the finger-tapping task was uniform in nature or changed with respect to location of each tap (all that is described is that the rate of finger-tapping was 3 per second). If the concurrent finger-tapping task is uniform, the disparity in decrements may indeed be accounted for in terms of distracter tasks employed in Smyth et al. (2005) differing in complexity.

In summary, Experiment 4.1 demonstrated that the forward modified-reconstruction serial position function of unfamiliar-faces was unaffected by either the concurrent task of articulatory suppression or finger-tapping during the presentation phase. The finding has two important implications. First, the unfamiliar-face function for this paradigm is not governed by verbal labelling. No difference between the quiet and articulatory suppression conditions demonstrated that following the blocking of articulation, performance was unaffected. The absence of a verbal labelling strategy is further emphasised by a non-significant difference between the concurrent finger-tapping and the concurrent articulatory suppression conditions. Second, the non-significant interaction between articulatory suppression and serial position demonstrated that the serial position function was not qualitatively changed by articulatory suppression. This was shown via three separate serial position functions analyses (ANOVA, trend and primacy/recency analysis). More specifically, the results illustrated that the primacy observed for forward modified-reconstruction of unfamiliar-faces was not due to verbal labelling. The observed disparity between the forward modified-reconstruction of odours (Experiment 3.3) and unfamiliar-faces (Experiment 3.2) cannot, therefore, be explained in terms of verbal labelling and subsequent rehearsal of the faces inducing primacy for faces but not for odours.

Experiment 4.2

As shown with articulatory suppression for unfamiliar-faces following the single-probe serial position recall (Experiment 2.4) and modified-reconstruction paradigms (Experiment 4.1), it is important to demonstrate that the serial position function reported is a direct reflection of the modality being investigated. This articulatory suppression manipulation allows one to eliminate the hypothesis that the serial position function might be a characteristic of a verbal representation of those stimuli. If participants are verbally labelling the odours, any function demonstrated is merely a representation of verbal rather than olfactory memory.

There is mixed evidence with regard to the relationship between odours and verbalisation. As described in the Chapter 3 Introduction, the relationship between odours and verbalisation is contradictory (e.g. Cain, 1979; Jehl et al. 1997). White (1998) argued that since non-human animals possess an olfactory memory system than can operate independently of verbalisation, there appears no a priori reason why humans should not. Notwithstanding this point, participants may still attempt to facilitate performance via verbal elaboration whenever possible. Indeed olfactory yes/no recognition performance has been shown to be facilitated by presentation of odour names (Lyman and McDaniel, 1986) and a combination of odour labels and visual imagery (Lyman and McDaniel, 1990) at original presentation.

The sample demographic becomes particularly salient when discussing potential verbal labelling of the olfactory stimuli. Throughout the olfactory experiments (Experiments 1.1, 2.1, 3.3 and Appendix 3, Experiments 2-4) described in this thesis, a large female bias exists (75.52% of the participants were female). It has been shown that females possess superior olfactory identification abilities compared to that of males (e.g. Cain, 1982, Experiment 1; Schab and Crowder, 1995). Furthermore, females have not only displayed this identification superiority for labels provided by the experimenter but also for self-generated labels (Cain, 1982, Experiment 2). The majority of the participants in the olfactory experiments (75.52%), therefore, potentially possess a greater proficiency with odour-label associations. The likelihood that participants are employing a verbal-based strategy is consequently increased. If a verbal-based strategy is employed, any function produced might be characteristic of verbal memory of odour labels rather than olfactory stimuli per se. Therefore, to eliminate the role of verbalisation, modified-reconstruction of odours was performed with articulatory suppression at presentation.

Articulatory suppression has been shown to have some detrimental impact on olfactory recognition (Annett and Leslie, 1996; Miles and Hodder, 2005; Perkins and McLaughlin Cook, 1990; Reed, 2000). However, in Experiment 4.2 the principle focus investigated was the extent to which articulatory suppression qualitatively impacted the serial position function. Unlike the articulatory suppression task employed in Experiment 4.1, participants are unable to perceive the olfactory stimuli whilst performing articulatory suppression (a participant cannot inhale an odour whilst articulating out loud). The task employed in Experiment 4.1, therefore, required adaptation. Similar to the articulatory suppression condition employed by Miles and Hodder (2005, Experiment 6), an ISI of 5000 ms was introduced in which the participant repeated the word "the" during presentation intervals after each odour was presented.

In Experiment 4.2, a control silent condition was included in which participants remain quiet throughout the 5000 ms ISI. This condition was included to ensure that the act of extending the ISI does not alone qualitatively alter the serial position function. Recall for the olfactory modified-reconstruction task in Experiment 3.3 (mean accuracy=38.17%) was substantially reduced compared to that for the visual modified-reconstruction task in Experiment 3.2 (mean accuracy=62.33%). Reduced performance for the odour study decreases concern with respect to participants learning the order presentation of the odours for each testing procedure. That is, if participants were at ceiling one might hypothesise that this is due to the learning of testing procedure orders. Since the learning of testing procedure orders was not a concern, a within-subjects design was employed, wherein participants performed both the articulatory suppression and quiet conditions. Indeed, in a 4-odour modified-reconstruction pilot study (see Appendix 3, Experiment 3) mean performance levels (mean recall = 45.89%), although increased, remained substantially lower than that for the visual modality (62.33%). Moreover, when first half (mean recall accuracy=44.56%) and second half (mean recall accuracy=46.99%) performance was compared a non-significant difference was observed (t<1), indicating that participants were not learning the testing procedure orders.

In the present experiment the 4-odour (compared to 5-odours in Experiment 3.3) methodology was employed to increase overall performance. Low overall performance levels are a concern as close to chance performance may obscure serial position effects. Lower performance levels were predicted for two reasons. First, it was mooted that increasing ISI to 5000 ms may reduce performance as it provides greater opportunity for trace decay. Second, the additional task of articulatory suppression may reduce recall due to additional demands on attention.

A significant interaction between serial position and articulatory suppression condition provides evidence that the serial position function for odours is governed via verbal labelling. A non-significant interaction suggests that verbal labelling does not determine the shape of the serial position function.

Method

Participants. Twenty-four (3 male and 21 female: mean age 20 years and 7 months, 22 non smokers) Cardiff University volunteer from a variety of disciplines participated in exchange for £7.00 honorarium. None had participated in the previous modified-reconstruction experiments. Participants suffering from a cold or blocked nose were excluded.

Materials. Seventy two odours were selected at random from the 120 odours described in Experiment 1.1.

Design. The design was as described in Experiment 4.1 and included the addition that participants performed both the articulatory suppression and quiet conditions. . Therefore, a 2x3x4 within-subjects factorial design was adopted wherein the counterbalanced condition of articulatory suppression or quiet was performed on Day 1 and Day 2.

Procedure. The procedure was as described in Experiment 3.3 and included the exception that a 5000 ms ISI was employed during the presentation phase. The presentation phase reflected that of Miles and Hodder (2005, Experiment 6) in which participants either remained silent throughout the 5000 ms ISI or performed the articulatory suppression task (repetition of the word "the" throughout the interval at a rate of approximately 2-3 repetitions per second). Additionally, participants returned on the following day and performed the same task but completing the opposite condition to that of Day 1.

Results

Serial position analysis

Mean correct recall following the forward and backward testing procedures for the non-articulatory suppression condition are demonstrated in Figure 4.3a and the articulatory suppression condition is demonstrated in Figure 4.3b. A 3-factor (2x2x4) within-subjects ANOVA was computed whereby the first factor represents suppression condition (articulatory suppression versus quiet), the second factor represents testing procedure (forward versus backwards) and the third factor represents serial position (1-4). Recall for the quiet condition was significantly higher than that of the articulatory suppression condition, $F(1,23)=5.70$, $MSe=2.85$ (quiet condition mean correct recall = 49.83%; articulatory suppression condition mean correct recall = 42.59%). A non-significant main effect of testing procedure was found, $F=1.17$ (forward mean correct recall = 47.92%; backward mean correct recall = 44.5%), and a main effect of serial position, $F(3,69)=14.96$, $MSe=1.48$. Although a main effect of articulatory suppression was found, crucially, there was no interaction between articulatory suppression condition and serial position, $F<1$, or a three-way interaction between articulatory suppression, testing procedure and serial position, $F=1.02$. This finding indicates that the act of articulatory suppression did not qualitatively alter the serial position function.

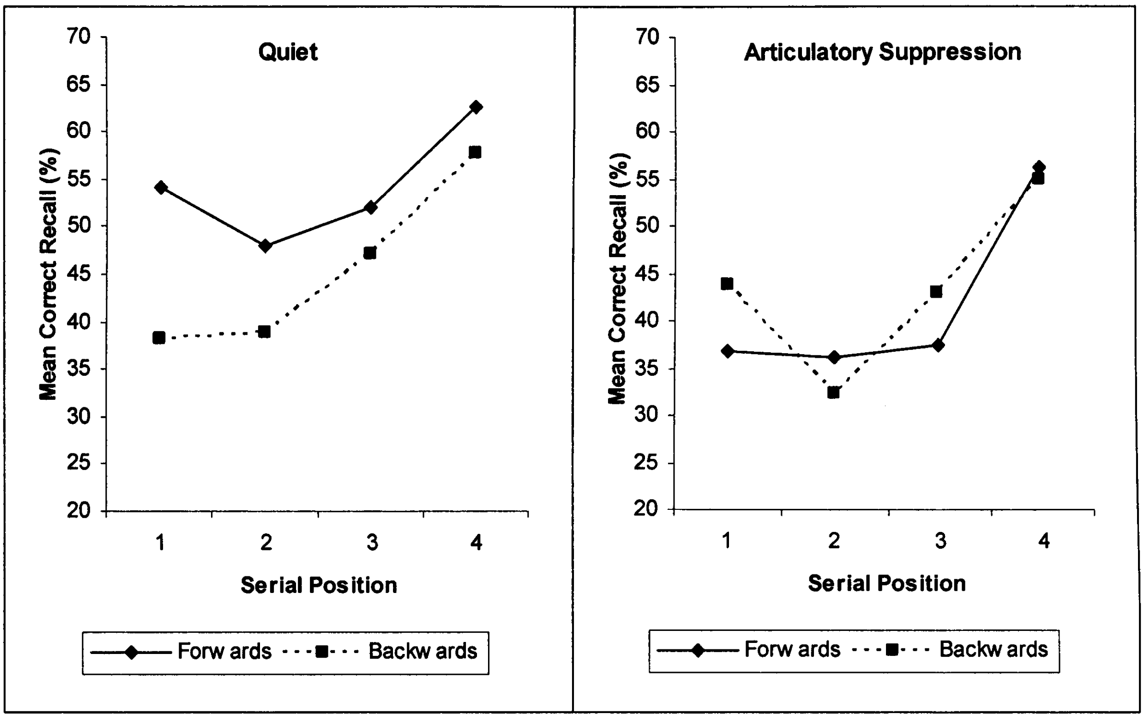


Figure 4.3(a-b): Mean percentage correct recall for the quiet (a) and articulatory suppression conditions (b) following the forward and backward testing procedures and as a function of serial position.

The effect of articulatory suppression on forward modified-reconstruction was more closely analysed. Figure 4.4 demonstrates the mean percentage correct recall for forward modified-reconstruction of odours following the quiet and articulatory suppression conditions. A 2-factor (2x4) within-subjects ANOVA was conducted on the forward testing procedure only to assess the independent effect of articulatory suppression (quiet versus articulatory suppression) on the serial position function (1-4). Recall for the quiet condition (mean correct recall =54.17%) was significantly greater than the articulatory suppression condition (mean correct recall = 41.67%), $F(1,23)=10.58$, $MSe=2.84$. A main effect of serial position was found, $F(3,69)=10.62$, $MSe=1.12$, but crucially, a significant interaction between serial position and articulatory suppression was not present, $F<1$. The finding indicates that although the act of articulatory suppression reduced overall performance level, the shape of the function was not qualitatively altered. That is, when any opportunity for verbal labelling/rehearsal is eliminated, a qualitatively equivalent function is produced.

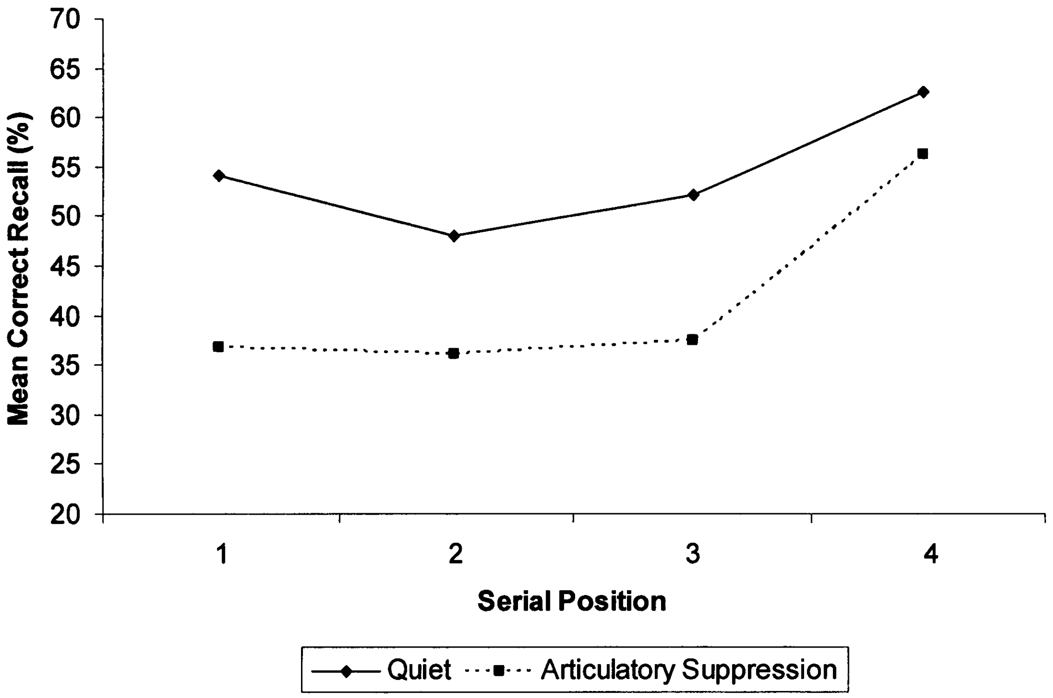


Figure 4.4: Mean percentage correct recall following forward modified-reconstruction of odours for the quiet and articulatory suppression conditions as a function of serial position.

Trend Analysis:

Trend analyses were conducted to further assess the extent of serial position function similarity between forward modified-reconstruction of odours performing quiet/articulatory suppression during presentation.

> **Quiet during presentation phase**: Significant quadratic, $F(1,23)=34.24$, MSe=1.75, and non-significant linear components, $F=1.92$, were found.

> **Articulatory suppression during presentation phase:** Both significant quadratic, $F(1,23)=4.24$, $MSe=1.93$, and significant linear components were found.

The trend analysis indicates that qualitatively different functions were produced for the forward testing procedure under articulatory suppression during the presentation phase compared to when quiet. A significant quadratic and non-significant linear component for the quiet condition indicates a bowed serial position function. This was not found for the articulatory suppression condition.

Primacy and Recency Analysis

A further analysis of primacy and recency was conducted upon the serial position function following forward modified-reconstruction of odours. This analysis is described in the Statistical Methodology section (Chapter 2).

Quiet during presentation phase: A non-significant difference was found between recall at serial position 1 (mean recall = 54.12%) and the mean of positions 2-3 (mean recall = 50.00%), t=1.09. Recall at serial position 4 (mean recall = 62.5%) was significantly greater than the mean of positions 2-3, $t(23)$=2.69, p<.05.

Articulatory suppression during presentation phase: A non-sigificant difference was found between recall at serial position 1 (mean recall = 36.81%) and the mean of positions 2-3 (mean recall = 36.81%), t=0. Recall at serial position 4 (mean recall = 56.25%) was significantly greater than the mean of positions 2-3, $t(23)$=3.39, p<.05.

This additional analysis demonstrated that recency but not primacy was present following forward modified-reconstruction of odours employing quiet and articulatory suppression during the presentation phase.

Discussion

The three serial position function analyses (serial position, trend and primacy/recency analysis) generally suggested that the forward modified-reconstruction serial position function for 4-odour sequences is qualitatively equivalent following either quiet or articulatory suppression during the presentation phase. The main effect of articulatory suppression can be explained via two possible accounts. First, performing the concurrent articulatory suppression task might employ additional cognitive resources and therein increase task difficulty. Second, participants are employing an additional verbal based strategy. If such a verbal-based strategy is being employed, it seems likely that verbalisation is a facilitative strategy rather than performance of the task being uniquely reliant upon verbal labelling. The facilitative role of verbal labelling is indicated via participants being capable of performing the task following blocking of articulation and via the finding that articulatory suppression did not qualitatively alter the serial position function.

The absence of an interaction between serial position and quiet/articulatory suppression is consistent with both Reed (2000) and Miles and Hodder (2005). In these studies articulatory suppression is found to reduce overall 2AFC recognition performance but not qualitatively change the serial position function.

It should be noted that the main effect of articulatory suppression is in contradiction to Experiment 4.1. In that experiment a non-significant difference was found between forward modified-reconstruction of unfamiliar-faces following quiet, articulatory suppression and finger-tapping during the presentation phase. One might argue this to be evidence of qualitative differences in visual and olfactory memory. However, in Experiment 4.2 increased ISIs (5000 ms ISI to allow articulation between odours) were employed, thereby fundamentally changing the nature of the task compared to unfamiliar-faces in Experiment 4.1.

There is one important caveat to the proposal that forward modified-reconstruction of odours produces qualitatively equivalent functions for quiet and articulatory suppression conditions. The quiet condition revealed a significant quadratic component whereas the articulatory suppression condition produced both significant quadratic and linear components. On viewing Figure 4.4, one might argue that this difference is governed by the primacy component wherein primacy is more pronounced in the quiet condition. Such pronounced primacy might induce greater curvature in that data producing the bowed function illustrated by the quadratic but not linear function.

Indeed, the effect of articulatory suppression appeared to impact the primacy and recency components disproportionately (i.e. recall at position 1 decreased by 17.37%, whereas recall at position 4 decreased by 6.25%). This shift is consistent with the finding of Reed (2000, Experiment 5) following articulatory suppression for the

2AFC recognition paradigm. Within this experiment, recency declined by approximately 5%, whereas primacy fell approximately 20%. The finding again suggests that olfactory memory is characterised by recency for both 2AFC recognition and forward modified-reconstruction. However, the observation of primacy is a verbal-induced artificial effect not indicative of olfactory STM.

In summary, Experiment 4.2 demonstrated that participants can perform the modified-reconstruction task when articulation is restricted. That is, participants are capable of recalling the order of odours without verbal labelling. The findings generally indicate that articulatory suppression did not qualitatively impact the serial position function. However, articulatory suppression did reduce overall performance levels suggesting that an additional verbal elaboration strategy may be employed.

Experiment 4.3

In Experiments 4.1 and 4.2 verbal labelling during modified-reconstruction of unfamiliar-faces and odours, respectively, has been restricted. Such a manipulation prevented the recoding of stimuli into verbal representations in order to determine the function characterised uniquely by visual and olfactory stimuli. In Experiments 4.3(a-d) the modified-reconstruction function produced for verbal stimuli was investigated.

Ward et al. (2005) argued that the serial position function is task, rather than modality, dependent. They found that serial order reconstruction of sequences of both unfamiliar-faces and nonwords produced equivalent functions, i.e. both primacy and recency were present. The following series of experiments (Experiments 4.3a-d) investigated the extent to which verbal stimuli (e.g. nonwords) produce equivalent modified-reconstruction functions to that previously demonstrated for non-verbal stimuli.

There is, therefore, a four-point rationale for the application of nonwords to the modified-reconstruction paradigm. First, Experiment 4.1 and 4.2 demonstrated the modified-reconstruction functions produced for odours and unfamiliar-faces when verbalisation is restricted. Similar to the olfactory and face stimuli previously employed, nonwords are unfamiliar but differ with respect to verbalisation.

Experiment 4.3(a-d) investigated the impact of employing stimuli that can be verbally coded. More specifically, does verbal coding qualitatively alter the modified-reconstruction function? Second, Ward et al. (2005) demonstrated serial reconstruction of nonwords produced a bowed serial position function. Experiment 4.3(a-d) investigated the extent to which this function was replicated for the forward modified-reconstruction paradigm. Third, Ward et al. (2005) demonstrated that stimuli type (unfamiliar-faces or nonwords) did not qualitatively alter the serial position function. Experiment 4.3(a-d) investigated the extent to which this finding was replicated with the modified-reconstruction paradigm. Nonword functions in the present data were compared with the functions produced in previous modified-reconstruction experiments. Fourth, Ward et al. (2005) investigated cross-stimuli equivalence of visual stimuli only (unfamiliar-faces and nonwords presented visually). Experiment 4.3(a-d) expanded this domain to investigate equivalence across visual and aural presentation of nonwords.

Ward et al. (2005) found that sequence length (4-, 5- and 6-items) did not affect the serial position function of serial order reconstruction of nonwords. In Experiment 4.3(a-d) sequences of 5- and 6-nonwords (presented visually and aurally) were employed to check equivalence across sequence length for the modified-reconstruction paradigm. The four experiments are reported together as methodologies were the same with the exception of sequence length and method of presentation.

A non-significant interaction between serial position and modality of presentation provides evidence that qualitatively equivalent functions are produced following aural and visual nonword presentation. A significant interaction suggests that different functions are produced for the visual and aural modality and that the stimuli are processed separately/differently.

Method

Participants. There were twenty-four participants in each experiment. All were Cardiff University undergraduate volunteers from a variety of disciplines. All reported normal hearing and participated in exchange for £3.00 honorarium.

Participants were restricted from participating in more than one of the four experiments. Details of the participants are:

Experiment 4.3a (visual, 5-item sequences): 8 males and 16 females (mean age 23 years and 2 months).
Experiment 4.3b (aural, 5-item sequences): 9 males and 15 females (mean age 21 years and 9 months).
Experiment 4.3c (visual, 6-item sequences): 4 males and 20 females (mean age 21 years and 11 months).
Experiment 4.3d (aural, 6-item sequences): 5 males and 19 females (mean age 22 years and 6 months).

Materials. A corpus of 143 nonwords was created using the same construction method as reported by Ward et al (2005). Single syllable nonwords were initiated by employing one of 32 initial consonants (or multiple consonant) e.g. "b", "cl", "m", "pr", "st", "z". These consonant(s) were then combined with one of 9 vowel sounds, such as "a", "oo", "u", "ie". The words were completed with one of 39 consonant (multiple consonant) endings, e.g. "dge", "tch", "g", "sh", "x".

As described by Ward et al. (2005) constraints were imposed to limit the formation of peculiar or familiar sounding words. First, a single terminal consonant was always employed when the vowel sound comprised more than one letter. Second, a single letter vowel sound was always employed when the word ended with a consonant cluster. These constraints were proposed by Ward et al. in order to prevent the formation of idiosyncratic letter combinations such as "broodge". Third, words were excluded from the corpus if they were known English words, or when presented aurally sounded identical to known English words. The corpus of nonwords is available in Appendix 2.

In Experiment 4.3a and 4.3c the nonwords were presented visually and displayed centrally on the computer screen in Times New Roman font size 100. In Experiments 4.3b and 4.3d, the nonwords were transformed into a single MP3 auditory file using the text-to-speech program IE speaker. The auditory file was then edited into single word files using the editing software Audacity. Nonwords were edited such that the articulation length of each did not exceed 500 ms. The nonwords were then presented by headphones at a volume of 75dB.

Design. The design closely followed previous modified-reconstruction experiments (Experiments 3.2-3.5 and 4.1-4.2). As in previous modified-reconstruction experiments, participants were presented with 18 trials. There were six trials for each of the forward, backward and control testing procedures, and included the proviso that 2 or more consecutive trials were not of the same testing procedure. Sequence content was randomised but included the proviso that no sequence contained nonwords that began with the same letter.

Procedure. The procedure followed that described for unfamiliar faces in Experiment 3.2, with two exceptions. First, at presentation each nonword was presented either in the centre of the screen or via the headphones. Second, each nonword had an on time of 500ms and a 500ms ISI.

Results

Serial Position Analysis

Figure 4.5(a-d) demonstrates the mean percentage correct recall following the forward and backward testing procedures of sequence of 5- and 6-nonwords presented visually (a. and c.) and aurally (b. and d.).

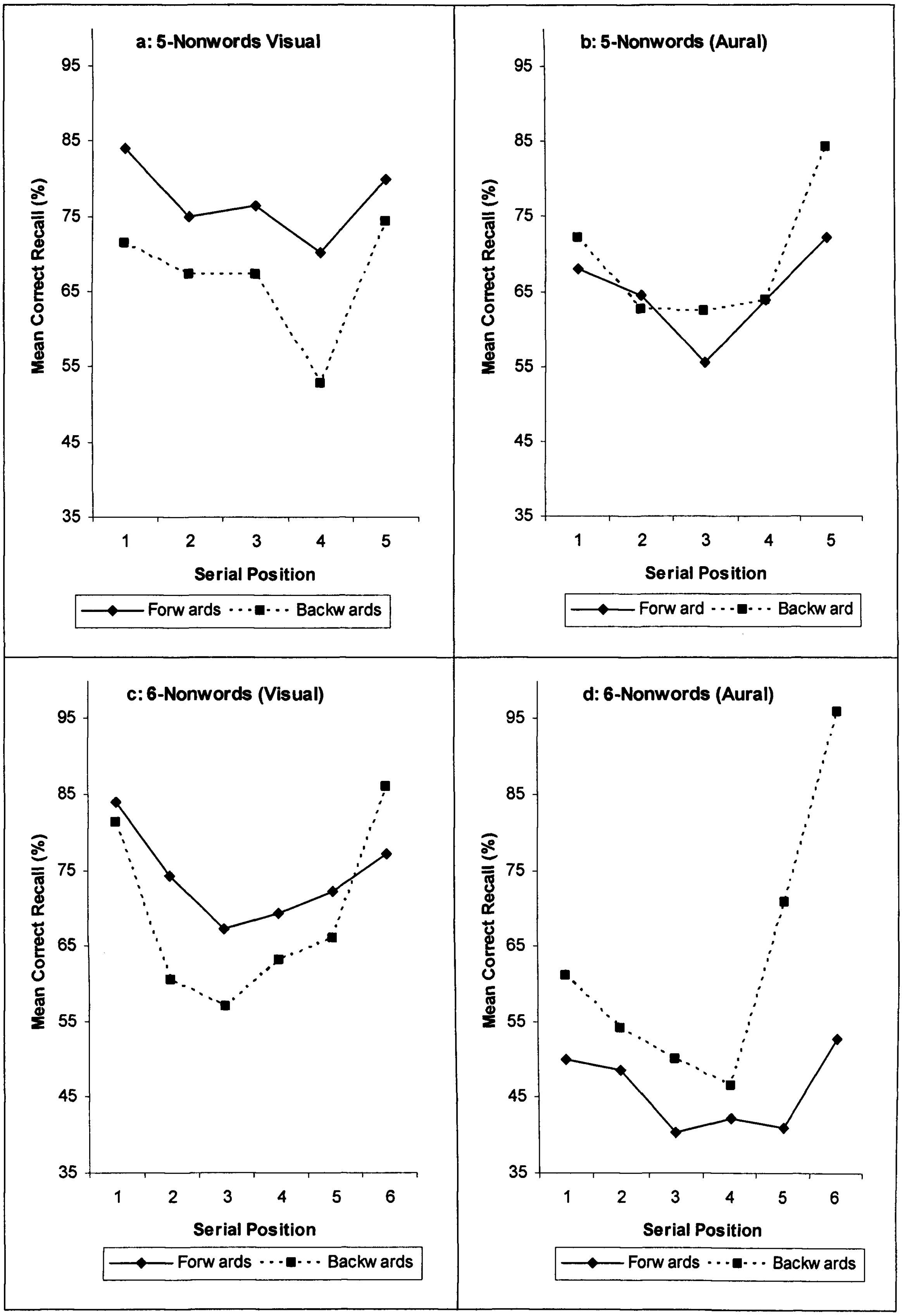


Figure 4.5(a-d): Mean percentage correct recall for 5-nonwords presented visually (a) and aurally (b) and 6-nonwords presented visually (c) and aurally (d) following

modified-reconstruction for the forward and backward testing procedures as a function of serial position.

A 2-factor within-subjects ANOVA was conducted on the data for each of the four experiments. The first factor represents the testing procedure (forward or backward) and the second factor represents serial position.

5-nonwords (visual): there was a main effect of testing procedure, $F(1,23)=14.27$, $MSe=1.78$ (forward mean correct recall = 77.08%; backward mean correct recall = 66.67%), and a significant main effect of serial position, $F(4,92)= 8.66$, $MSe=0.80$. The interaction between testing procedure and serial position was non-significant, $F=1.47$. Further analysis (Newman Keuls) of the main effect of serial position revealed that recall at positions 1, 2, 3 and 5 was significantly greater than that at position 4.

5-nonwords (aural): there was a non-significant main effect of testing procedure, $F=2.07$ (forward mean correct recall = 64.86%; backward mean correct recall = 69.09%), and a main effect of serial position, $F(4,92)=8.62$, $MSe=1.04$. The interaction between testing procedure and serial position was non-significant, $F=1.90$. Further analysis (Newman Keuls) of the main effect of serial position revealed that recall at serial position 5 was significantly greater than that of positions 1, 2, 3 and 4. Additionally, recall at serial position 1 was significantly greater than that at position 3.

6-nonwords (visual): there was a non-significant main effect of testing procedure, $F=1.86$ (forward mean correct recall = 74.07%; backward mean correct recall = 68.98%), and a main effect of serial position, $F(4,92)=12.14$, $MSe=1.03$. Together with a significant interaction, $F(5,115)=3.95$, $MSe=0.69$. Further analysis (Newman Keuls) of the interaction revealed that for the forward testing procedure recall at serial position 1 was significantly greater than that of positions 3 and 4. For the backward testing procedure recall at both serial positions 1 and 6 was significantly greater than that at positions 2, 3, 4 and 5. Comparisons across the forward and backward testing procedures revealed no significant differences at any of the serial positions.

6-nonwords (aural): there was a significant main effect of testing procedure, $F(1,23)=24.46$, $MSe=3.15$ (forward mean correct recall = 45.8%; backward mean correct recall = 63.08%), and a main effect of serial position, $F(5,155)=17.57$, $MSe=1.17$. Together with a significant interaction, $F(5,115)=10.90$, $MSe=0.97$. Further analysis (Newman Keuls) of the interaction revealed that for the forward testing procedure no significant differences between serial positions. For the backward testing procedure recall at serial position 6 was significantly greater than that at positions 1, 2, 3, 4 and 5. Recall at serial position 5 was significantly greater than that at positions 2, 3 and 4. Recall serial at position 1 was significantly greater than that at position 4. Comparisons across the forward and backward testing procedures revealed that recall for the backward testing procedure was significantly greater than the forward testing procedure at both positions 5 and 6.

Trend Analysis

Trend analyses were conducted to further assess the extent of serial position function similarity between the four modified-reconstruction experiments.

5-nonwords (visual): For the forward testing procedure a significant quadratic, $F(1,23)=5.61$, $MSe=0.98$, and a non-significant linear components, $F=1.92$, were found. For the backward testing procedure a significant quadratic, $F(1,23)=7.12$, $MSe=1.17$ and a non-significant linear components, $F=2.25$, were found.

5-nonwords (aural): For the forward testing procedure a significant quadratic, $F(1,23)=13.79$, $MSe=0.75$, and a non-significant linear components, $F<1$, were found. For the backward testing procedure significant quadratic, $F(1,23)=15.87$, $MSe=1.32$ and significant linear components were found.

6-nonwords (visual): For the forward testing procedure a significant quadratic, $F(1,23)=7.63$, $MSe=1.69$, and a non-significant linear components, $F=1.53$, were found. For the backward testing procedure a significant quadratic, ($F(1,23)=32.21$, $MSe=1.69$ and a borderline linear component, $F=3.42$, $p=.08$, were found.

6-nonwords (aural): For the forward testing procedure a significant quadratic, $F(1,23)=8.45$, $MSe=1.07$, and a non-significant linear components, $F<1$, were found. For the backward testing procedure both a significant quadratic, $F(1,23)=59.32$, $MSe=1.17$ and a significant linear component were found.

The trend analysis indicated that the forward testing procedure for the modified-reconstruction produced a bowed function (i.e. only a quadratic trend) for the four experiments. That is a bowed function was produced irrespective as to the mode of nonword presentation (visual/aural) or sequence length (5-6 items).

Primacy and Recency Analysis
A further analysis of primacy and recency was conducted upon the serial position function following forward modified-reconstruction of nonwords. This analysis is described in the Statistical Methodology section (Chapter 2).

5-nonwords (visual): A significant difference was found between recall at serial position 1 (mean recall = 84.03%) and the mean of positions 2-4 (mean recall = 73.84%), $t(23)=2.06$, $p<.05$. Recall at serial position 5 (mean recall = 79.86%) was borderline significantly greater than that of the mean of positions 2-4, $t(23)=2.05$, p=.05.

5-nonwords (aural): A significant difference was found between recall at serial position 1 (mean recall = 68.06%) and the mean of positions 2-4 (mean recall = 61.33%), $t(23)=2.19$, $p<.05$. Recall at serial position 5 (mean recall = 72.22%) was significantly greater than that of the mean of positions 2-4, $t(23)=2.67$, $p<.05$.

6-nonwords (visual): A significant difference was found between recall at serial position 1 (mean recall = 84.03%) and the mean of positions 2-5 (mean recall = 70.83%), $t(23)=3.14$, $p<.05$. Recall at serial position 6 (mean recall =

77.08%) was not significantly greater than that of the mean of positions 2-5, $t(23)=1.45, p=.16$.

6-nonwords (aural): A non-significant difference was found between recall at serial position 1 (mean recall = 50.00%) and the mean of positions 2-5 (mean recall = 43.06%), $t(23)=1.64, p=.11$. Recall at serial position 6 (mean recall = 52.78%) was significantly greater than that of the mean of positions 2-5, $t(23)=2.09, p<.05$.

This additional analysis demonstrated that both recency and primacy was present for forward modified-reconstruction of 5-nonwords irrespective as to mode of presentation (visual/aural). Forward modified-reconstruction of visually presented sequences of 6-nonwords revealed primacy but not recency. In contrast, modified-reconstruction of aurally presented sequences of 6-nonwords revealed recency but not primacy.

Response Distribution

A further analysis was conducted on the distribution of erroneous responses for the forward and backward testing procedure across Experiments 4.3(a-d). Consistent with previous experiments (Experiment 2.1-2.4 and Experiment 3.2-3.5) incorrect responses are, generally, more frequently allocated to adjacent serial positions. This analysis can be found in more detail in Appendix 4. The finding suggests that participants, even when incorrect, possess a vague temporal knowledge of the approximate position within a sequence. The propensity for displacement of incorrect responses to positions near the correct probe is consistent across the modalities discussed within this thesis (olfactory, visual and auditory) and suggests modal-equivalent (or at least analogous) coding mnemonics across stimuli types.

Cross-Modal Comparisons

To assess the extent to which visual and auditory presentation of nonwords produces qualitatively equivalent serial position functions, performance was compared following both 5- and 6–nonword sequences.

5-Nonword Sequences

Since overall recall scores differed for forward modified-reconstruction of 5-visually (mean recall = 77.08%) and 5-aurally presented nonwords (mean recall = 64.86%) scores were standardised to *Z*-scores. Figure 4.6(a-b) demonstrate the mean correct recall and mean *Z*-score correct following visual and aural presentation of 5-nonword sequences. A 2-factor (2x5) between subjects ANOVA was computed, where the first factor represents modality (visual versus aural) and the second factor represents serial position (1-5). The ANOVA revealed a null effect of modality, $F<1$, and a significant main effect of serial position, $F(4,184)=5.48$, $MSe=0.44$). The interaction was non-significant, $F=2.14$.

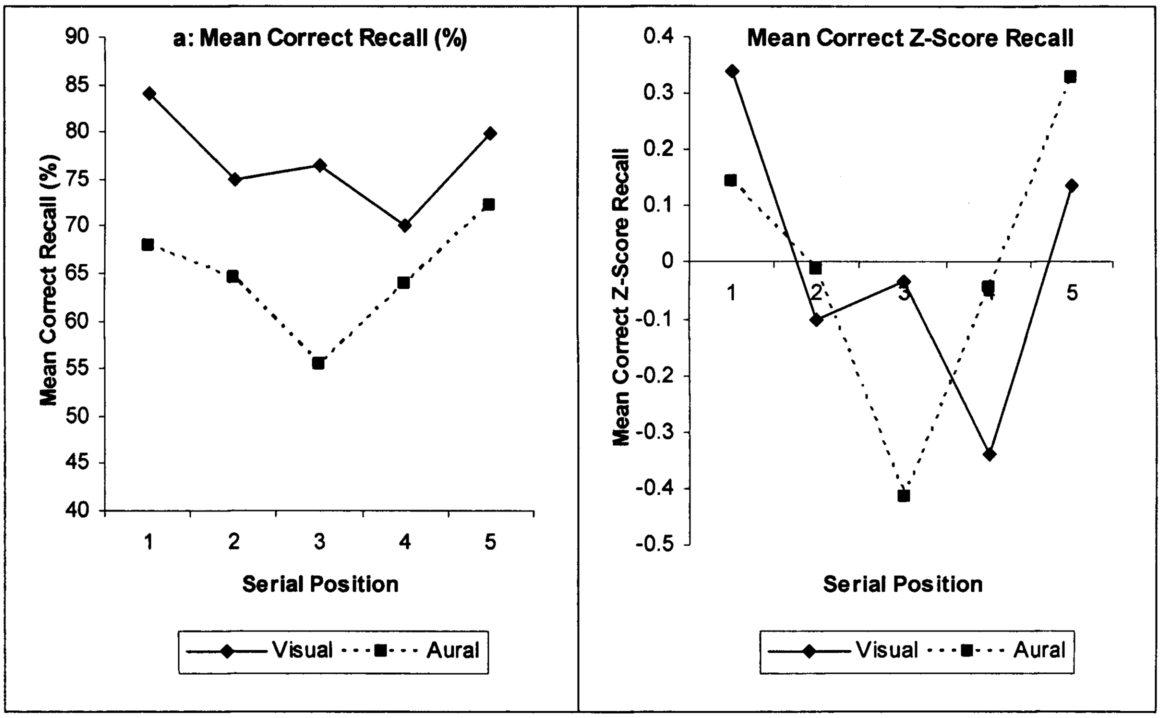


Figure 4.6(a-b): Mean percentage correct recall (a) and mean correct *Z*-score recall (b) following forward modified-reconstruction of sequences of 5-nonwords presented visually and aurally as a function of serial position.

6-Nonword Sequences

Since overall recall scores differed for forward modified-reconstruction of 6-visually (mean recall = 74.07%) and 6-aurally presented nonwords (mean recall = 45.8%) scores were standardised to *Z*-scores. Figure 4.7(a-b) demonstrate the mean correct recall and mean *Z*-score correct following visual and aural presentation of 6-nonword sequences. A 2-factor (2x6) mixed design ANOVA was computed, where the first factor represents modality (visual versus aural) and the second factor represents serial position (1-6). The ANOVA revealed a null effect of modality, $F<1$, and a significant main effect of serial position, $F(5,230)=3.69$, $MSe=0.50$). The interaction was non-significant, $F=1.67$.

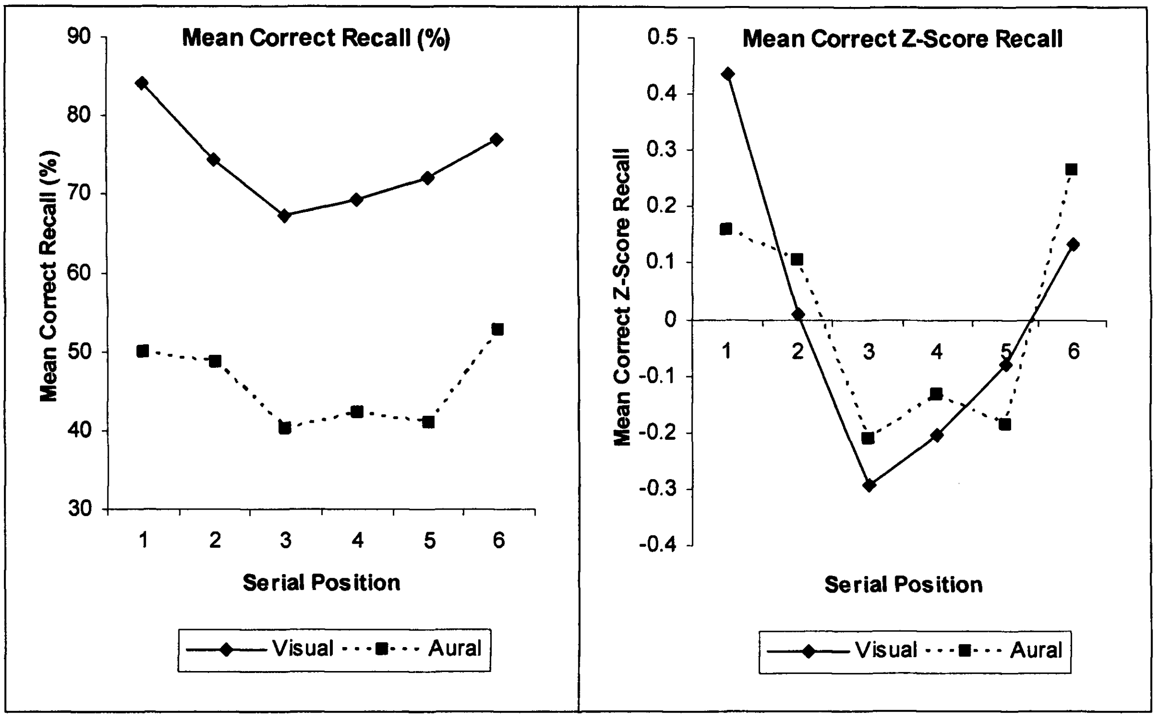


Figure 4.7(a-b): Mean percentage serial position recall (Figure a) and mean standardised *Z*-score recall (Figure b) following forward modified-reconstruction of visual and aurally presented nonwords as a function of serial position.

Discussion

In general Experiment 4.3(a-d) provided evidence that the serial position function produced for forward modified-reconstruction for nonwords is qualitatively equivalent irrespective of presentation mode (visual or aural). Forward modified-reconstruction for nonwords produced a quadratic component for 5- and 6-sequences of both visually and aurally presented nonwords. Such trends are indicative of a bowed serial position function. Furthermore, a cross-modal comparison between visual and aural presentation at each sequence length revealed close concordance following *Z*-score standardisation.

In Chapter 5 it was argued that the observed cross-model serial position function differences between odours and unfamiliar-faces may be due to stimuli-specific differences rather than modality per se. In Experiment 4.3 the same stimuli were employed for both modalities (i.e. the same nonwords were employed) and only modality of presentation was manipulated. This allowed one to assess the effect of modality independently of stimuli-specific characteristics. This manipulation revealed functional equivalence between nonwords presented visually and aurally.

The primacy/recency analysis revealed that for 5-nonword sequences, forward modified-reconstruction of both visually and aurally presented nonwords produced primacy and recency. Such a finding is consistent with a bowed function. However, applying the same analysis to 6-nonword sequences, the visual condition produced primacy and not recency, whereas the aural condition produced recency and not primacy. The finding indicates some evidence of cross-modal dissociation at the serial position terminals for 6-nonword sequences. However, it should be noted that a significant interaction was not found between modality of presentation and serial position for 6-nonword sequences, F=1.67.

Experiment 4.3(a-d) demonstrated that forward modified-reconstruction for nonwords produced an equivalent function to that demonstrated for serial order reconstruction of 4-, 5- and 6-nonwords (Ward et al., 2005, Experiment 3). Both Ward et al. and the present experiment revealed a bowed function for nonwords. Furthermore, Ward et al. (2005) demonstrated qualitatively equivalent serial position functions for serial order reconstruction of nonwords and unfamiliar-faces. This cross-stimuli consistency has been replicated in the current experiment for the forward modified-reconstruction task. Application of this paradigm has revealed a bowed function for both nonwords (Experiment 4.3) and unfamiliar-faces (Experiment 3.2). Experiment 4.3(a-d) has expanded the serial position functional equivalence reported by Ward et al. between visually presented nonwords and unfamiliar-faces to include nonwords presented aurally.

Although serial position functions are broadly qualitatively equivalent following visual and aural presentation of nonwords, it should be noted that the modality of presentation induced quantitatively different performance levels. Recall is substantially greater for forward modified-reconstruction of the visual (mean correct recall = 75.58%) compared to the aural modality (mean recall = 55.13%). This difference indicated that either disparities in presentational methods induced performance differences, or, the modal-specific memorial mechanism for auditory stimuli is inferior to that of a visual memory system.

The effect of list-length appears to impact visual and aural forward modified-reconstruction differentially. Recall following forward modified-reconstruction of aurally presented nonwords is significantly higher for 5-item sequences (mean recall accuracy = 64.86%) compared to 6-item sequences (mean recall accuracy = 45.83%), $t(46)=3.35, p<.05$). However, there is a non-significant difference between 5-item (mean recall accuracy = 77.08%) and 6-item list (mean recall accuracy = 74.07%) recall levels for forward modified-reconstruction of visually presented nonwords ($t<1$). The finding indicates that list length differentially impacted the visual and aural modalities.

The non-significant effect of list length for visually presented nonwords is also inconsistent with Ward et al. (2005, Experiment 3) who found that reconstruction of serial order for sequences of 4-, 5- and 6-nonwords all significantly differed in performance levels. The absence of a list-length effect for forward modified-reconstruction of visually presented nonwords indicates cross-paradigm differences between serial order reconstruction and forward modified-reconstruction.

Furthermore, recall levels of 5- and 6-nonword sequences are substantially less in the Ward et al. study (approximately 70% and 50%, respectively) compared to that for forward modified-reconstruction of visually presented nonwords in the present experiment (77% and 74%, respectively). The finding suggests that the serial order reconstruction task is more cognitively taxing than that of forward modified-reconstruction. The performance disparity might be explained in terms of greater trace decay in the Ward et al. study due to the longer absolute intervals between presentation and test (in Ward et al. each word is presented for 1500 ms followed by a 500 ms ISI). This interpretation seems unlikely, especially following the employment of verbal stimuli, as the lengthened intervals provided enhanced opportunities for sub-vocal rehearsal of the list items.

However, the employment of a sub-vocal rehearsal strategy was investigated in Appendix, 3 Experiment 5. In this experiment, modified-reconstruction of 6-nonword sequences presented visually was replicated with the addition that participants performed articulatory suppression during the presentation phase. Figure 4.8(a-b) compares mean correct recall and mean correct *Z*-scores for forward modified-reconstruction of 6-visually presented nonwords following quiet (Experiment 4.3c) and articulatory suppression (Appendix 3, Experiment 5).

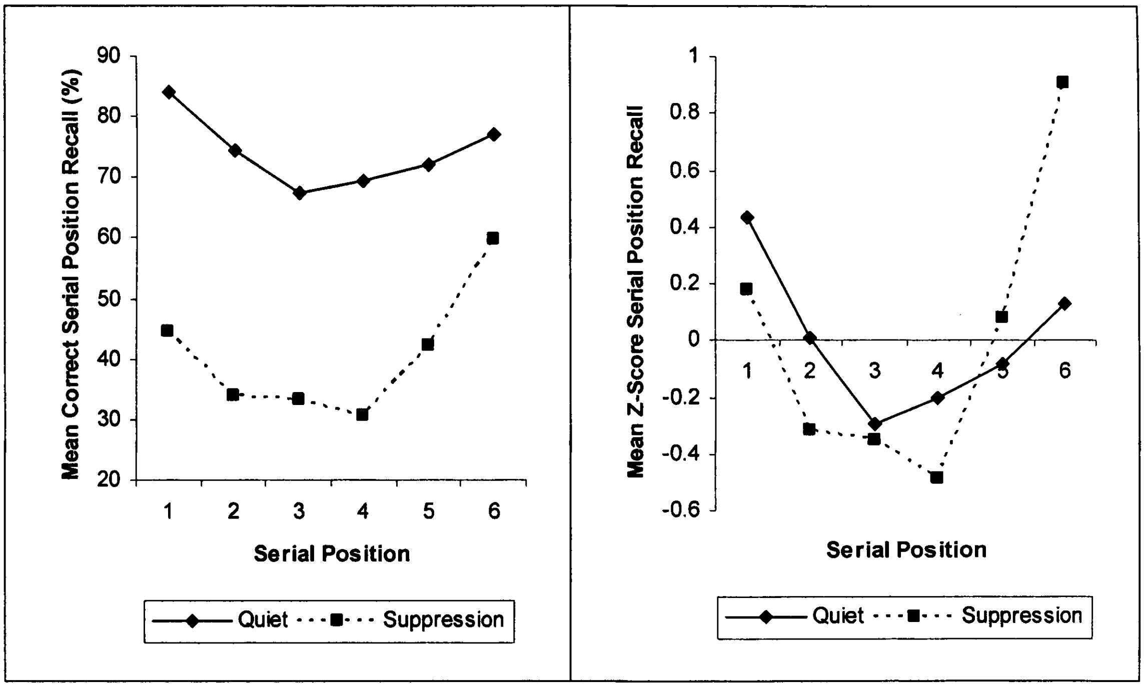


Figure 4.8(a-b): Mean percentage correct recall (a) and mean correct *Z*-score recall (b) following forward modified-reconstruction of 6-nonwords presented with quiet or articulatory suppression as a function of serial position.

The act of articulatory suppression both reduced overall recall rates and differentially affected the pre-recency portion of the function (a significant interaction between articulatory suppression and serial position was found, $F(5,230)=3.29$, $MSe=1.01$). The greater impact on earlier list items suggests that the facilitative effect of repeated rehearsal of these early list items was removed by articulatory suppression. Fewer rehearsal opportunities are available for later list items; therefore, the impact of articulatory suppression is reduced. However, it should be noted that following articulatory suppression mean recall at serial position 1 (mean correct recall = 44.44%) was significantly greater than that of the mean recall of positions 2-5 (mean correct recall = 35.07%), $t(23)=2.20$, $p<.05$. Additionally, mean recall at serial position 6 (mean recall = 59.72%) was significantly greater that of the mean recall of positions 2-5, $t(23)=6.61$, $p<.05$. This analysis demonstrates that both primacy and recency endured articulatory suppression. Such a finding indicates that verbal rehearsal was a facilitative strategy, rather than fundamental to the maintenance of verbal serial order and the U-shaped function.

In summary, Experiment 4.3 demonstrated that forward modified-reconstruction of nonwords produced a bowed serial position function following both visual and aural presentation. In the present experiment, stimuli characteristics were held constant such that only modality of presentation was manipulated. The findings suggest that amodal, or analogous mechanisms, underpin memory for items presented visually and aurally. Furthermore, this bowed function was demonstrated not to be reliant upon rehearsal, as primacy and recency was shown to be resistant to articulatory suppression.

Chapter 6 Discussion

In Chapter 6, the role of verbal coding in performance of the modified-reconstruction task was investigated. In Experiment 4.1 it was found that neither articulatory suppression nor finger-tapping qualitatively changed the forward modified-reconstruction function produced for unfamiliar-faces. Such a finding is consistent with Smyth et al. (2005) who found that the primacy observed following serial order reconstruction of unfamiliar-faces was not impaired by articulatory suppression. This finding implies that (i) unfamiliar-faces were encoded in a visual and non-verbal code and (ii) that the cross-modal discrepancy at the primacy component between unfamiliar-faces and odours (Experiments 3.2, 3.3 and 3.4) was not an artefact of unfamiliar-faces being labelled and subsequently rehearsed.

In Experiment 4.2, articulatory suppression during the presentation phase did not qualitatively alter the serial position function. Although it has been shown that top down verbal processing can facilitate odour memory (Lyman and McDaniel, 1986) and impact the olfactory perception (Distel and Hudson, 2001), Experiment 4.2 demonstrates that olfactory order memory (i) operates without verbal labels and (ii) produces a qualitatively equivalent function to when verbal labelling/reherasal is not restricted. Importantly, both Experiments 4.1 and 4.2 demonstrate that the functions produced are characteristic of visual and olfactory memory respectively rather than memory for the verbal labels of these visual and olfactory items.

In Experiments 4.1 and 4.2 functions were investigated with verbal labelling/rehearsal restricted. However, in Experiment 4.3(a-d) verbalisation was permitted with the modality of presentation manipulated. Serial order reconstruction of visually presented nonwords and unfamiliar-faces has been shown to produce qualitatively equivalent bowed functions (Ward et al., 2005). In Experiment 4.3(a-d) the investigation of functional equivalence was expanded to investigate equivalence between nonwords presented visually and nonwords presented aurally. Both presentation modalities were applied to the modified-reconstruction task and broadly produced evidence of functional equivalence across modalities for 5- and 6-nonword sequences. Unlike previous cross-modal comparisons, in Experiment 4.3, stimuli characteristics are held constant and only modality of presentation is manipulated. Therefore, any qualitative differences are modality-based rather than explicable by stimuli-specific differences. The finding indicates that analogous/identical mnemonics are employed for forward modified-reconstruction of nonwords. Furthermore, the functions are consistent with those produced for forward modified-reconstruction of unfamiliar-faces and pure-tones in Chapter 5. The preliminary indication is, therefore, that both modified-reconstruction of visual and aurally presented stimuli produce qualitatively equivalent serial position functions, i.e. primacy and recency. Consistent with Ward et al., functional equivalence is found irrespective of stimuli being verbal or non-verbal.

One might argue that the functional equivalence in Experiment 4.3 is due to both nonword modalities being converted into a verbal code and rehearsed sub-vocally. However, a pilot study (n=24) demonstrated that forward modified-reconstruction of visually presented nonwords produced an equivalent function (i.e. both primacy and recency) following articulatory suppression during the presentation phase.

Experiments 4.1-4.3 have demonstrated that verbal labelling/rehearsal did not underpin the olfactory or visual modified-reconstruction functions. However, even when verbal labelling is permitted the functions produced for visual and auditory stimuli are not qualitatively altered.

Key Findings

In Chapter 6, restriction of a verbal labelling strategy (through articulatory suppression) was found not to qualitatively impact the forward modified-reconstruction serial position function produced for unfamiliar-faces or odours. Therefore, neither the olfactory nor visual serial position functions were determined by verbal memory. Furthermore, primacy demonstrated with unfamiliar-faces was not, therefore, an artefact of verbal labelling and subsequent rehearsal. Application of verbal stimuli (nonwords, presented either visually or aurally) to the forward modified-reconstruction paradigm produced qualitatively equivalent serial position functions to that of pure-tones and unfamiliar-faces.

CHAPTER 7
GENERAL DISCUSSION

7.1 Chapter 7 Overview

Chapter 7 begins with a review of the thesis objectives. The summary of findings and their implications are then discussed. This is followed by proposals that might account for the different pattern of data observed for olfactory memory. A critique of both the theoretical basis of the thesis and methodologies employed is then provided. The Chapter closes with a final conclusion of the thesis.

7.2 Research Aims

There were four overarching aims of the thesis. First, to determine the serial position functions produced for recognition and serial position recall for olfactory stimuli. Second, to ensure that the olfactory functions were characteristic of olfactory memory rather than memory for the verbal labels of olfactory stimuli. Third, to compare these serial position functions with those produced for stimuli from the visual and auditory modalities in order to assess functional concordance and modularity. Fourth, to determine methods of analysis such that a comprehensive and reliable assessment of primacy and recency was computed.

7.2.1 Serial Position Functions. The thesis sought to clarify controversy in the literature concerning serial position effects in olfactory memory. Few studies have investigated serial order odour memory (e.g. White, 1992; White and Treisman, 1998) and when olfactory recognition has been investigated, mixed evidence has been reported. For example, Lawless and Cain (1975) and Gabassi and Zanuttini (1983, cited in White, 1992) reported an absence of serial position effects. These flat serial position functions have been used as evidence to suggest that odours are encoded qualitatively differently to that of other stimuli. For example, Engen and Ross (1973) have proposed that odours are encoded in a structure-less holistic manner. This process promotes all-or-none-encoding, wherein if successfully encoded, odours are stored as unitary items, impervious to interference. However, although Wilson and Stevenson (2006) described Lawless and Cain (1975) as immediate testing, a 10-

minutes retention interval was employed. This increased interval may have attenuated recency. In the Gabassi and Zanuttini (1983, cited in White, 1992) study, sequences of 14 odours were employed. This is substantially lower than the 5-7 odour lists usually employed in olfactory recognition tasks (e.g. Miles and Hodder, 2005; Reed, 2000; White and Treisman, 1997). It is therefore possible that a 14 odour list was greater than the olfactory span, with floor effects masking serial position effects.

More recently, serial position effects were found with single probe yes/no recognition (White, 1992; White and Treisman, 1998) and 2AFC recognition (Miles and Hodder, 2005; Reed, 2000). Both White (1992) and White and Treisman (1997) reported recency but not primacy following yes/no single probe recognition of odours. In contrast, Reed (2000) reported both primacy and recency following 2AFC recognition of odours. However, in a very close methodological replication, Miles and Hodder (2005) were unable to replicate the primacy effect, finding only recency on some of the experiments.

7.2.2 Modularity. It is unclear as to the serial position functions that characterise olfactory recognition and serial position recall. Furthermore, the different methodologies employed (e.g. single sequential 2AFC test pair for odours, Reed, 2000; a series of simultaneous 2AFC test pairs for abstract matrices, Phillips and Christie, 1977) complicate serial position function comparisons with other stimuli. Therefore, in the present thesis identical tasks were employed for the different stimuli. Indeed, it has been argued that olfactory memory operates via a stimuli-specific slave system of working memory analogous to the visuo-spatial sketchpad (Andrade and Donaldson, in press). Evidence for serial position functions that differed cross-modally would support such fractioning of memory. In contrast, Ward, Avons and colleagues (e.g. Avons, 1998; Ward et al., 2005) have proposed that the serial position function is task rather than modality dependent. Although, such a proposal does not necessitate stimuli to be processed amodally, such an account does, at least, imply that the stimuli are processed via an analogous mechanism.

7.2.3 Verbal Labelling in Olfactory Memory. Wilson and Stevenson (2006) have argued that top down processing plays an important role in olfaction (e.g. visual cues often accompany the presentation of odours). Furthermore, the labelling of odours has been shown to improve memory/discrimination. For example, nameable odours have been shown to be better recognised (Murphy et al., 1991), more intense (Distel and Hudson, 2001) and better discriminated (Rabin, 1988). Nevertheless, many studies investigating olfactory memory have required participants to associate verbal labels to the odours. These labels are then employed as the to-be-remembered items (e.g. Miles and Jenkins, 2000). Such a methodology confounds the assessment of olfactory memory. Once verbal labelling is employed, the memorial representation becomes contaminated and it is unclear the extent to which memory is underpinned through the odour or memory for a verbal label of that odour.

In the present set of studies, a large stimulus set of odours was employed in order to limit familiarity and hence, reduce verbal labelling opportunities. To date, only a relatively small number of studies have investigated olfactory 2AFC recognition (e.g. Reed, 2000; Miles and Hodder, 2005) and few have examined olfactory memory for order when not confounded by verbal labels (e.g. White and Treisman, 1997). Indeed, White and colleagues are atypical in investigating the olfactory serial position function via comparisons to other stimuli applied to the same relative recency task (White, 1992; White and Treisman, 1997). This control comparison should be employed more frequently for reasons that are twofold: first, the olfactory serial position function produced is limited theoretically if there are no baseline functions produced for the task. Second, if cross-modal comparisons are to be performed, without different modality stimuli applied to the task, any conclusions are merely conjecture, as differences/similarities may be the result of task-specific idiosyncrasies.

7.2.4 Statistical Analysis of Primacy and Recency. A further advancement in the present thesis is the use of multiple analyses to assess the presence of primacy and recency. A fundamental component of the thesis concerned the comparison between stimuli from different modalities. Qualitatively different functions across stimuli were employed as evidence that different mnemonics were utilised for the different stimuli. The statistical analyses employed may differ in the extent to which they support/oppose the presence of primacy and/or recency. For example, a significant quadratic trend component may imply curvature in the data and, therefore, the presence of both primacy and recency. However, following an ANOVA, the identical data set may fail to produce a main effect of serial position, suggesting a flat serial position function (i.e. no primacy or recency). The range of analyses employed can, therefore, determine the presence of primacy and recency and, to a certain extent, determine interpretations. If the interpretations can differ depending upon the analysis employed, interpretations may be misleading, disingenuous or both.

In the present thesis, therefore, three analyses of serial position effects were employed. First, an ANOVA was computed on the serial position data. If a significant main effect of serial position was observed, further analysis (Newman Keuls) was employed to determine the positions that significantly differed. Second, trend analyses were conducted to assess the general shape of the serial position function. Third, the first and terminal items were compared to the mean of the middle positions to assess the presence of primacy and/or recency. The employment of three analyses provided a broader representation to the reader as to the shape of the function and, more importantly, a clearer understanding as to the extent to which cross-modal functions were equivalent.

7.3 Summary of Findings and Implications

7.3.1 Experiment Summary Table. The current thesis contains a large corpus of experimental data with numerous statistical analyses. The following table is included to provide a brief summary of each experiment and key statistical findings.

Statistical Summary Table

Exp.	Stimuli	Key Manipulation(s)	List Length	On-Time/ ISI	ANOVA - Main Effect of Serial Position and post-hocs	Trend Analyses	Primacy/ Recency Analysis
1.1a	Olfactory (odours)	2AFC recognition, forward and backward testing (blocked) (2x6)	6	3000ms/ 2000ms	Serial Position (√) Forward – no sig. differences Backward – 6>1, 2 & 4. 5>1	Forward: linear (x) quadratic (x) Backward: linear (√) quadratic (x)	Forward: primacy (x) recency (x) Backward: primacy (x) recency (√)
1.1b	Olfactory (odours)	2AFC recognition, forward and backward testing (blocked) (2x6)	6	3000ms/ 2000ms	Serial Position (√) (But no post-hocs as no interaction between testing procedure and serial position)	Forward: linear (x) quadratic (x) Backward: linear (√) quadratic (√)	Forward: primacy (x) recency (x) Backward: primacy (x) recency (√)
1.2	Visual (faces)	2AFC recognition, forward and backward testing (mixed) (2x6)	6	600ms/ 400ms	Serial Position (√) Forward – no sig. differences Backward – 6>1, 2, 3, 4 & 5	Forward: linear (x) quadratic (x) Backward: linear (x) quadratic (√)	Forward: primacy (x) recency (x) Backward: primacy (x) recency (√)

Exp.	Stimuli	Key Manipulation(s)	List Length	On-Time/ ISI	ANOVA - Main Effect of Serial Position and post-hocs	Trend Analyses	Primacy/ Recency Analysis
1.3	Visual (faces)	2AFC recognition, forward and backward testing (mixed), sequential and simultaneous test-pair presentation (2x2x6)	6	600ms/ 400ms	Sequential: Serial Position (√) Forward - no sig. differences Backward – 6>1-5	Sequential Forward: linear (x) quadratic (x)	(NB not reported in main text) Sequential Forward: primacy (x) recency (x)
						Sequential Backward: linear (√) quadratic (x)	Sequential Backward: primacy (x) recency (√)
					Simultaneous: Serial Position (√) Forward - no sig. differences Backward – 6>1-5 1 & 2>5	Simultaneous Forward: linear (x) quadratic (x)	Simultaneous Forward: primacy (x) recency (x)
						Simultaneous Backward: linear (x) quadratic (√)	Simultaneous Backward: primacy (√) recency (√)
1.4	Auditory (tones)	2AFC recognition, forward and backward testing (mixed) (2x6)	6	600ms/ 400ms	Serial Position (√) Forward – no sig. differences Backward – 6>1, 2, 3, 4 & 5	Forward: linear (x) quadratic (x)	Forward: primacy (x) recency (x)
						Backward: linear (√) quadratic (√)	Backward: primacy (x) recency (√)

Exp.	Stimuli	Key Manipulation(s)	List Length	On-Time/ ISI	ANOVA - Main Effect of Serial Position and post-hocs	Trend Analyses	Primacy/ Recency Analysis
2.1a	Olfactory (odours)	Single-probe serial position recall	4	1000ms/ 1000ms	Serial Position (x)	linear (x) quadratic (x)	primacy (x) recency (x)
2.1b	Olfactory (odours)	Single-probe serial position recall	5	1000ms/ 1000ms	Serial Position (x)	linear (x) quadratic (x)	primacy (x) recency (x)
2.1c	Olfactory (odours)	Single-probe serial position recall	6	1000ms/ 1000ms	Serial Position (x)	linear (x) quadratic (x)	primacy (x) recency (x)
2.2a	Visual (faces)	Single-probe serial position recall	4	1000ms/ 1000ms	Serial Position (√) 4>1, 2 & 3 1>2	linear (√) quadratic (√)	primacy (√) recency (√)
2.2b	Visual (faces)	Single-probe serial position recall	5	1000ms/ 1000ms	Serial Position (√) 5>1, 2, 3 & 4 1 & 2> 3 & 4	linear (x) quadratic (√)	primacy (√) recency (√)
2.2c	Visual (faces)	Single-probe serial position recall	6	1000ms/ 1000ms	Serial Position (√) 6>1, 2, 3, 4 & 5 1> 2, 3, 4 and 5	linear (x) quadratic (√)	primacy (√) recency (√)
2.3a	Auditory (tones)	Single-probe serial position recall	4	1000ms/ 1000ms	Serial Position (√) 4>1, 2 & 3 1 & 3>2	linear (√) quadratic (√)	primacy (x) recency (√)
2.3b	Auditory (tones)	Single-probe serial position recall	5	1000ms/ 1000ms	Serial Position (√) 5>1, 2, 3 & 4 4>1, 2 & 3	linear (√) quadratic (√)	primacy (x) recency (√)
2.3c	Auditory (tones)	Single-probe serial position recall	6	1000ms/ 1000ms	Serial Position (√) 6>1, 2, 3, 4 & 5 5>4	linear (√) quadratic (√)	primacy (x) recency (√)

Exp.	Stimuli	Key Manipulation(s)	List Length	On-Time/ ISI	ANOVA - Main Effect of Serial Position and post-hocs	Trend Analyses	Primacy/ Recency Analysis
2.4	Visual (faces)	Single-probe serial position recall (quiet and articulatory suppression conditions)	4	1000ms/ 1000ms	Quiet: Serial Position (√) 1 & 4>2 & 3	Quiet: linear (x) quadratic (√)	Quiet: primacy (√) recency (√)
					Suppression: Serial Position (√) 4>1, 2 & 3 1>2 & 3	Suppression: linear (√) quadratic (√)	Suppression: primacy (√) recency (√)
3.1	Visual (faces)	Serial order reconstruction	7	750ms/ 500ms	Serial Position (√) 1>1-6 7>2, 3, 4, 5 & 6 2>4 & 5	linear (√) quadratic (√)	primacy (√) recency (√)
3.2	Visual (faces)	Serial order modified-reconstruction (forward testing is reported only)	7	750ms/ 500ms	Serial Position (√) 7>3, 4, 5 & 6 1>3, 4 & 5 2>4 & 5	linear (x) quadratic (√)	primacy (√) recency (√)
3.3	Olfactory (odours)	Serial order modified-reconstruction (forward testing is reported only)	5	3000ms/ 2000ms	Serial Position (√) 5>1-4	linear (x) quadratic (√)	primacy (x) recency (√)
3.4	Visual (faces) & Olfactory (odours)	Serial order modified-reconstruction (forward testing is reported only)	6	1000ms/ 1000ms	Visual: Serial Position (√) 1>3, 4 & 5	Visual: linear (√) quadratic (x)	Visual: primacy (√) recency (x)
					Olfactory: Serial Position (√) 6>2 & 3	Olfactory: linear (x) quadratic (x)	Olfactory: primacy (x) recency (√)
3.5a	Auditory (tones)	Serial order modified-reconstruction (forward testing is reported only)	4	500ms/ 500ms	Serial Position (√) No sig. differences	linear (x) quadratic (x)	primacy (x) recency (x)

Exp.	Stimuli	Key Manipulation(s)	List Length	On-Time/ ISI	ANOVA - Main Effect of Serial Position and post-hocs	Trend Analyses	Primacy/ Recency Analysis
3.5b	Auditory (tones)	Serial order modified-reconstruction (forward testing is reported only)	5	500ms/ 500ms	Serial Position (√) 1>3 & 4 2>4	linear (x) quadratic (√)	primacy (√) recency (x)
3.5c	Auditory (tones)	Serial order modified-reconstruction (forward testing is reported only)	6	500ms/ 500ms	Serial Position (√) 1, 2 & 6>3, 4 & 5	linear (x) quadratic (√)	primacy (√) recency (√)
3.5d	Auditory (tones)	Serial order modified-reconstruction (forward testing is reported only)	7	500ms/ 500ms	Serial Position (√) 1 & 7>2-6	linear (x) quadratic (√)	primacy (√) recency (√)
4.1	Visual (faces)	Serial order modified-reconstruction (forward testing is reported only). Between-subjects articulatory suppression and finger-tapping.	7	750ms/ 500ms	A non-significant interaction between forward modified-reconstruction of faces with quiet, articulatory suppression and finger-tapping was found. Indicates function equivalent to that reported for Experiment 3.2.	Suppression: linear (x) quadratic (√) Tapping: linear (x) quadratic (√)	Suppression: primacy (√) recency (√) Tapping: primacy (√) recency (√)

Exp.	Stimuli	Key Manipulation(s)	List Length	On-Time/ ISI	ANOVA - Main Effect of Serial Position and post-hocs	Trend Analyses	Primacy/ Recency Analysis
4.2	Olfactory (odours)	Serial order modified-reconstruction (forward testing is reported only). Within-subjects quiet and articulatory suppression during presentation phase.	4	3000ms/ 5000ms	Main effect of serial position but no interaction between quiet and articulatory suppression indicating that AS did not qualitatively change the function.	Quiet: linear (x) quadratic (√) Suppression: linear (√) quadratic (√)	Quiet: primacy (x) recency (√) Suppression: primacy (x) recency (√)
4.3a	Visual (nonwords)	Serial order modified-reconstruction (forward testing is reported only)	5	500ms/ 500ms	Serial Position (√) 1, 2, 3 & 4>5	linear (x) quadratic (√)	primacy (√) recency (√)
4.3b	Auditory (nonwords)	Serial order modified-reconstruction (forward testing is reported only)	5	500ms/ 500ms	Serial Position (√) 5>1, 2, 3 & 4	linear (x) quadratic (√)	primacy (√) recency (√)
4.3c	Visual (nonwords)	Serial order modified-reconstruction (forward testing is reported only)	6	500ms/ 500ms	Serial Position (√) 1>3 & 4	linear (x) quadratic (√)	primacy (√) recency (x)
4.3d	Auditory (nonwords)	Serial order modified-reconstruction (forward testing is reported only)	6	500ms/ 500ms	Serial Position (√) No sig. differences	linear (x) quadratic (√)	primacy (x) recency (√)

Table 1: Summary of statistical results for each experiment.

7.3.2 Modularity. In the present thesis Experiments 1.1-1.4 investigated item memory whereas Experiments 2.1-2.4, 3.1-3.5 and 4.1-4.3 investigated order memory. In Chapter 3, the item-based task (2AFC recognition) produced recency but not primacy following the backward testing procedure (consistent with Phillips and Christie, 1997; Ward et al, 2004) and an absence of serial position effects following the forward testing procedure (consistent with Avons, 1998; Avons and Mason, 1999). These functions were found with odour (Experiment 1.1a-b), unfamiliar-face (Experiment 1.2) and pure-tone stimuli (Experiment 1.4). Equivalent functions across stimuli suggest that the items are being processed amodally, or at least analogously. In contrast, qualitatively different serial position functions were shown following the order-based tasks. In Chapter 4, employing the single-probe serial position recall task, unfamiliar-faces showed both primacy and recency, pure-tones showed recency only and, in contrast, odours demonstrated a flat function. Similarly, following the modified-reconstruction task in Chapters 5, both unfamiliar-face and pure-tone stimuli demonstrated both primacy and recency, whereas in contrast, odours demonstrated recency in the absence of primacy. Qualitatively different serial position functions support a modularity account and suggest that the stimuli are processed through stimuli-specific mechanisms. Qualitatively different functions for the order-based tasks are also inconsistent with Ward et al. (2005) who proposed that the serial position function is qualitatively determined by the task and not the stimuli. Experiments 2.1-2.4 and 3.1-3.5 demonstrated the opposite.

It is, therefore, apparent that item- and order-based memorial processes impact differentially upon arguments for modularity. This interpretation is consistent with the view of Guérard and Tremblay (under review) but inverts their proposed impact of employing item- and order-based tasks. Guérard and Tremblay (under review) argued that item-based tasks produce evidence in support of modularity, whereas order-based tasks provide evidence in favour of amodal processing. In the present thesis the reverse was observed. However, it should be noted that in their review of the literature, Guérard and Tremblay (under review) did not include olfactory memory studies.

Evidence is, therefore, apparent for qualitative equivalence between odours, unfamiliar-faces and pure-tones for item-based tasks but not for order–based tasks. It seems unparsimonious to argue that an amodal system operates for item memory but not for an order based memory. One might conclude, therefore, that an analogous cross-stimuli process operates for item memory but not for order memory. The question remains as to why olfaction should operate analogously with visual and auditory memory for an item-based task but not for an order-based task.

7.3.3 Limited Olfactory Familiarity with Order-Based Tasks. One possible empirically testable hypothesis is that olfaction differs on order-based tasks because of a lack of familiarity with the memorial process. Intuitively, item recognition is a common process for the olfactory system wherein recognition is, for example, required to determine whether an item is edible (e.g. Wilson and Stevenson, 2006), the pleasantness of potential food (e.g. Duclaux et al., 1973, cited in Wilson and Stevenson, 2006) and whether an item could be hazardous (e.g. Rozin et al., 2000; Russell, Cummings, Profitt, Wysocki, Gilbert, and Cotmat, 1993). These tasks do not necessitate memory for order. It is, therefore, possible that serial position equivalence with respect to olfactory recognition is observed due to familiarity with the memorial process, whereas a lack of practice with olfactory order tasks induced qualitatively different functions. Indeed, Desor and Beauchamp (1974) have demonstrated that for odour differentiation at least, training can improve performance. Such a hypothesis can be empirically tested through training participants with olfactory order-based tasks. If lack of familiarity governs function differences, one might predict functions to become consistent with visual and auditory stimuli, i.e. demonstrating both primacy and recency following practice.

However, there are a number of concerns with a familiarity-based argument of this type. First, no practice-based facilitation was observed in the present experiments. That is, participants were not shown to perform better in the second half of the olfactory order experiments. However, the number of trials might merely be an insufficient number of practice trials. Indeed, Hummel, Guel, and Delank (2004) have demonstrated that individuals who work in the perfume industry possess superior odour discrimination. However, this superiority does not manifest itself following only a single day working in such an odorous environment; indicating that prolonged practice is required. Second, despite the lack of familiarity with order-based tasks, participants were still capable of performing the single-probe serial position recall and modified-reconstruction tasks at a level above that of the floor. For example, in Experiment 2.1c in which participants were required to recall the order of a 6-odour list, mean correct recall was observed at 37.4%. Performance at chance would produce recall accuracy at 16.7%. Therefore, despite a large memorial load on an olfactory order-based task that is supposedly unfamiliar, performance remains substantially above that of chance. Participants are, therefore, capable of storing the order of odours. However, it has yet to be resolved whether practice might induce an additional strategy/shift to one analogous to that employed for unfamiliar-face and pure-tone stimuli. Third, although serial position differences were observed, some memorial similarities were observed for olfactory order memory compared to that of both visual and auditory memory. For example, analogous to unfamiliar-face and pure-tone stimuli, erroneous responses for odour stimuli were most frequently allocated to adjacent serial positions (see Experiments 2.1a-c and Experiment 3.3; for detailed demonstration of response distributions see Appendix 4). Furthermore, following the single-probe serial recall task, both the odour and unfamiliar-face experiments revealed a response bias for earlier list items. These finding suggest some concordance between olfactory memory and that of visual/auditory memory despite an absence of familiarity with order based tasks. However, the role of familiarity with olfactory order-based in producing serial position function differences remains, currently, unresolved.

7.3.4 Serial Position Function Differences for Order-Based Tasks due to Chemical Sense Interference? A second possibility for differences observed in the serial position function for the olfactory order tasks compared to those for unfamiliar-faces and tones is premised upon between stimuli perceptual differences. Unlike auditory and visual perception, olfactory and gustatory cues are delivered along chemical channels (for a review see Wilson and Stevenson, 2006), wherein the chemical transmitters remain in the organ for an extended period following item presentation (anonymous reviewer). It is this prolonged presence in the sensory organ that one anonymous reviewer argued negates any cross-modal comparison, as continual interference between the olfactory stimuli both prevents the observation of primacy and produces instability in the patterns of data produced. According to this conceptualisation of olfactory memory, cross-modal disparity at the primacy component (e.g. Experiment 3.4) is due to retroactive interference experienced by the first item following subsequent list-item presentations. Such an account is not consistent with the data for three reasons.

(i) Performance is above chance for the olfactory order studies reported. This suggests that interference is not disrupting memory to such a degree that sequential memory is fundamentally compromised.

(ii) Recency but not primacy is a robust finding across the forward olfactory modified-reconstruction experiments (Experiments 3.3 and 3.4; Experiments 2 and 3, Appendix 3). According to the interference argument, primacy is not observed for odours (when observed for unfamiliar-faces) as presentation of list items retroactively interferes with the memory of the first item. However, recency is observed in the forward testing procedure despite the same number of items intervening between presentation and test for both the first and terminal item. Indeed, according to this view, one might predict recency to be less pronounced than primacy. This is because a greater cumulative number of items have been presented during the trial by the point at which the terminal item is tested. More specifically, there are a greater number of olfactory cues persisting within the organ at the point of terminal item testing and, therefore, the greatest interference potential. Despite this cumulative interference, recency is maintained

(iii) An odour-interference account might predict that the greater the number of odours that intervene between presentation and test, the greater the interference and, therefore, the lower the performance. With respect to the single-probe serial position recall paradigm (Chapter 4), if interference was disrupting the observation of primacy, one might predict recency and a linear, or at least exponential, decline in recall as interference increases. That is, for the terminal item no odours intervene between presentation and test, and consequently, performance is highest. However, despite performance levels substantially above chance, no serial position effects were found. If the lingering of odours in the organ is disrupting item perception, one might conversely argue that recall should be superior for the first item, since presentation of that item was perceived by an uncorrupted organ. Once again this was not observed.

(iv) Olfactory recognition functions were qualitatively equivalent to the functions observed for both visual and auditory stimuli. It is unparsimonious to suggest that chemical interference in the organ should qualitatively impact olfactory order memory but not olfactory item memory.

This accumulation of evidence suggests that it is not the interference of olfactory remnants in the organ that is responsible for the qualitatively different order serial position functions. This conclusion is consistent with the conceptualisation of odours as unitary entities impervious to interference (e.g. Chobor, 1992; Engen and Ross, 1973). The finding furthermore supports the proposed flexibility of olfaction by Wilson and Stevenson (2006), specifically, that odours can be both recognised and discriminated at various concentrations and amongst a variety of chemical backgrounds.

7.3.5 Serial Position Function Differences for Order-Based Tasks due to Inefficient Encoding of Odours? A third possibility is that qualitative differences may be observed for order functions for odours due to their inefficient encoding (see Herz and Engen, 1996, for a review). This hypothesis is flawed for reasons that are twofold.

(i) Inefficient encoding should reduce overall performance, promoting quantitative rather than qualitative changes in the serial position function. This is supported in the 4-odour modified-reconstruction pilot experiment (Experiment 3, Appendix 3). In this experiment list-length was reduced in order to inflate overall recall rates. Despite performance increasing, the function did not alter qualitatively, indicating that it was not low performance levels that obscured the observation of primacy for odours.

(ii) Once again, it is not parsimonious to propose that inefficient encoding should produce serial position function differences for order- but not item-based tasks.

7.3.6 Serial Position Function Differences for Order-Based Tasks due to a Different Role for Olfaction? A fourth possibility is that sensory-specific roles/demands produced qualitatively different functions for the order-based tasks. Köster and colleagues have argued that evolutionary demands have resulted in odours being encoded in a qualitatively different manner compared to that of other senses. Specifically, that olfaction is organised to detect changes in the environment rather than precise identification/recognition of odours (Møller et al., 2004). In olfactory perception, it is argued that early detection is important rather than precise identification (for example, to alert the individual of potentially hazardous materials, e.g. Rozin et al., 2000). However, from this 'detecting changes in the environment' account of olfaction (Møller et al., 2004), there is no apparent necessity for an olfactory system that can encode the order in which the odours were presented. Nevertheless, in Chapters 4-6 participants performed above the floor at both tasks. The 'detecting changes in the environment' distinction between olfaction and vision/audition does not, therefore, appear to provide an adequate explanation for different olfactory order serial position functions.

However, there does appear to be a fundamental characteristic of olfaction that prevents the observation of primacy. Unlike unfamiliar-faces and pure-tones, the observation of primacy for olfactory memory has rarely been found (e.g. it was demonstrated in human subjects by Reed, 2000, but Miles and Hodder, 2005, failed to replicate the finding) and, indeed, no evidence of olfactory primacy has been observed throughout the present thesis. Two tentative explanations are provided to account for the absence of primacy. First, Rundus (1971) highlighted that the primacy component in verbal memory is underpinned through verbal rehearsal, i.e. greater rehearsal opportunities existed for earlier list items. It has been demonstrated that verbal rehearsal does not determine primacy for memory for visual stimuli (Experiment 2.4; Experiment 4.1; Smyth et al., 2005). However, the possibility remains that primacy for both unfamiliar-faces and pure-tones is underpinned through an, as yet unidentified, non-verbal rehearsal mechanism. It is possible that olfactory memory lacks such a rehearsal system preventing the development of primacy.

The second tentative, and related, explanation for the absence of olfactory primacy concerns the plasticity of olfactory perception described by Wilson and Stevenson (2006). Memory and learning is proposed to be fundamental to olfaction (Wilson and Stevenson, 2006), wherein the perception of an odour is labile and changes dependent upon number of exposures and experiences. For example, increased number of exposures to a particular odour correlates with increased liking (Engen and Ross, 1973; Rabin and Cain, 1989). Similarly, pleasantness ratings for food decrease with satiety (Duclaux et al., 1973, cited in Wilson and Stevenson, 2006). The literature, therefore, suggests that the perception of an odour changes over exposures and that the latest perceptual experience is of most importance/utility. This perceptual evolution seems intuitive, as following the consumption of food that has induced illness or the morning after an evening of alcohol excess, neither product smells as pleasant as they did prior to illness (personal experience). Therefore, in olfaction, there appears to be a bias towards the most recent perceptual experience. Such a conceptualisation might explain why a non-verbal olfactory rehearsal mechanism may not exist: olfactory storage of earlier items is not as important as that for other modalities. Such a conceptualisation is preliminary, but might explain why recency is observed for forward modified-reconstruction and primacy is not. There is, however an obvious caveat, namely that this explanation only accounts for the modified-reconstruction function and cannot accommodate the absence of serial position effects for either single-probe serial recall or the 2AFC recognition forward testing procedure.

7.3.7 Summary. The findings of the present thesis, therefore, appear more consistent with a modularity account whereby different modal-specific systems operate in an analogous, yet independent manner. This is particularly apparent for order memory. Support for a separate olfactory system is found in Miles and Jenkins (2000) where it was reported that recency produced by olfactory serial recall was attenuated only by the presentation of a same modality suffix. The finding provides evidence that odours are stored in an olfactory memory code. Even when the items are deliberately recoded verbally for a serial recall task, it is the olfactory code that is the dominant representation (for the final list item). Similarly, Andrade and Donaldson (in press) demonstrated that a distracter olfactory task selectively impaired olfactory memory (as opposed to both verbal and visual distracter tasks). The finding indicates that neither visual nor verbal representations were employed to perform the olfactory memory task. Andrade and Donaldson (in press) provide an adapted working memory model that accommodates olfactory modularity. In this model a specific olfactory sub-system of memory operates separately from other sub-systems yet under the control of a central executive.

7.4 Methodological and Theoretical Criticisms

7.4.1 Stimulus Presentation Times. Problems exist following the cross-modal comparisons performed in the thesis. A recurring difficulty is that of differing stimulus presentation times between experiments. For example in Chapter 3 (2AFC recognition), although the ratio between exposure time and ISI was held constant cross-modally (3:2), the absolute presentation time differed between odours and the visual and auditory stimuli. Odours were presented for 3000 ms, in contrast, both unfamiliar-faces and pure-tones were presented for 600 ms. Such differences in stimulus presentation times were necessary in order to reduce recognition levels for visual recognition; a pilot study in which faces were presented for 3000 ms produced performance at the ceiling level. The difference in presentational durations (the presentation phase for odours is 30 s whereas for both unfamiliar-faces and pure-tones it is 6s) results in each olfactory trial being approximately 500% longer than both the visual and auditory trials. The suggestion of some mechanistic modularity in Chapter 3, may, therefore, be due to alternative strategies employed due to longer trial durations rather than due to modality-specific processing. In future, it might be of use to replicate these experiments employing equivalent 1000 ms presentation times across modalities. Indeed, Miles and Hodder (2005, Experiment 2) reported that participants are able to perform a single 2AFC recognition test pair paradigm following the reduction of exposure time to 1000 ms. Furthermore, Miles and Hodder (2005) reported an absence of serial position effects following exposure times of 1000ms (Experiment 2) but evidence of recency following 3000ms exposure time (Experiments 1, 3 and 6; however, recency was not replicated with a different set of hard-to-name odours in Experiment 5). The finding suggests that exposure time may be important in determining the olfactory serial position function.

In Chapter 4 (single-probe serial position recall; Experiments 2.1-2.4) this difference in cross-modal exposure durations was addressed directly such that both exposure times and ISIs were held constant for odours, unfamiliar-faces and pure-tones. Despite these methodological controls, qualitatively different serial position functions were reported for the three modalities demonstrating that cross-modal differences observed, at least for the single-probe serial position recall paradigm, are not driven by differences in stimulus exposure times. Similarly, in Chapter 5, identical presentation times were employed for modified-reconstruction of unfamiliar-faces and odours (Experiment 3.4). Despite these methodological controls, a serial position function dissociation was observed between olfactory and visual stimuli. This finding further supports the notion that presentational differences did not underpin the difference.

However, Parmentier and Jones (2004) found that following the reconstruction of order for the spatial locations of a sequence of white noise bursts, manipulating the exposure time (250ms and 1000ms) qualitatively changed the serial position function. Specifically, faster presentation times produced a more pronounced serial position function curvature. The finding suggests that exposure times can be important in determining the shape of the serial position function for order memory. This finding is particular pertinent in relation to Experiment 3.5 wherein the absolute presentation times differ for pure-tones compared to both odours and unfamiliar-faces (although the exposure time – ISI ratio of 1:1 is equivalent to Experiment 3.4). Cross-modal comparisons involving pure-tones should, therefore, be interpreted with this caveat in mind. Nevertheless, the 7-item functions for unfamiliar-faces and pure-tones mapped very closely (following *Z*-score standardisation), indicating congruence between visual and auditory stimuli despite the presentational differences.

7.4.2 Stimuli-Specific Characteristics. An alternative interpretation of the observed modal-specific functions is that the differences are underpinned not by modal-specific mnemonics/systems but due to stimulus-specific characteristics. Specifically, that perception of an odour is such a qualitatively different experience to that of an unfamiliar-faces/pure-tone that disparate functions will be produced. Indeed, as highlighted by Wilson and Stevenson (2006), unlike the visual system, the olfactory system does not have to process multiple orientations of the same stimuli and different levels of illumination. However, the olfactory system does have to interpret different levels of concentration, i.e. variations in the number of odour molecules in the air. As previously stated, the effect of stimuli-specific characteristics can only be investigated if the stimuli are kept constant and only the modality of presentation is manipulated. It is unclear how this might be achieved for odours. However, in Experiment 4.3(a-d) the stimuli (nonwords) presented were held constant and only the modality of stimuli presentation manipulated. In this experiment visual and auditory presentation of nonwords produced qualitatively equivalent serial position functions. The finding supports the functional equivalence found between unfamiliar-faces and pure-tones for forward modified-reconstruction (Experiments 3.2 and 3.5d).

7.5 Conclusions

The thesis has been concerned with the serial position functions following olfactory recognition and recall and a comparison of those functions with other modalities. Olfactory serial position functions have differed to those produced for unfamiliar-faces and pure-tones following the single-probe serial recall (Chapter 4) and modified-reconstruction (Chapter 5) paradigms. However, serial position function equivalence was observed following the 2AFC recognition task (Chapter 3).

Participants demonstrated the ability to perform both item recognition and serial position recall tasks with odours. Recency was observed for olfactory stimuli following both the 2AFC recognition task (consistent with Miles and Hodder, 2005 and Reed, 2000) and the forward modified-reconstruction paradigm. No evidence of olfactory primacy was found throughout the thesis; a finding in contrast with Reed (2000). It is argued that the olfactory serial position functions are characteristic of olfactory memory rather than memory for the verbal labels of the odours (e.g. consistent with Miles and Jenkins, 2000, Andrade and Donaldson, in press).

Evidence for modularity was observed with the order-based but not item-based tasks. Specifically, olfactory serial position functions were qualitatively different to other stimuli for the single-probe serial position recall and forward modified-reconstruction tasks but analogous for the 2AFC recognition paradigm. This finding is the opposite to that observed by Guérard and Tremblay (under review) who argued that item-based tasks produced evidence of modularity but not order-based tasks. In the present thesis, an amodal memory system for item-based but not order-based task is deemed unparsimonious.

The olfactory serial position function differences for order-based tasks indicate that a separate olfactory memory system/mnemonic underpins performance. The findings are inconsistent with an amodal processing system in which stimuli are stored in a qualitatively equivalent form irrespective of stimuli type. The apparent independence of olfactory memory is consistent with the proposed Working Memory Model extension (Andrade and Donaldson, in press) whereby a separate olfactory sub-system of memory exists in parallel to the phonological loop and visuo-spatial sketchpad (e.g.

Baddeley and Hitch, 1974). However, qualitatively equivalent serial position functions for 2AFC recognition indicate that analogous mechanisms may operate cross-modally for item recognition. It is tentatively proposed that a temporal distinctiveness account (Neath, 1993) might accommodate recency following the backward testing procedure.

The mechanisms underpinning the olfactory serial position function for order-based tasks remain unresolved. It is clear that differences are not an artefact of an inability to perform the task, as above floor performance is evident across the tasks. Inefficient encoding of olfactory stimuli (Chobor, 1992) might account for the quantitative serial position differences but cannot explain the qualitative differences. The robust absence of olfactory primacy is also perplexing. The absence of primacy is inconsistent with concepts of verbal rehearsal, distinctiveness, sequence borders and interference. A tentative explanation is provided whereby memory for early items is less important in olfaction. Further research is now required to establish the factors that determine the olfactory serial position function.

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Appendix One
Odour Stimulus Set

The stimulus set was provided by Dale Air limited and comprised of 120 non-food related odour boxes. The odours are listed below, however it should be noted that for replication purposes some of the odours are arbitrarily labelled, with the label of limited utility if one intended to independently reproduce the odour (e.g. 'dragon's breath').

Alpine Laundry Powder
Baby Powder
Beauty Soap
Bergamot
Boiler Room
Bouquet
Brewery
Burning Peat
Burnt Wood
Camomile
Cannon
Carbolic Soap
Caribbean Holiday
Cedar Wood
Christmas Tree
Church Incense
Cinnamon
Clinic/Hospital
Cloisters
Coal Face
Coal Fire
Coal Gas
Coal/Soot
Cut Grass
Deep Heat
Dentist-Clove Oil
Dinosaur
Dirty Linen
Dragon's Breath
Earthy
Eau De Cologne
Egyptian Mummy
Eucalyptus
Factory
Farmyard
Fish Market
Flatulence
Flowery
Forest
Fox
Freesia
Fresh Air
Frosty
Garden Shed
Grass/Hay
Gun Smoke
Havana Cigar
Hawaiian
Heather/Bracken
Honeysuckle
Hyacinth
Incense
Iron Smelting
Jaguar Spray
Jasmine
Lavender
Leather
Leather/Hide
Lemon, Eucalyptus & Mint
Machine Oil
Man-o-War
Methane
Mahogany
Mixed Spice
Mountain Heather
Mummy
Mustard Gas
Musty
Oak
Old Drifter
Old Inn
Old Smithy
Old River
Out At Sea
Ozone
Peat
Pencil Shavings
Peppermint
Phosgene Gas
Pine
Pineapple Plantation
Pine/Heather/Peat
Pit Ponies
Polish-Wax
Pot-Pourri
Riverbank
Rope/Tar
Roses
Rotten Egg
Rubbish Acrid
Sandalwood
Sea Breeze
Sea Shore
Ships Canon
Smoke
Sports Rub
Stable/Horses
Stars Dressing Room
Steam/Oil/Ships
Steam/Oil/Trains
Street Bomb
Sun, Sand & Coconut
Swamp
Sweaty Feet
Sweet Peas
Tobacco Leaf
Train Smoke
Tropical
Tropical Rain Forest
Urine
Victoria Lavender
Violets
Volcano
Vomit
Wallflower
Washday
Wild Stag
Wine Cask-Oak
Woodsmoke
Ylang Jasmine and Myrrh

Appendix Two
Nonword List

The nonword stimulus set was constructed using the method described in Ward et al. (2005). This process is also detailed in the materials section of Experiment 4.3(a-d).

BAF
BESH
BLOVE
BIME
BISH
BOVE
BUP
BIEB
BRALCH
BRAP
CELCH
COOB
CHATCH
CHIB
CHOOF
CLADGE
CLOF
CLUPE
CROB
CROOG
DALCH
DOTCH
DRUP
DADGE
DULF
DRANG
DRATCH
DROD
DREET
DRILM
FALF
FUB
FOLCH
FOOG
FEAG
FRACK
FRATCH
FROVE
FOTCH
FRIEM
GACK
GODGE
GIK
GUVE
GROF
GELCH
GROST
GRUBE
GRANG
GRUT
HALCH
HADGE
HISH
HUFT
HIEB
HOLCH
HETCH
HELCH
HEAB
HOOG
JALCH
JADGE
JAFT
JOOB
JEX
JETCH
JISH
JOLCH
JIEM
JEFT
KALCH
KOFT
KIEK
KULCH
KIEB
KALF
LALCH
LESH
LUDGE
LUTCH
LEEG
LIEG
LEEB
MALCH
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NULCH
NOOG
NIEP
NULF
NODGE
POLM
PRUTCH
PLAB
PLIDGE
PLIBE
PLOOG
PRABE
PRISH
PLATCH
PLOG
RALCH
ROLCH
RULCH
RUTCH
SETCH
SOOB
SNAB
SNIBE
SHIG
SHISH
STOLF
SCADE
STUST
SCALCH
TABE
TOOG
TOTCH
THADGE
TRALCH
TUTCH
TROB
THABE
TREG
TROOB
ZIBE
ZAB
ZABE
ZADGE
ZAF
ZAPE
ZEFT
ZIBE
ZILF
ZOOG
ZOTCH

Appendix 3
Supplementary Experiments

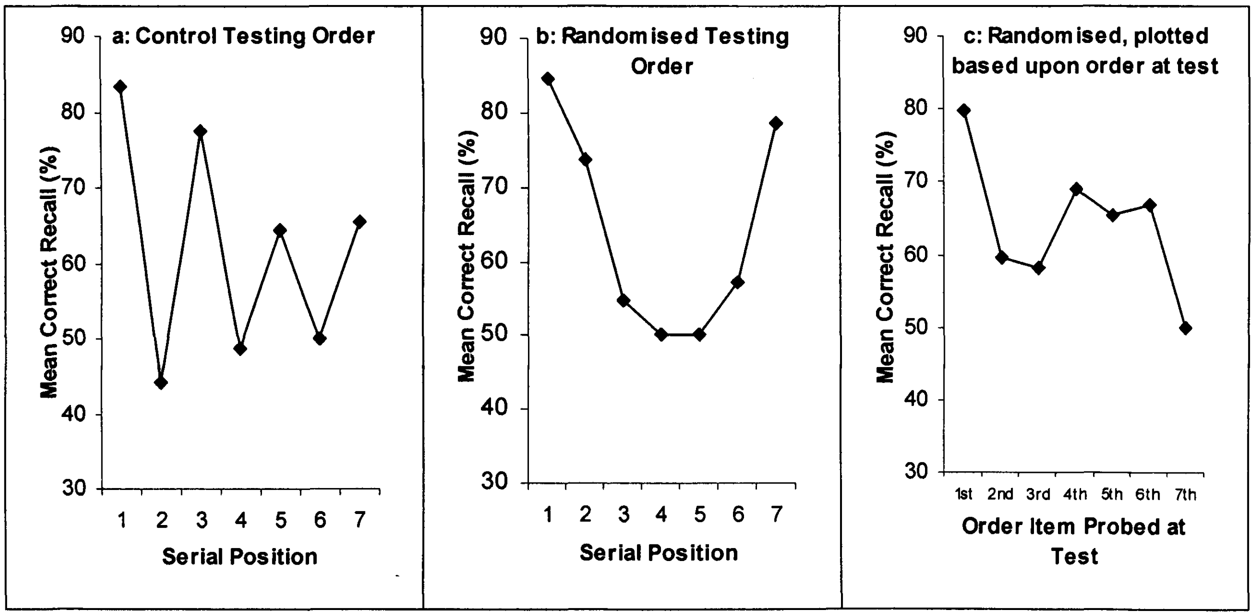
Experiment 1: Modified-Reconstruction employing Randomised and Constant Control Testing Procedures

Experiment Aim: To investigate the extent to which the recall benefit for first tested item is due to the learning of testing order or due to some inherent benefit originating from being tested first.

Method

Participants. Twelve (2 male and 10 female: mean age 21 years and 5 months) Cardiff University volunteer of various disciplines.
Materials. Sixty three unfamiliar-faces.
Design. A 2x7 within-subjects factorial design. Testing procedure (constant control procedure where order is the same and randomised control condition where order changes for each trial). Serial position (1-7).
Procedure. As described for Experiment 3.2.

Results



Summary

Benefit for the item tested first in the control testing procedure was not due to learning of order but due to an inherent benefit possessed by the item tested first. When randomised order condition is replotted (c) based upon the order of testing (irrespective of serial position) a benefit is observed for first tested item. However, as demonstrated in figure (b), primacy is still observed despite that item being tested first on an equal number of occasions to serial positions 2-7. Forward testing procedure primacy is, therefore, not uniquely due to the serial position being tested first.

Experiment 2: Modified-Reconstruction of 6-odours

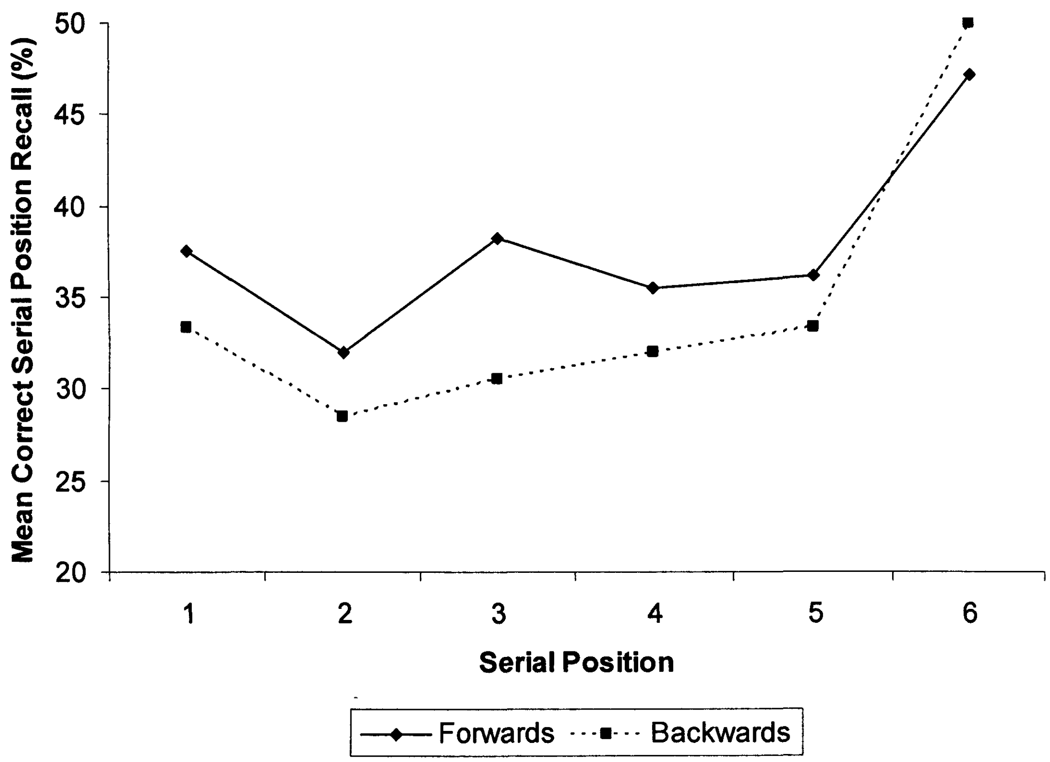
Experiment Aim: Pilot to investigate the extent to which participants can perform the modified-reconstruction task.

Method

Participants. Twenty-four (5 male and 19 female: mean age 20 years and 5 months, 19 non smokers) Cardiff University volunteer of various disciplines.
Materials. 108 odours.
Design. A 2x6 within-subjects factorial design. Testing procedure (forward and backwards). Serial position (1-6).
Procedure. As described for Experiment 3.3.

Results

Main effect of serial position, $F(5,115) = 5.88$, $MSe=1.14$. Main effect of testing procedure non significant, $F=1.31$. Interaction non-significant, $F=1.35$. Further analysis (Newman Keuls) of the main effect of serial position, 6 > 1, 2, 3, 4 and 5.



Primacy and Recency Analysis

Forward: No significant difference between position 1 and mean of positions 2-5 ($t<1$). Serial position 6 significantly greater than mean of positions 2-6, $t(23)=2.17$, $p<.05$.

Summary

Participants were capable of performing modified–reconstruction with 6-odours. Forward modified-reconstruction produced recency but not primacy.

Experiment 3: Modified-Reconstruction of 4-odours

Experiment Aim: To investigate the extent to which the absence of primacy for forward modified-reconstruction was governed by low performance obscuring the observation of primacy. Therefore, sequence length shortened to increase mean recall.

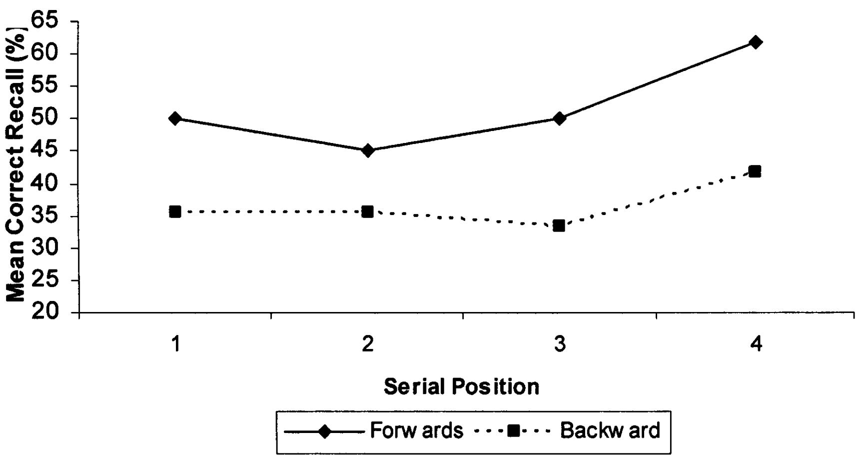
Method

Participants. Twenty-four (5 male and 19 female: mean age 20 years and 5 months, 23 non smokers) Cardiff University volunteer of various disciplines.
Materials. Seventy two odours.
Design. A 2x4 within-subjects factorial design. Testing procedure (forward and backwards). Serial position (1-4).
Procedure. As described for Experiment 3.3.

Results

Serial Position Analysis

Main effect of serial position $F(3,69) = 6.98$, $MSe = 1.04$. Main effect of testing procedure, $F(2,46) = 11.70$, $MSe=1.96$, $p<.05$. Non-significant interaction between serial position and testing procedure ($F=1.29$). Further analysis (Newman Keuls) of forward testing procedure: 4 > 1, 2 and 3.



Primacy and Recency Analysis

Forward Testing Procedure: No significant difference between position 1 and mean of positions 2-3 ($t<1$). Serial position 4 significantly greater than mean of positions 2-3, $t(23)=4.04$, $p<.05$.

Summary

Recency and no primacy still observed for the forward testing procedure despite performance increased to 50%. The absence of primacy for odours was, therefore, not due to low performance obscuring primacy.

Experiment 4: Adapted-Reconstruction of 4-Odours

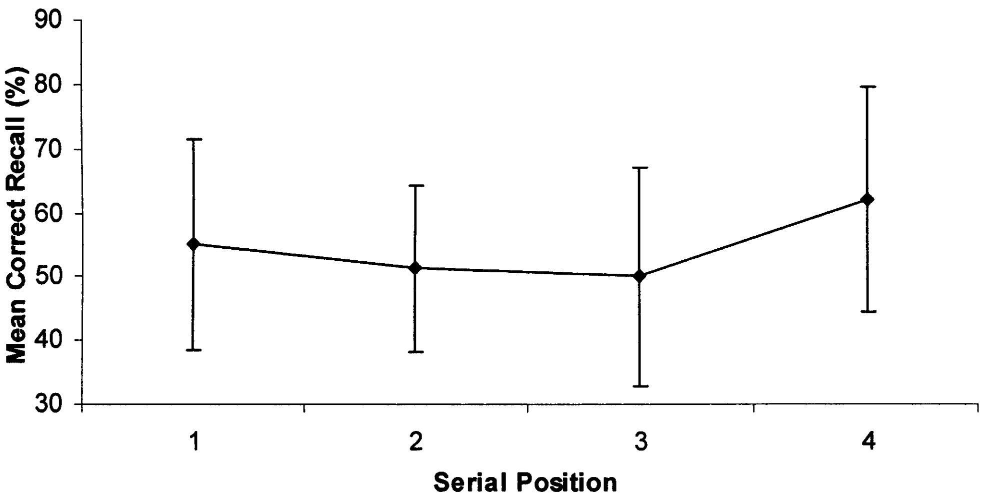
Experiment Aim: Investigate the extent to which the absence of primacy in forward modified-reconstruction of odours is due to participants not being able to compare all list items at test (as possible for the serial order reconstruction task). Participants are given all list items at test and told to provide the odours in the original order of presentation through inhaling each item as many times as necessary.

Method

Participants. Twenty four (7 male and 17 female: mean age 21 years and 4 months, 20 non-smokers) Cardiff University volunteer of various disciplines.
Materials. Forty odours.
Design. Serial position (1-4). Ten trials.
Procedure. As described for Experiment 3.3 and Appendix Experiment 2. Presented four odours and at test phase given all odours to re-order.

Results

Serial Position Analysis
Main effect of serial position, $F(3,69) = 5.24$, $MSe = 1.35$. Further analysis (Newman Keuls): 4 > 1, 2 and 3.



Primacy and Recency Analysis
No significant difference between position 1 and mean of positions 2-3 (t=1.50).
Serial position 4 significantly greater than mean of positions 2-3, $t(23)=3.56, p<.05$.

Summary

Recency and an absence of primacy is found for this adapted-reconstruction paradigm with odours. Participants are given all list odours at test to compare and inhale as much as necessary. This is analogous to the serial order reconstruction task. The experiment demonstrates that the absence of primacy for forward modified-reconstruction of odours is not due to participants not being able to compare odours at test.

Experiment 5: Modified-Reconstruction of 6-Visually Presented Nonwords Following Articulatory Suppression

Experiment Aim: Investigate the extent to which the primacy component observed for forward modified-reconstruction of nonwords was due to rehearsal or whether primacy is found generally for visually presented stimuli. Articulatory suppression during the presentation phase was employed to prevent rehearsal of nonwords.

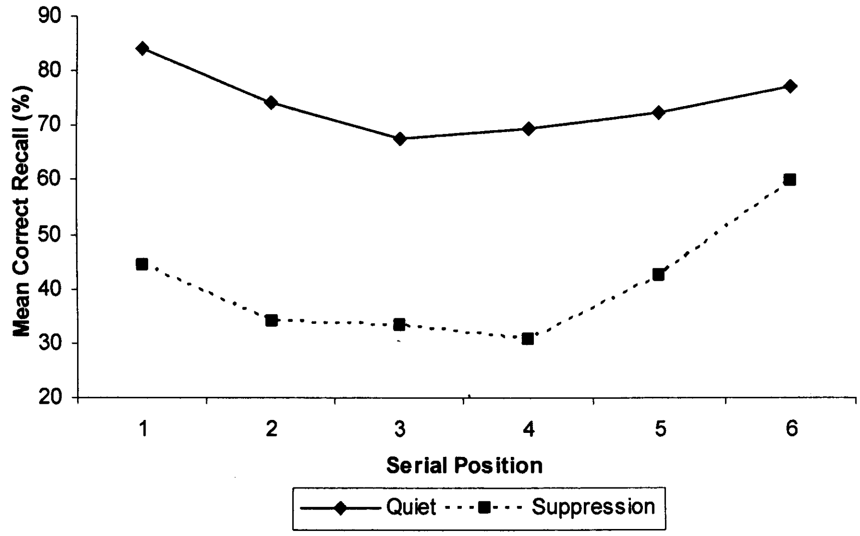
Method

Participants. Twenty four (3 male and 21 female: mean age 20 years and 3 months) Cardiff University volunteer of various disciplines.
Materials. 108 nonwords presented visually as in Experiment 4.3c.
Design. A 2x6 within-subjects factorial design. Testing procedure (forward and backwards). Serial position (1-6). As described in Experiment 4.3c.
Procedure. As described for Experiment 4.3c with the additional articulatory suppression instruction during the presentation phase.

Results

Serial Position Analysis

Comparison between quiet forward modified-reconstruction of nonwords (Experiment 4.3c) and forward modified-reconstruction of nonwords with articulatory consition (Appendix Experiment 4). 2x6 mixed ANOVA. Main effect of articulatory suppression, $F(1,46)=52.41$, $MSe=1.01$). Main effect of serial position, $F(5,46)=9.65$, $MSe=1.01$. Significant interaction between presentation condition and serial position, $F(5,230)=3.29$, $MSe=1.01$. Further analysis (Newman Keul) revealed that recall in the quiet condition was significantly better than the articulatory suppression condition at positions 1-5 but not a position 6.



Primacy and Recency Analysis

Forward Testing Procedure: Serial position 1 significantly greater than the mean of positions 2-6, $t(23)=2.20, p<.05$. Serial position 7 significantly greater than mean of positions 2-6, $t(23)=6.61, p<.05$.

Summary

Articulatory suppression disproportionately reduced recall for the first serial position suggesting that rehearsal facilitated primacy. However, a first item benefit was still present following articulatory suppression indicating that forward modified-reconstruction of visual stimuli is characterised by both primacy and recency irrespective of verbal rehearsal.

Experiment 6: Modified-Reconstruction of Mixed-Stimuli Lists (Alternating Unfamiliar-Faces and Pure –Tones)

Experiment Aim: Investigate the extent to which mixed lists of unfamiliar-faces and pure-tones produced a single function or modality-specific functions.

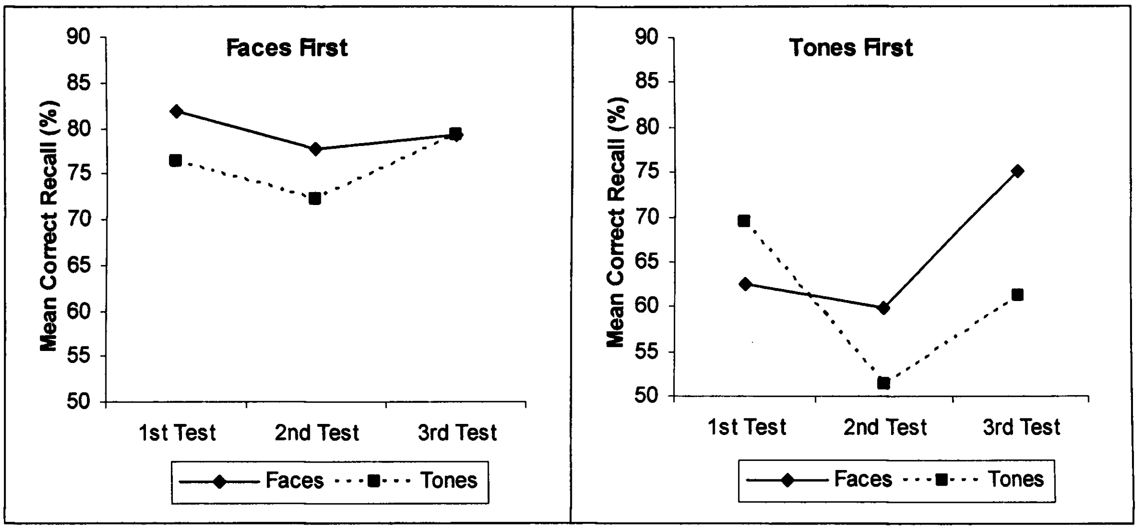
Method

Participants. Twenty four (4 male and 20 female: mean age 20 years and 3 months) Cardiff University volunteer of various disciplines.
Materials. 54-unfamiliar-faces and 54-pure tones.
Design. 2x3x6 within-subjects design. Modality of stimuli (unfamiliar-faces and pure-tones). Testing procedure (forward, backward and control). Serial position (1-6).
Procedure. As described for Experiment 3.4 and 3.5c.

Results

If participants are grouping the unfamiliar-faces and pure-tones into sub-lists one might predict equivalent functions between the face function in lists where faces are presented first (positions 1, 3 and 5) and lists where faces are presented second (positions 2, 4 and 6). Similarly, one might predict equivalent functions when tones are presented first in the sequence (positions 1, 3 and 5) and lists where tones are second.

A three-factor (2x2x3) within-subjects ANOVA. Main effect of unfamiliar-faces being first in the sequence, $F(1,23)=6.92$, $MSe=1.99$. Null effect of modality ($F=1.60$). Main effect of serial position, $F(2,46)=4.11$, $MSe=0.43$. Non-significant interactions between modality tested first and modality, $F<1$, modality tested first and serial position, $F=1.14$, and between modality and serial position, $F=1.81$. Borderline significant three-way interaction between modality tested first, modality and serial position was observed, $F(2,46)=3.13$, $MSe=0.30$, $p=.05$.



Summary

Borderline significant three-way interaction indicates that the sub-functions were not qualitatively the same for each modality. This provides tentative evidence that the mixed stimuli sequences were not processed/memorised as two stimuli-specific and separate lists. The finding is tentative evidence against amodal processing.

Experiment 7: Modified-Reconstruction of Mixed-Stimuli Lists (Blocked Unfamiliar-Faces and Pure –Tones)

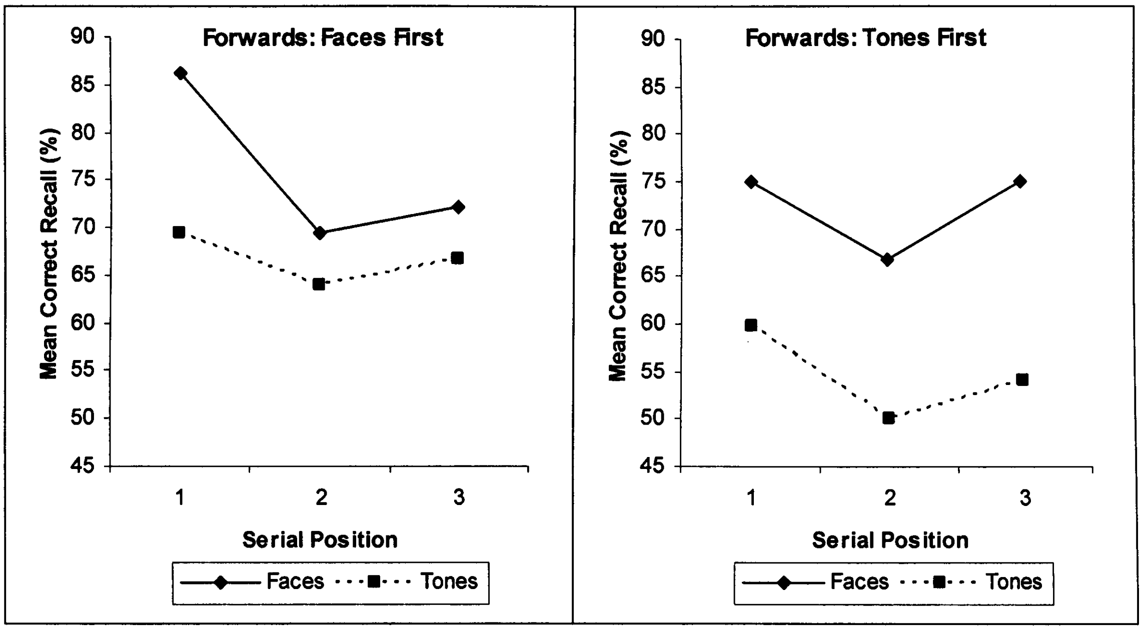
Experiment Aim: Repetition of Experiment 6 but employing blocks of three unfamiliar-faces and 3 pure-tones within the 6-item sequence. Following separation into unfamiliar-face and pure-tone sub-sequences, the manipulation allows clearer assessments if modular-specific lists are produced. For example, when unfamiliar-faces are presented in positions 1, 2 and 3, if the function is bowed the recency cannot easily be explained in terms of extended recency. Therefore, equivalent functions for unfamiliar-faces and pure-tones when tested at positions 1-3 and positions 4-6 would be strong evidence of separate stimuli-specific processing.

Method

Participants. Twenty four (3 male and 21 female: mean age 20 years and 9 months) Cardiff University volunteer of various disciplines.
Materials. 54-unfamiliar-faces and 54-pure tones.
Design. 2x6x6 within-subjects design. Modality of stimuli (unfamiliar-faces and pure-tones). Testing procedure (forward, forward broken, forward blocked backward, backward, backward broken and backward blocked broken). Serial position (1-6).
Procedure. As described for Experiment 3.4 and 3.5c.

Results

Analysing only the forward testing procedure, there is a non-significant interaction between stimuli (unfamiliar-faces and pure-tones) and serial position (1-3) when faces are tested first, F=1.83, and a non-significant interaction when tones are tested first, F<1.



Summary

A non-significant interaction between stimuli and serial position indicates that qualitatively equivalent functions were being produced for unfamiliar-faces and pure-tones. This supports modal-specific processing.

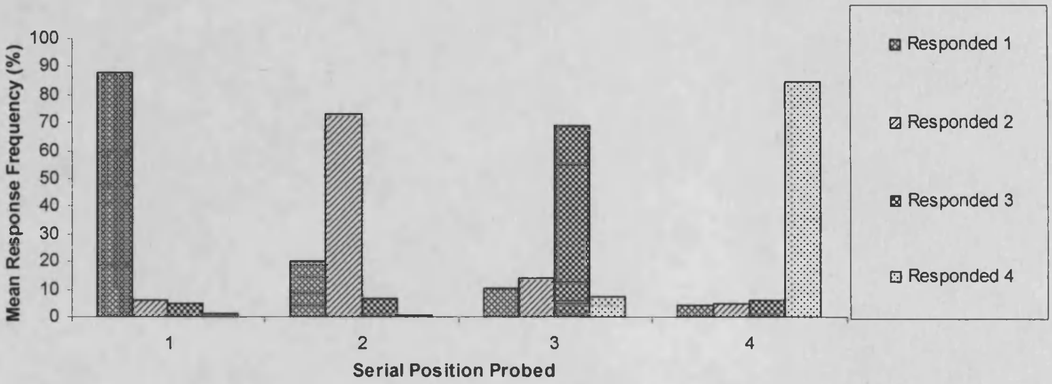
N.B. However, is should be noted that Experiments 6 and 7 possess numerous methodological and theoretical problems. Their inclusion is intended more as a suggestion towards future study paradigms, whereby mixed list sequences may have the potential to elucidate more upon the extent of amodal/modal-specific processing.

Appendix 4
Response Distributions

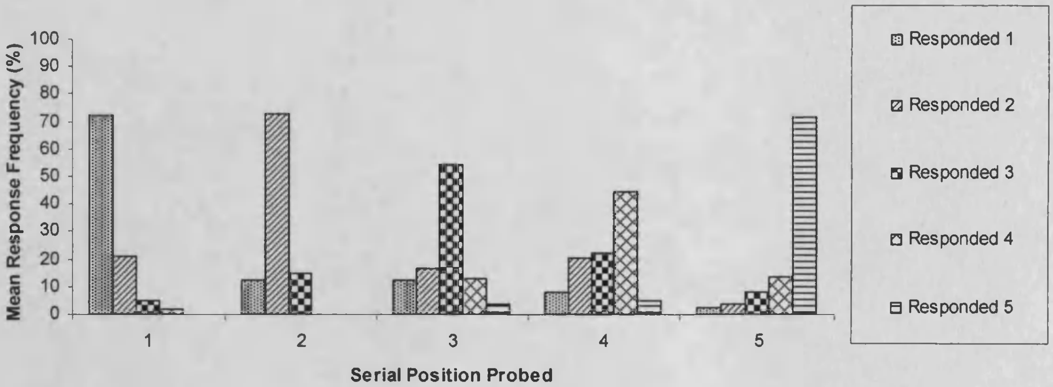
ANOVAs for mean displacement distances of erroneous responses are reported. Following main effects, further analysis (Newman Keuls) of significant differences are reported in brackets.

Experiment 2.2(a-c): Single-Probe Serial Recall of Unfamiliar-Faces

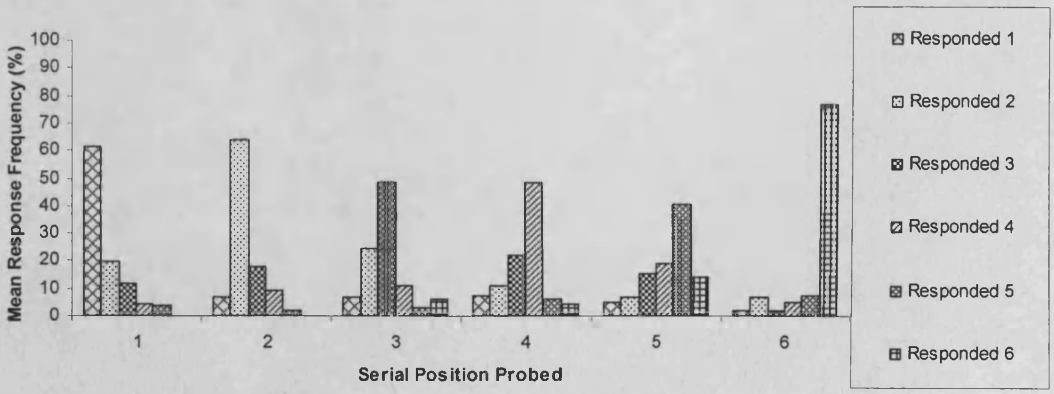
Experiment 2.2a: $F(2,46)=16.41$, $MSe=0.22$. (1 > 2 and 3).



Experiment 2.2b: $F(4,92)=62.65$, $MSe=0.04$. (1 > 2, 3, 4 and 5) (2>3, 4 and 5) (3 and 4 > 5)

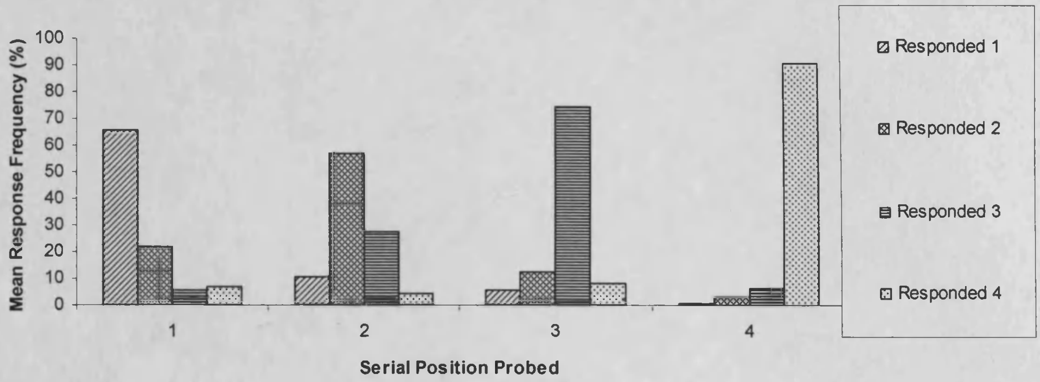


Experiment 2.2c: $F(4,92)=62.65$, $MSe=0.04$. (1 > 2, 3, 4 and 5) (2 > 3, 4 and 5) (3 and 4 > 5)

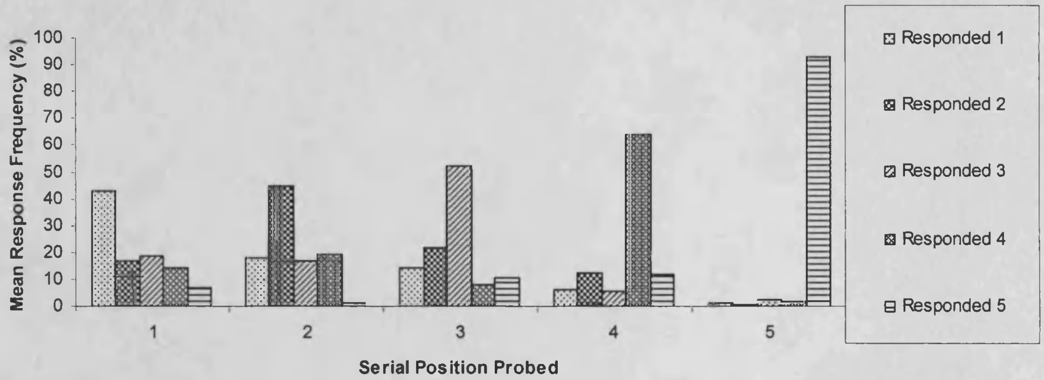


Experiment 2.3(a-c): Single-Probe Serial Recall of Pure Tones

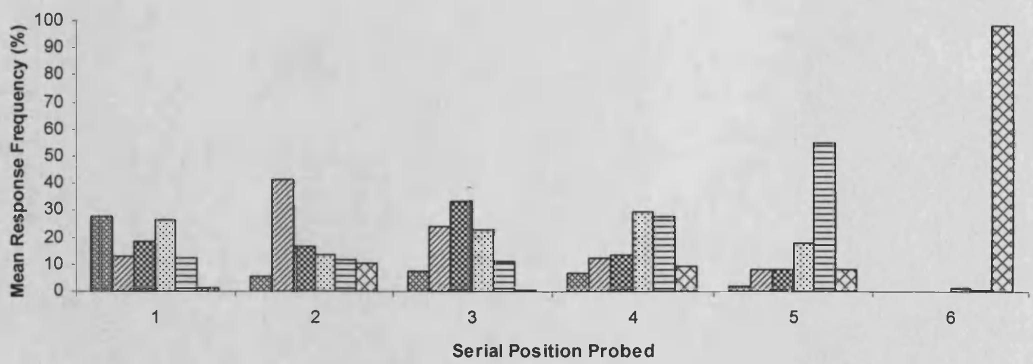
Experiment 2.3a: $F(2,46)=30.11$, $MSe=0.23$. (1 > 2 and 3)



Experiment 2.3b: $F(3,69)=22.23$, $MSe=0.08$. (1 and 2 > 3 and 4) (3 > 4)

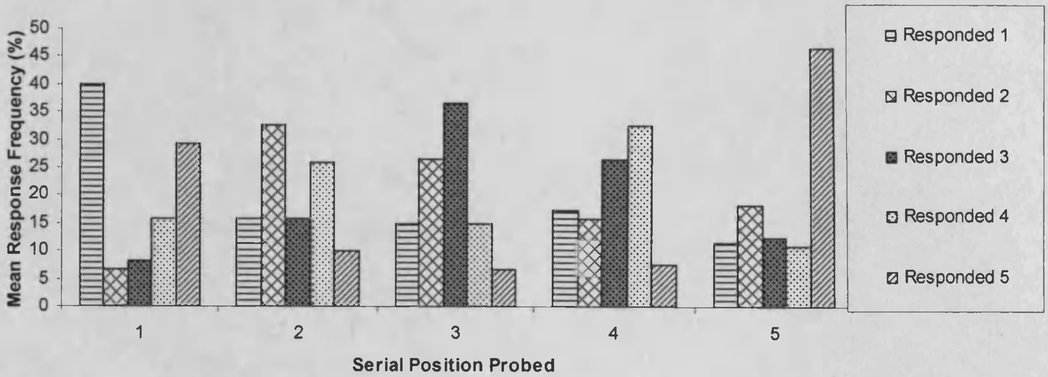


Experiment 2.3c: $F(4,92)=30.78$, $MSe=0.07$. (1 > 2, 3, 4 and 5) (2 and 3 > 4 and 5) (4 > 5)



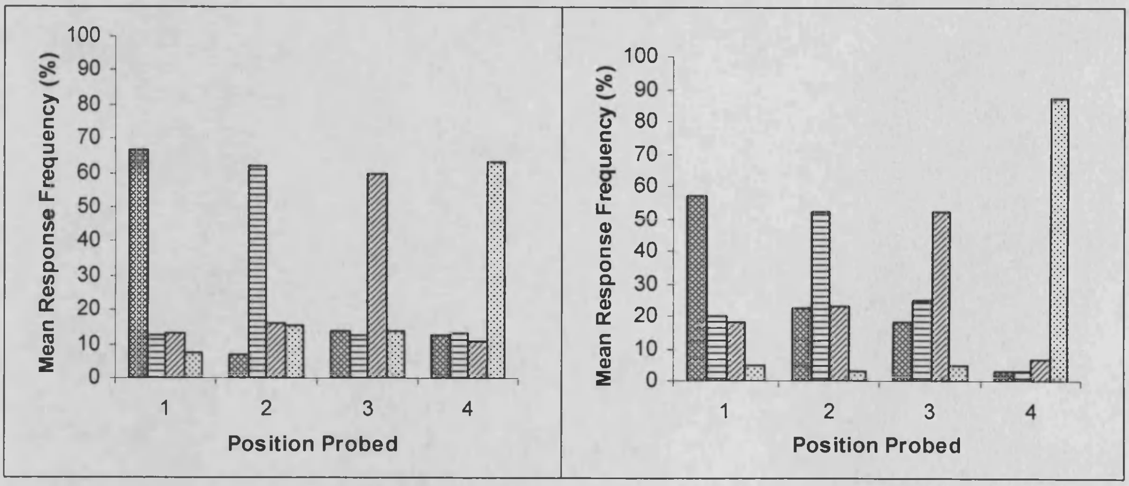
Experiment 3.3: Modified-Reconstruction 5-Odours

Backward Testing Procedure: $F(3,23)=2.71$, $MSe=0.15$, $p=.05$.

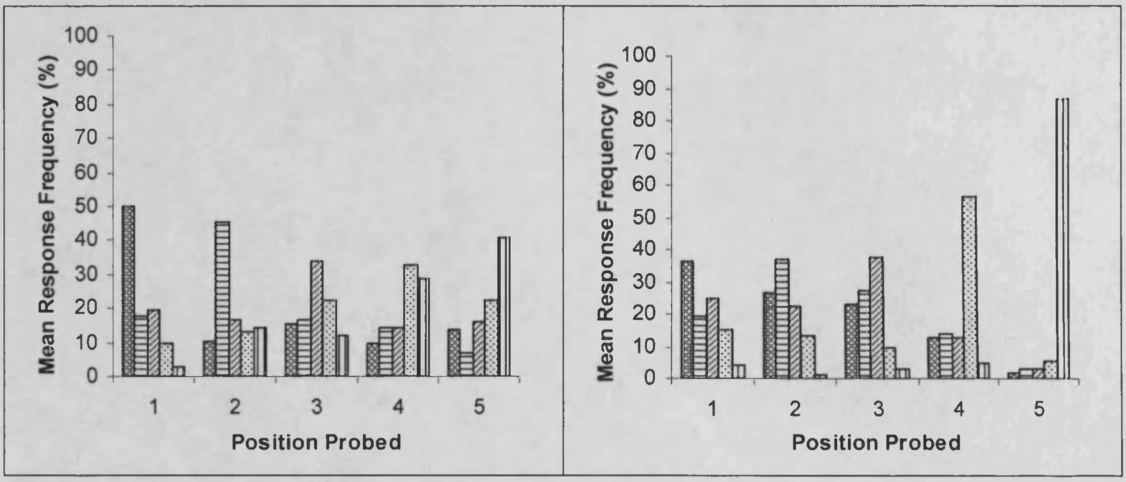


Experiment 3.5(a-d): Modified Reconstruction of Pure-Tones

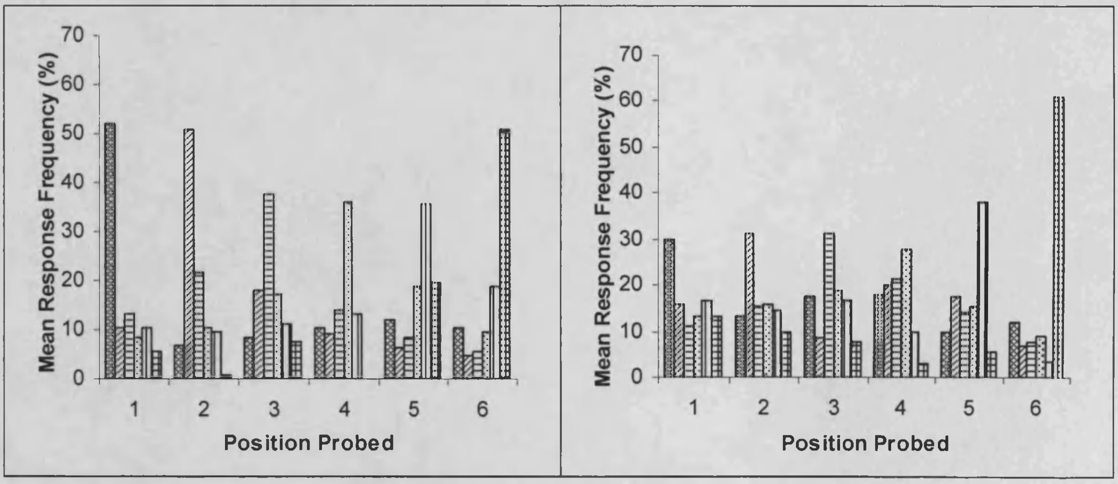
4-Pure Tone Sequences: Forward testing procedure, $F<1$. Backward testing procedure, $F(2,46)=20.81$, $MSe=0.18$. (1 > 2 and 3) (2 > 3)



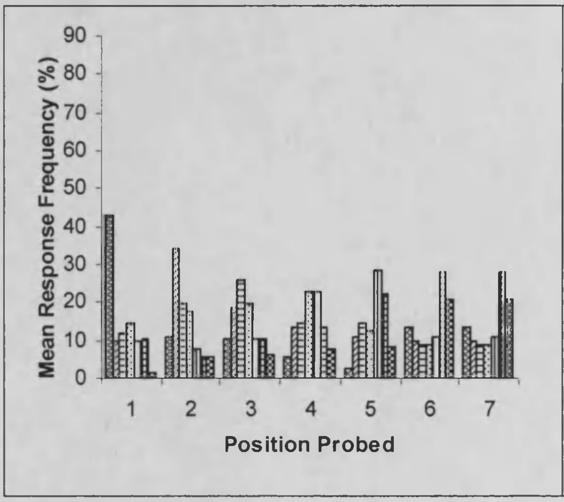
5-Pure Tone Sequences: Forward testing procedure, $F(3,69)=12.66$, $MSe=0.17$. (1 and 2 > 3 and 4) Backwards testing procedure, $F(3,69)=19.66$, $MSe=0.16$. (1 and 2 > 3 and 4) (3 > 4)

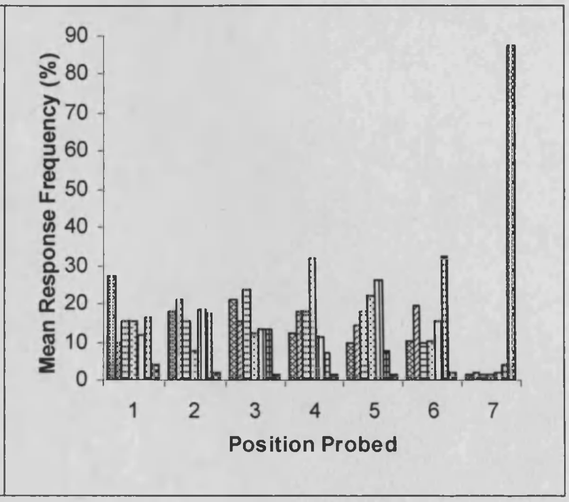


6-Pure Tone Sequences: Forward testing procedure, $F(4,92)=9.71$, $MSe=0.11$. (1 > 2, 3, 4 and 5) Backward testing procedure, $F<1$.



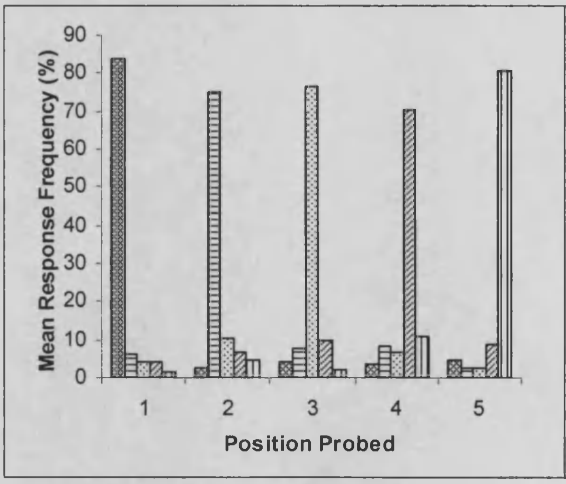
7-Pure Tone Sequences: Forward testing procedure, $F(5,115)=9.19$, $MSe=0.10$. (1 > 2, 3, 4, 5 and 6) (2 > 4) Backward testing procedure, $F(5,115)=11.82$, $MSe=0.09$. (1 > 5 and 6) (2, 3, 4 and 5 > 6)

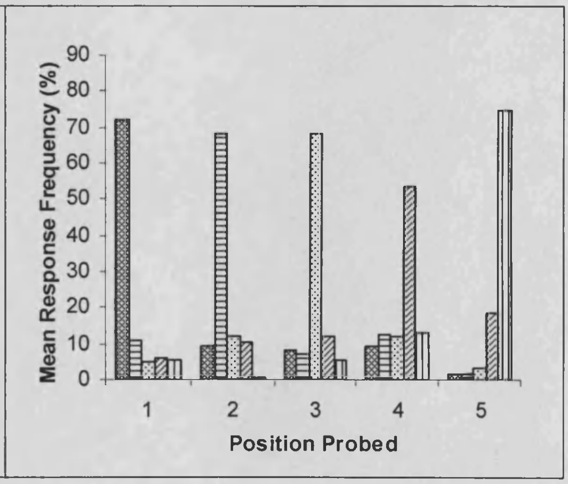




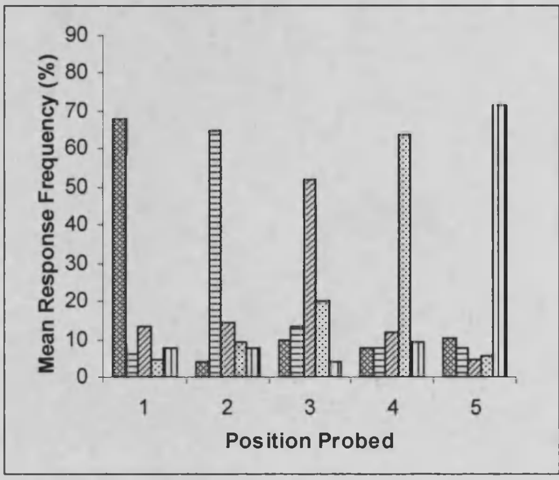
Experiment 4.3(a-d): Modified Reconstruction of Nonwords

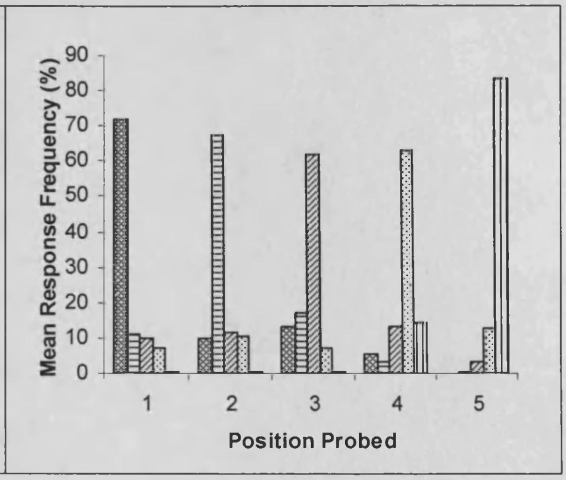
5-Nonwords Presented Visually: Forward testing procedure, $F(3,69)=5.75$, $MSe=0.07$. (1 > 2, 3 and 4) Backward testing procedure, $F(3,69)=15.26$, $MSe=0.07$. (1 > 2, 3 and 4) (2 > 3 and 4)



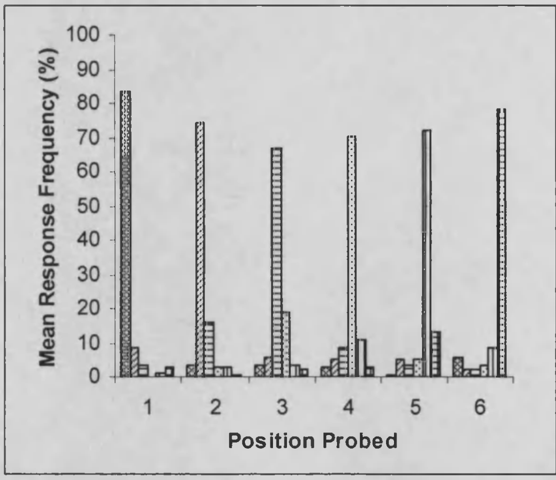


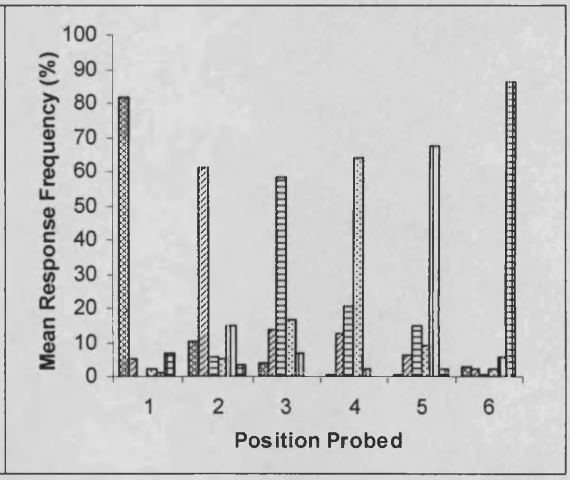
5-Nonwords Presented Aurally: Forward testing procedure, F=1.10. Backward testing procedure, $F(3,69)$=31.15, MSe=0.08. (1 > 2, 3 and 4) (2 > 3 and 4) (3 > 4)



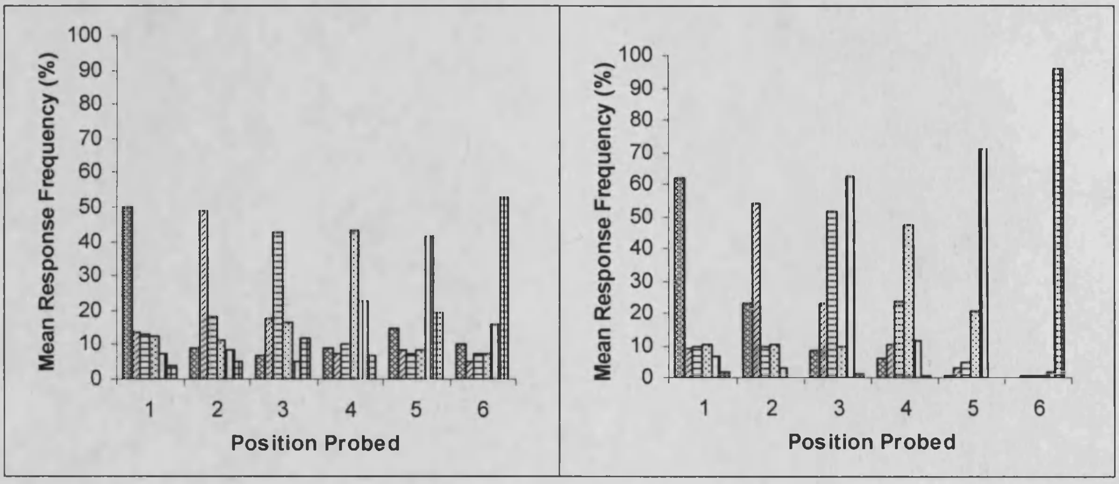


6-Nonwords Presented Visually: Forward testing procedure, $F(4,92)$=12.28, MSe=0.08. (1 > 2, 3, 4 and 5) Backward testing procedure, $F(4,92)$=5.00, MSe=0.12. (1 > 2, 3, 4 and 5)





6-Nonwords Presented Aurally: Forward testing procedure, $F(4,92)=5.25$, $MSe=0.16$. (1 > 2, 3, 4 and 5) Backwards testing procedure, $F(4,92)=34.02$, $MSe=0.06$. (1 > 2, 3, 4 and 5) (2 > 3, 4 and 5) (3 > 5)



Appendix 5
Means and Standard Deviations

Experiments 2.1-2.4 and Experiment 3.1 are not reported as means and standard deviations are demonstrated in graphical form in the main text.

Mean percentage correct scores are reported, plus standard deviations for percentage, rather than raw, scores.

Experiment 1.1a: 2AFC Recognition of Odours (blocked design)

		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	70	71.25	70.41	74.58	74.58	69.58
	S.D.	17.44	19.85	20.53	18.87	14.13	17.06
Backward		-	-	-	-	-	-
	Mean%	63.3	68.3	70.83	68.33	77.5	81.66
	S.D.	17.86	20.78	16.68	18.01	17.65	10.5

Experiment 1.1b: 2AFC Recognition of Odours (mixed design)

		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	69.17	70	70.83	64.17	65	69.58
	S.D.	15.58	16.15	11.76	17.17	14.74	17.32
Backward		-	-	-	-	-	-
	Mean%	66.67	65.42	65	69.17	68.75	78.75
	S.D.	18.80	18.41	14.14	16.4	12.96	15.97

Experiment 1.2: 2AFC Recognition of Unfamiliar-Faces

		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	87.5	82.5	83.75	88.75	87.08	86.67
	S.D.	10.32	11.52	11.35	0.80	13.34	10.96
Backward		-	-	-	-	-	-
	Mean%	83.33	87.08	81.25	86.25	77.5	93.75
	S.D.	13.73	10.0	9.9	9.24	15.7	8.2

Experiment 1.3: 2AFC Recognition of Unfamiliar-Faces (sequential and simultaneous test-pair presentation)

Sequential Presentation		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	89.58	80.83	83.33	87.92	85.83	82.92
	S.D.	11.97	12.82	15.51	11.02	14.72	13.34
Backward		-	-	-	-	-	-
	Mean%	82.92	85	85.83	87.92	80.42	96.25
	S.D.	11.22	12.85	11	16.15	11.6	7.7
Simultaneous Presentation		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	84.58	81.25	81.25	82.08	82.92	78.33
	S.D.	13.82	16.5	12.27	11.03	12.33	17.36
Backward		-	-	-	-	-	-
	Mean%	85	85	80.42	77.08	71.67	98.33
	S.D.	14.44	12.51	13.67	16.81	14.35	21.2

Experiment 1.4: 2AFC Recognition of Pure-Tones

		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	64.17	50.83	63.33	58.75	58.75	56.25
	S.D.	17.67	17.67	13.08	16.23	20.92	15.56
Backward		-	-	-	-	-	-
	Mean%	60.42	52.08	57.92	54.17	62.67	82.08
	S.D.	13.34	14.73	13.52	15.58	18.8	11.41

Experiment 3.2: Pseudo-reconstruction employing sequences of 7-unfamilair faces

		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6	S.P. 7
Forward	-	-	-	-	-	-	-	-
	Mean%	82.64	79.61	68.75	60.42	63.19	71.53	89.58
	S.D.	17.36	15.52	19.23	21.88	20.84	18.70	9.60
Backward	-	-	-	-	-	-	-	-
	Mean%	74.31	58.33	62.5	49.31	54.17	68.75	83.33
	S.D.	17.01	24.08	20.41	26.68	26.58	22.69	16.30

Experiment 3.3: Modified-reconstruction with 5-odour sequences

		S.P 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5
Forward	-	-	-	-	-	-
	Mean %	44.17	40.00	36.67	40.83	53.37
	S.D.	27.65	31.76	24.68	24.66	24.79
Backward	-	-	-	-	-	-
	Mean %	40.00	32.50	35.83	32.50	46.67
	S.D.	28.28	26.25	23.16	23.45	22.59

Experiment 3.4: Modified-reconstruction with 6-odour and 6-face sequences

Odours		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	44.44	38.19	39.58	42.16	48.61	53.47
	S.D.	25.85	22.78	27.28	25.53	27.77	25.57
Backward		-	-	-	-	-	-
	Mean%	36.53	25.69	21.23	22.48	25.54	26.68
	S.D.	25.53	25.69	21.23	22.48	25.54	26.68
Unfamiliar-Faces		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	89.58	83.33	80.56	80.56	76.39	82.64
	S.D.	11.85	16.30	17.49	19.45	24.04	18.04
Backward		-	-	-	-	-	-
	Mean%	81.94	70.14	68.75	65.28	81.94	88.89
	S.D.	18.33	25.53	26.61	27.77	17.66	15.28

Experiment 3.5: Modified-reconstruction with 4-, 5- 6- and 7-tone sequences

4-Items		S.P. 1	S.P. 2	S.P. 3	S.P. 4	-	-	-
Forward	-	-	-	-	-	-	-	-
	Mean%	66.67	61.11	59.72	62.5	-	-	-
	S.D.	24.08	21.8	21.53	22.12	-	-	-
Backward	-	-	-	-	-	-	-	-
	Mean%	56.94	52.08	52.08	87.5	-	-	-
	S.D.	17.66	19.85	23.73	18.55	-	-	-
5-Items		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	-	-
Forward	-	-	-	-	-	-	-	-
	Mean%	50	45.14	34.03	34.03	42.36	-	-
	S.D.	25.54	21.81	19.95	15.91	19.65	-	-
Backward	-	-	-	-	-	-	-	-
	Mean%	35.42	34.03	36.11	54.17	85.42		
	S.D.	22.21	23.30	22.88	25.18	15.78		
6-Items		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6	-
Forward	-	-	-	-	-	-	-	-
	Mean%	52.08	48.61	38.19	35.42	35.42	50.69	-
	S.D.	25.21	18.98	20.55	20.45	23.22	21.81	-
Backward	-	-	-	-	-	-	-	-
	Mean%	29.17	29.86	31.25	27.78	37.5	61.11	-
	S.D.	20.41	24.56	18.59	18.82	21.56	10.67	-
7-Items		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6	S.P. 7
Forward	-	-	-	-	-	-	-	-
	Mean%	43.06	31.94	24.31	23.61	29.17	29.86	46.53
	S.D.	20.8	18.33	19.02	18.98	19.81	17.01	24.07
Backward	-	-	-	-	-	-	-	-
	Mean%	25.69	19.44	22.92	29.86	25	33.33	85.42
	S.D.	21.98	16.05	22.42	20.84	19.03	23.57	23.22

Experiment 4.1: Modified-reconstruction employing sequences of 7-unfamilair faces with articulatory suppression/finger-tapping

Articul. Suppr.		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6	S.P. 7
Forward	-	-	-	-	-	-	-	-
	Mean%	75.00	62.50	56.25	59.03	57.64	59.03	79.17
	S.D.	20.85	20.41	26.38	23.56	26.00	24.56	21.56
Backward	-	-	-	-	-	-	-	-
	Mean%	70.14	56.25	54.17	48.61	49.31	58.33	73.36
	S.D.	21.56	27.00	24.70	26.43	21.81	25.06	18.37
Finger-Tapping		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6	S.P. 7
Forward	-	-	-	-	-	-	-	-
	Mean%	79.17	73.61	62.5	65.28	62.5	61.81	79.17
	S.D.	21.56	21.38	22.66	27.33	27.03	28.44	22.12
Backward	-	-	-	-	-	-	-	-
	Mean%	60.04	51.39	53.47	44.44	38.19	54.86	70.14
	S.D.	25.45	24.53	23.04	25.85	25.76	22.78	29.89

Experiment 4.2: Modified-reconstruction with 4-odour sequences employing articulatory suppression and silence during presentation phase

Silent		S.P. 1	S.P. 2	S.P. 3	S.P. 4
Forward	-	-	-	-	-
	Mean %	54.17	47.92	52.08	62.05
	S.D.	23.18	28.36	25.21	24.26
Backward	-	-	-	-	-
	Mean %	38.19	38.89	47.22	57.64
	S.D.	21.69	23.91	24.41	23.64
Articulatory Suppression		S.P. 1	S.P. 2	S.P. 3	S.P. 4
Forward	-	-	-	-	-
	Mean %	36.81	36.11	37.50	56.25
	S.D.	25.05	26.31	24.70	25.92
Backward	-	-	-	-	-
	Mean %	43.75	32.39	43.06	54.86
	S.D.	21.32	21.69	21.01	24.32

Experiment 4.3: Modified-reconstruction with 5- and 6-nonword sequences presented visually and aurally

5-Nonword Visual		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	-
Forward		-	-	-	-	-	-
	Mean%	84.03	75	76.39	70.14	79.86	-
	S.D.	20.55	20.85	19.61	24.56	17.01	-
Backward		-	-	-	-	-	-
	Mean%	71.53	67.36	67.36	52.78	74.31	-
	S.D.	16.65	23.3	25.29	27.22		-
5-Nonword Aural		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	-
Forward		-	-	-	-	-	-
	Mean%	68.06	64.58	55.56	63.89	72.22	-
	S.D.	25.5	21.03	24.9	21.23	19.45	-
Backward		-	-	-	-	-	-
	Mean%	72.22	62.58	62.5	63.89	84.28	-
	S.D.	20.66	20.21	24.2	17.49	7.74	-
6-Nonword Visual		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	84.03	74.31	67.36	69.44	72.22	77.08
	S.D.	19.95	21.56	27.57	26.77	22.88	16.16
Backward		-	-	-	-	-	-
	Mean%	81.25	60.42	56.94	63.19	65.97	86.1
	S.D.	22.15	28.58	30.26	28.22	28.01	21.8
6-Nonword Aural		S.P. 1	S.P. 2	S.P. 3	S.P. 4	S.P. 5	S.P. 6
Forward		-	-	-	-	-	-
	Mean%	50	48.61	40.28	42.16	40.97	52.78
	S.D.	27.36	28.2	28.2	26	24.56	23.4
Backward		-	-	-	-	-	-
	Mean%	61.11	58.17	50	46.53	70.83	95.83
	S.D.	27.22	24.7	25.06	27.35	21	8.86