# LINGUISTIC DETERMINANTS OF SERIAL SHORT-TERM MEMORY: THE ROLE OF (CO) ARTICULATORY FLUENCY

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# DECLARATION AND STATEMENTS

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This work has not been previously accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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# SUMMARY

Linguistic familiarity effects are principally attributed to the item-based, process of redintegration whereby partially-decayed, temporary representations are reconstructed at retrieval using long-term phonological knowledge of items. An alternative tested in this thesis was that familiarity influences memory at the sequence (rather than the item) level by enhancing the efficacy with which items may be assembled into sequences, especially in relation to the process of coarticulation. Specifically, these studies examined the role played by co-articulatory fluency of the boundaries between list items – necessarily a sequence- rather than item-level factor – on verbal short-term serial recall performance. The first empirical series identified that articulatory duration differences between items differing in level of familiarity only became apparent when sequence duration rather than single item or pair duration was measured. Furthermore, the experiments found that the observed improvement in recall with practice was due to increasing coarticulatory fluency in producing the sequence rather than greater fluency in producing the items. Empirical series 2 examined further whether coarticulation, rather than the formation of associative links between items in a set, led to faster articulation rates and improved recall for familiar lists. It was found that the articulatory fluency resulting from familiarisation with sequences of items generalised to sequences of different items so long as those items shared between-item coarticulatory transitions with the familiarised items. These results suggest that linguistic familiarity effects in short-term memory are, at least in part, due to articulatory fluency. The results of this thesis are discussed in relation to a wider view of short-term memory research that suggests short-term memory performance is parasitic on general perceptual and motor/gestural processes.

# Chapter 1:

# Introduction to Verbal Short-term Memory

## 1.1 Overview of Thesis

Present-day understanding of verbal short-term memory comes primarily from research using serial recall tasks, which commonly involve the recall of familiar items in an unfamiliar sequence. This technique has not only identified that memory span for an ordered sequence is relatively short (at most seven to nine items can be recalled correctly), it has also identified some canonical effects upon short-term memory performance. These include effects of word length (e.g. Baddeley, Thomson & Buchanan, 1975; Schweickert & Bouruff, 1986), lexicality (e.g. Hulme, Maughan & Brown, 1991; Hulme, Roodenrys, Brown & Mercer, 1995; Roodenrys, Hulme & Brown, 1993), phonological similarity (e.g. Conrad & Hull, 1964; Baddeley, 1968; Schweickert, Guentert & Hersberger, 1990), and word frequency (e.g. Gregg, Freedman & Smith, 1989; Roodenrys, Hulme, Lethbridge, Hinton & Nimmo, 2002). In explaining these serial recall phenomena the conceptual and empirical focus has been predominantly on the properties of the individual items making up a sequence rather than on the superordinate properties of the sequence particularly as it relates to the assembly and rehearsal of a sequence.

Consequently, current interpretations of how various short-term memory phenomena affect immediate serial recall performance stem from the character of the individual items making up the to-be-remembered lists. Standard accounts of short-term memory focus on how speech processes maintain the items in a temporary short-term memory store, mainly through subvocal articulation of the items (e.g. Baddeley, 1986, 2000). Consistent with this emphasis on the fate of individual items there has also been a distinction made between long-term and short-term influences upon immediate memory. Short-term influences predominantly involve the maintenance and storage of material in the short-term store through the process of rehearsal, whereas long-term influences commonly involve the notion of redintegration which involves the reconstruction of partially decayed traces from the short-term store at retrieval, using existing long-term phonological knowledge.

Contemporary models of short-term memory typically incorporate a reconstruction stage (e.g. Brown, Preece & Hulme, 2000; Burgess & Hitch, 1999; Lewandowsky & Farrell, 2000; Nairne, 1990) as well as retaining some key elements of the working memory model such as the idea of temporary short-term storage and/or trace decay. Regardless of whether short-term memory phenomena are explained in terms of rehearsal efficiency or redintegration efficiency; both approaches predominantly focus on the characteristics of individual items without taking into account the characteristics involved in planning and producing whole sequences which is arguably what is required in serial recall responses. For example, current computational models of memory for serial order also focus on the retrieval of individual items, with little reference to how other items in a sequence can affect serial recall performance (e.g. Burgess & Hitch, 1996; 1999; Page & Norris, 1996).

An alternative viewpoint that will be considered and for which evidence will be sought throughout the present thesis is rather than reflecting specialised mnemonic processes such as a phonological store and long-term representations, short-term serial recall performance is the result of language perception and production processes which act to organise and preserve the order of to-be-remembered sequences. If this is the case then constraints involved in sequence planning and production should also constrain verbal serial recall performance. Moreover, throughout this thesis, there will be a corresponding emphasis on the sequence rather than the item.

Thus, the present thesis is concerned with the importance of the articulatory characteristics involved in the assembly and production of sequences in determining serial short-term recall performance. The thesis attempts to illustrate the role of speech planning and production processes in explaining linguistic familiarity effects observed in serial recall tasks. Specifically, it focuses on how the constraints of speech production, in particular the articulatory fluency and complexity of coarticulations involved in sequence production, also serve to constrain immediate serial recall performance.

Previously the roles of speech gestures and coarticulations involved in sequence production have been overlooked in explaining serial short-term memory performance. It will be suggested presently that previous methods used to measure articulatory duration and/or rate of spoken verbal stimuli, have focussed rarely on the whole duration of sequences, instead they typically concentrate on the duration of individual or pairs of items. It is possible that such methods are insensitive to coarticulatory differences and may have led to the domination of the idea that articulatory factors are less important than the contribution of long-term memory to short-term recall performance when explaining linguistic familiarity effects.

The present thesis is presented over four chapters; the first chapter will be a short review of short-term verbal serial memory and the current explanations given for various short-term memory phenomena, including rehearsal and redintegration processes. Chapter 1 will then go on to discuss how short-term memory is possibly parasitic upon language production and perception processes and how constraints of language production may affect verbal serial short-term memory performance, but which have been previously overlooked in studies of serial short-term memory phenomena. The chapter will then go on to discuss how sequence based articulatory factors such as ease of coarticulation and fluency may have been overlooked in descriptions of serial recall performance, suggesting that previous methods of measurement which have ruled out an articulatory basis to some short-term memory effects may not have captured the full contribution of coarticulation.

Chapter 2 is the first of two empirical chapters, describing five experiments, which investigate whether linguistic familiarity effects traditionally attributed to redintegration processes could also be partially attributed to the constraints of the speech-based process of coarticulation. The experiments will assess the contribution of increased coarticulatory fluency to improvement in serial recall performance independent of redintegration and whether familiarity influences memory at the sequence level by enhancing the fluency with which items can be assembled into sequence. In addition the experiments presented in Chapter 2 examine whether measuring the articulatory duration of items in isolation and pairs is insufficient to fully capture coarticulatory differences which may exist between familiar and unfamiliar items. A more accurate method of measuring articulatory duration will be proposed involving the measurement of 6-7 item sequences (the typical list length required for serial recall experiments). One final experiment will then be described investigating whether the observed effects of coarticulation could possibly be explained in terms of association.

Chapter 3 is the second empirical chapter and will discuss further the idea that language perception and production processes are co-opted in the service of serial recall tasks, before describing how language production and perception processes can adapt to recent experience. A number of studies which have been carried out indicating how the language production system can be altered from relatively short listening and or production experience and how this could affect familiarity in serial recall performance. Chapter 3 will then go on to describe three experiments which investigate whether or not coarticulations can be generalised to different sequences of items which share the coarticulations of a familiarised list of items where production has been practiced. These experiments attempt to disentangle further the effects of association and coarticulation and see whether coarticulation can be generalised.

Finally Chapter 4 will discuss the findings and their implications especially in relation to what they can tell us about the perceptual /motor basis to short-term verbal memory, and the importance of the planning, assembly and production of sequences rather than just individual item production in memory tasks.

## 1.2. Serial Verbal Short-term Memory

Short-term verbal memory for serial order is an important and widely researched area in the field of experimental psychology, not least because it underlies many basic cognitive tasks including sentence comprehension, mental arithmetic and reasoning. However, performance of immediate serial recall is strictly limited, with memory span for adults typically being a maximum of only six or seven unrelated monosyllabic words (Gathercole & Baddeley, 1993). Present understanding of verbal short-term memory comes predominantly from research using immediate serial recall tasks. This procedure involves the presentation of familiar items in an unfamiliar order, which is followed by a cue for the participant to recall the items in their original order of presentation. This technique has identified a number of distinctive factors that are known to affect verbal short-term memory performance including, those of word length, word frequency, lexicality, language familiarity and phonological similarity. In addition, factors such as the modality of presentation, irrelevant sound and articulatory suppression have also been found to have distinctive effects on serial recall performance. Numerous theories have been proposed about the mechanisms controlling short-term memory performance, some of which will be reviewed in the current thesis. Typically, these factors influencing memory performance are interpreted in terms of how the properties of the items affect the short-term retention of individual items in a to-be-remembered sequence, predominantly through sub-vocal rehearsal mechanisms.

The most established and empirically tested description of verbal memory is the working memory model (Baddeley & Hitch, 1972; Baddeley, 1986; 2000), a model which explains many key short-term memory phenomena in terms of interaction between a short-term store and phonological loop mechanism. Classically, verbal short-term memory performance was essentially just regarded as a reflection on the number of items that an individual can successfully rehearse immediately after the last item has been presented (Baddeley, Thomson & Buchanan, 1975). Although more recently, it has been suggested that long-term representations aid the recall of items from the short-term store through the process of redintegration (e.g. Schweickert, 1993). Both rehearsal and redintegration explanations of serial recall phenomena will be the focus of this review. Current models of short-term memory typically include an item reconstruction stage as well as a separate mechanism which determines the order of output (e.g. Burgess & Hitch, 1996; 1999; Page & Norris, 1998). However a recent suggestion and one that will be considered throughout this thesis, is that immediate serial recall is not so much the result of an interaction between a phonological store and long-term representations but rather a case of perceptual and production processes which act to preserve the order of to-be-remembered sequences (e.g. Jones, Macken & Nicholls, 2004; Jones, Hughes & Nicholls, 2006; Macken & Jones, 2003). If this is the case then constraints involved in sequence planning and production should also constrain verbal serial recall performance.

### 1.2.1. The Standard View of Short-term memory: Trace decay and Rehearsal Models.

Traditionally, models of serial short-term memory performance combine the constructs of trace decay and rehearsal in a complementary fashion. According to these models, to-be-remembered items are encoded and represented in a short-term store by phonological traces, which are the abstract representations of verbal events and are subject to decay within a couple of seconds. However, this decay can be overcome by a process of rehearsal (subvocal articulation), which refreshes the decaying representations. The elements of trace decay and rehearsal are implicated in many models of short-term memory performance.

1.2.1.1. *Phonological Loop/Working Memory Model*

One of the most influential and extensively researched of this type of model is the working memory model or phonological loop model (Baddeley, 1986, 2000; Baddeley & Hitch, 1974) which has been used to explain the majority of short-term memory phenomena. The two key components in the working memory model, which are critical for the explanation of verbal short-term memory performance, are the phonological store and the phonological loop. The phonological store is regarded as the passive component, which acts as a temporary store for auditory input. This temporary store construct is believed to be susceptible to interference from irrelevant sound and also the items held in it are subject to decay over time. The phonological loop is the generative/productive component, which is used to both recode visual information into phonological form as well as refresh decaying representations through subvocal rehearsal.

According to this model, to-be-remembered items are phonologically encoded into the phonological store – an automatic process in the case of auditory-verbal information – or if the verbal information is visually presented the phonological loop can encode the information into phonological form. Once in the phonological store these abstract phonological item traces are subject to rapid decay, the duration of a trace before decay occurs is thought to be as little as between 1.8 and 2.2 seconds (Baddeley, Thomson & Buchanan, 1975; Schweickert & Bouruff, 1986). However, to counteract the decay process rehearsal or subvocal articulation can be carried out which refreshes the item representations and maintains the information in the short-term memory store. During the rehearsal process, the phonological codes in the phonological store are believed to be sequentially converted into articulatory motor programmes and vocalised either overtly or covertly, leading to a revivification of the degrading traces. Although the 'phonological loop' bears a striking resemblance to language production processes, typically, this is not explicitly addressed in the model, instead it is seen as related to but separate from normal language processes.

Through the interplay between the phonological store and the phonological loop, the working memory model has been able to account for a range of short-term memory phenomena. The word length effect – more accurate recall performance of short words than long words in immediate serial recall –and articulatory suppression effects – where memory span is drastically reduced if participants utter irrelevant material during list presentation – are attributed to the action of the phonological loop. The length of an item determines how often it can be rehearsed in a set time and uttering irrelevant material engages the articulatory loop so it cannot be used for rehearsal. Whereas the irrelevant sound effect, which occurs when the recall of lists of items is disrupted by the presentation of irrelevant spoken material, and the phonological similarity effect (Conrad & Hull, 1964), where sequences of similar sounding words (e.g. *b, d, t, v*) are recalled less accurately in order than sequences of dissimilar sounding items (e.g. *k, l, m, x*) are both situated in the phonological store. In the case of the former, phonological representations of the articulatory suppression are thought to interfere with the storage of the to-be-remembered items whereas phonological similarity is attributed to the confusion of similar sounding representations in the phonological store, reducing recall accuracy.

There are some striking interactions that occur between modality of presentation, irrelevant sound and the phonological similarity of to-be-remembered items which have been the basis to the phonological loop model. For example the phonological similarity effect abolished under articulatory suppression but only when the presentation mode of stimuli is auditory not when it is visual (Baddeley, Lewis & Vallar, 1984; Murray, 1968). This effect is attributed to the action of the phonological store, whereby for auditory presentation the similar sounding item codes are confused with one another in the phonological store. Such an effect does not occur in the visual mode as the items are prevented from entering the phonological store in the first place and therefore any confusion is prevented, as the phonological loop is otherwise engaged in articulatory suppression.

More recently though the interaction between modality of to-be-remembered information presentation and the affect of irrelevant sound and suppression has been re-examined, and it has been argued that rather than reflecting the action of a specialised short-term store, the phonological similarity effect is the result of perceptual and articulatory planning factors involved in organising the to-be-remembered material (Jones, Macken & Nicholls, 2004; Jones, Macken & Hughes, 2006) – an issue extremely pertinent to the present thesis and one which will be addressed in more detail later in this chapter. First the evidence for subvocal rehearsal or articulatory basis to short-term memory performance will be considered.

### 1.2.2 Evidence for the role of rehearsal in short-term memory performance.

Trace decay and rehearsal theories indicate the 'phonological' basis to verbal short-term serial recall performance, by placing emphasis on the importance of speech or speechlike codes. For example the phonological loop is regarded as a mechanism, which is used to refresh the decaying traces in the phonological short-term store through subvocal rehearsal. The nature of the phonological loop is assumed to be a specialised 'articulatory rehearsal process' and therefore distinct from normal articulatory processes (Baddeley, 1986). Nevertheless, evidence for the important role of rehearsal in short-term memory performance has come from a number of sources.

1.2.2.1 *Speech rate and memory span*

The most compelling evidence for rehearsal processes in serial short-term memory has come from the well documented relationship between short-term memory span and speech rate: the faster rate at which an individual speaks the larger their memory span has been found to be. This monotonic relationship between maximal speaking rate and memory span has been consistently shown in both adult and children populations (Hulme et al., 1984; Cowan, 1992; Schweickert & Bouruff, 1986). Children display a developmental increase in memory span that is reflected by an increase in their speech rate (Cowan, Keller, Hulme, Roodenrys, McDougall & Rack, 1994; Cowan, Wood, Wood, Keller & Nugent, 1998; Henry, 1994). Thus, articulation or speech rate is commonly viewed as a measure of ones rehearsal processes; the proposal being that the faster one can speak the faster one can rehearse items before decay occurs. However, it has been argued that the while the speed of overt articulation (rehearsal) is correlated with the speed of internal/subvocal rehearsal, it is also distinct suggesting the subvocal rehearsal process is separate to existing language production processes (Baddeley & Wilson, 1985).

1.2.2.2 *Word-length effect*

The word length effect – more accurate recall of lists of short items (monosyllabic words) compared to lists of longer items (five syllable words) – is another source of evidence for a role for rehearsal in short-term memory performance. The word-length effect is one of the most salient features of immediate serial recall and has been replicated many times using different sets of stimuli and with both visual and auditory presentation. The general consensus is that more items of a short articulatory duration can be rehearsed before decay occurs than those of a long articulatory duration, resulting in less decay of short items compared to long items (Baddeley, Thomson & Buchanan, 1975; Hulme, Maughan & Brown, 1991).

1.2.2.3 *Cross-linguistic studies*

Results of cross-linguistic studies that have compared the digit span of speakers of different languages have also shown evidence of word-length effects and rehearsal differences. These studies have shown that speakers of languages with digits of short-spoken articulatory duration have a higher memory span for digits than speakers of languages that have longer digit duration (Ellis & Hennelly, 1980; Naveh-Benjamin & Ayres, 1986). For example, Chinese digit span has been found to be as high as 9.9 (Hoosain, 1982) whereas English digit span is only between 6 and 7 digits long (Gathercole & Baddeley, 1993), this is reflected in the shorter spoken duration of Chinese digits compared to English digits. In another study Cowan, Wood, Nugent & Treisamn, (1997) produced an artificial word length effect by instructing participants to pronounce the same words quickly or slowly, slower pronounced word lists were recalled less accurately than the faster pronounced word lists. Thus, there is a wealth of evidence suggesting that the amount one can remember in the short-term is directly related to how quickly items can be articulated, with longer items receiving less opportunity for rehearsal than shorter items.

1.2.2.4 *Word-length or complexity?*

More recent formulations point to a controversy over what the word-length effect actually represents, specifically, it has been suggested that it is not the spoken duration of items per se that produces the word-length effect, but more the phonological complexity of items (Caplan, Rochon & Waters, 1992; Service, 1998). These accounts of the word-length effect propose the reason that longer words are harder to recall is because phonologically they are more complex than short items and that there are limits on how much phonological information can remain in a retrievable state (Neath & Nairne, 1995). For example, the Feature Model (Nairne, 1990) stipulates that short-term retention is cue-driven like long-term memory and words are made up of multiple segments which need to be assembled correctly for the identification of an item, so to enable recall of items one must assemble the segments of degraded traces into useable retrieval cues. However, the more segments (phonemes) the item has (longer words) the greater the probability of an error being made for these items than shorter items, which contain fewer segments.

Similarly, it has also been suggested that the word length effect is more a product of the phonological structure of the word rather than features of its articulation that determine the magnitude of the word-length effect (Caplan, Rochon & Waters, 1992). Items with more phonological segments are thought to take more speech planning than items with less phonological segments. A series of studies have been carried out, by Caplan et al. (1992, 1994), on patients with Apraxia of speech, which is a disorder characterised by a deficit in speech planning rather than a deficit in the production of speech. These studies challenged traditional accounts of the word length effect by finding that items matched on number of syllables but with a longer vowel sounds were actually articulated faster than those with a short vowel sounds, however, there was no difference in span for the two types of item. These studies also suggest that rather than the features of articulation (such as the articulatory complexity involved in producing an item, it is the phonological structure of the word that determines the extent of the word-length effect.

The distinction between overt rehearsal and speech planning is an issue, which will be returned to later in this chapter. There is also the possibility that these effects just discussed and the controversy surrounding the origin of the word length are artefactual and arise from inconsistencies in the way articulatory duration of experimental stimuli has been measured (see; Mueller, Seymour, Kieras & Meyer, 2003). One of the key aims of the present thesis is to determine a more accurate way of measuring the articulatory duration of items used as serial recall stimuli, specifically one focussing on measurements which take into account the coarticulations involved in producing whole sequences.

1.2.2.5 *Articulatory Suppression*

Despite the controversy surrounding what actually produces the word-length effect, there is extensive evidence showing that memory performance varies with the articulatory duration of different classes of item, and this has been given as support for the activity of the phonological loop and the importance of subvocal rehearsal on memory performance. Another important source of evidence for classical models embodying trace decay and rehearsal models has come from the effect of articulatory suppression on serial recall performance. Using articulatory suppression as a factor in serial recall experiments has been a useful tool to examine the contribution of rehearsal to serial recall performance for different types of stimuli. Articulatory suppression has been found to abolish word length effects but effects such as the lexicality effect have been found not to be completely abolished (Besner & Davelaar, 1982). Thus, under articulatory suppression, the word-length effect disappears as neither short or long items are able to benefit from rehearsal, thus the item traces decay. Because articulatory suppression is believed to engage the articulatory loop, it cannot then be used to first encode visual items in the phonological store and second, it cannot be used to rehearse and refresh the phonological traces in short-term memory (Baddeley et al., 1975). Thus, if participants are already engaged in some sort of articulatory activity they are unable to perform sub-vocal rehearsal and refresh the decaying representations in the phonological store to retain the order of the to-be-remembered items.

1.2.2.6 *Neuropsychological Studies*

It has become apparent from neuropsychological studies that rehearsal may not even need to be enacted to still have an affect on serial recall performance. There is evidence from neuropsychological studies that just planning the rehearsal of items is sufficient to retain information. For example patients with dysarthria, which is a disorder characterised by a severe disturbance of overt articulation, when the muscle control of articulators is severely disturbed, still show normal memory span and word length effects. In contrast, patients with Apraxia of speech, characterised by an impairment of the sequencing and planning of speech, do exhibit impaired memory performance (Waters et al., 1992). Thus, it seems likely that rehearsal may not need to be enacted merely the planning of items for rehearsal may affect short-term memory (Baddeley & Wilson, 1985; Bishop & Robson, 1989; Vallar & Cappa, 1987). Thus rehearsal may not require subvocal or overt articulation but instead use a specification of articulatory gestures. The neuropsychological evidence for the nature of rehearsal processes will be discussed further later in the present thesis in relation to the nature of rehearsal in serial recall tasks

Although evidence in support of a rehearsal component to short-term memory is well documented, recent research into other short-term memory phenomena (e.g. word frequency, lexicality effects) has cast doubt on the importance of the role played by articulatory processes in determining memory, specifically for items differing in familiarity. Results have come to light that indicate that there are differences that exist between familiar and unfamiliar item recall, which are independent of any differences in rehearsal rate or speech rate. Such findings have led to the suggestion that there is a separate process to rehearsal that aids the recall of information from short-term memory. Specifically it is proposed that linguistic familiarity differences observed in serial recall are the product of the contribution of long-term memory representations to the short-term recall of verbal material. Evidence for such a role for long-term in short-term recall performance will be discussed presently.

## 1.3 Evidence for Long-term Memory Contribution to Short-term Memory Performance

The role of rehearsal and the phonological loop model is well documented; but there has been an accumulation of evidence indicating that rather than rehearsal being the sole determinant of immediate serial recall performance, another critical factor is the accessibility and availability of long-term representations of items to aid recall. What follows is a review of this proposal that long-term memory significantly contributes to short-term serial recall phenomena through a process of trace reconstruction. Such a proposal argues that the effects of linguistic familiarity are primarily the product of differential support from long-term memory rather than articulatory differences.

The early finding that engaging in articulatory suppression does not lead to a zero score in serial recall performance, but instead a reduced span of 3 or 4 items has been cited as evidence that rehearsal is possibly not the sole determinant of serial recall performance, and subsequently given as evidence for the possible role that long-term memory plays in short-term serial recall performance. (e.g. Craik, 1971; Baddeley et al., 1975; 1984; Ellis & Hennelly, 1980). Since then there has been an accumulation of evidence suggesting that long-term memory contributes to efficient short-term serial recall performance, specifically in the case of linguistic familiarity effects.

Linguistic familiarity effects are a class of short-term memory phenomena, whereby items that are familiar to a participant are recalled more accurately in serial recall tasks than items that are unfamiliar to the participant these include the word frequency effect- better recall of words that occur more frequently in language than less frequent words (Gregg et al., 1989; Hulme et al., 1997; Roodenrys, Hulme, Alban, Ellis & Brown, 1994) language familiarity effect – items in one's first language are recalled better than items in a less familiar language (Chincotta & Underwood, 1996; Thorn & Gathercole, 1999, 2000) and the lexicality effect – more accurate recall of word than nonword items (Hulme, Maughan & Brown, 1991; Turner, Henry & Smith, 2000; Besner & Davelaar, 1982; Gathercole et al., 2001). Traditionally, it was proposed that familiarity effects arise because familiar items can be rehearsed more rapidly than unfamiliar items as familiar items involve a more effective and practiced output phonology, therefore reflecting the rehearsal process of the phonological loop. Indeed. a number of early studies did indicate that rare words take longer to articulate than more common words; even when the items are matched on the number of letters they contained (Geffen & Luszcz, 1983; Wright, 1979).

More recently though the differences in the articulatory duration of stimuli that differ in familiarity has been rejected as an adequate explanation for the serial recall differences that exist (Hulme et al., 1991; Hulme et al., 1995; 1997; Thorn & Gathercole, 2001). Furthermore, a number of recent studies have shown that differences still exist between items of differing familiarity (e.g. words and nonwords), even when they are supposedly matched on articulation rate or when there is an apparent absence of any differences in the articulatory duration of the different classes of item (Thorn & Gathercole, 2001; Hulme & Brown, 1993, 1995, Roodenrys et al., 1997, 2002). In addition some cross-linguistic differences in memory span have not been found to be completely abolished when rehearsal is prevented; further evidence that long-term memory representations aid the recall of short-term memory tasks (Brown & Hulme, 1992). Consequently, articulatory determinants have been rejected as an adequate explanation for the linguistic familiarity effects in serial recall performance in favour of a contribution from long-term memory representations. The process by which long-term memory is thought to aid short-term memory performance is known as redintegration

### 1.3.1 Redintegration

Redintegration is a process of reconstruction which is typically thought to occur at retrieval, and which utilises long-term memory representations (e.g. Schweickert, 1993; Brown & Hulme, 1995). The conventional account of redintegration assumes that when the temporary trace of an item is accessed from the phonological store it may be partially decayed, so a redintegration process is initiated which reconstructs the incomplete representation using existing long-term memory representations of items. Thus the degraded trace is reconstructed from prior knowledge — the more available and accessible this long-term knowledge, the better the redintegrative support should be. There are a number of levels at which long-term memory information is thought to be used to reconstruct the degraded phonological traces; existing long-term memory representations are either thought to affect the original activation levels of items in the short-term phonological store at encoding and/or during rehearsal. Thus, when a word is encoded the long-term representations of familiar items result in stronger activation of these items, so they decay at a slower rate (Thorn, Gathercole & Frankish, 2005). Alternatively, it is more widely proposed that long-term representations primarily affect the redintegration of items as they are being retrieved at recall, hence available phonological knowledge of an item is used to fill in the gaps of degraded representation. The mounting evidence for a case for redintegration will now be discussed

#### 1.3.1.1 *Lexicality Effects*

One of the most compelling demonstrations for a long-term memory contribution to short-term recall performance comes from the lexicality effect: better recall performance for familiar/word items compared to unfamiliar/nonword items (Hulme et al., 1991; Hulme et al., 1995; Gathercole, Frankish, Pickering & Peaker, 1999; Roodenrys, Hulme, Lethbridge, Hinton & Nimmo, 2002). Despite some studies, which have shown that familiar items are spoken slightly more rapidly than unfamiliar items (Hulme et al., 1991, 1995) the lexicality effect is not interpreted as an effect of speech rate, as the differences between word and nonword duration are considered much smaller than the differences between word and nonword recall performance (Hulme, Roodenrys, Brown & Mercer, 1995). Differences between word and nonword recall have also been found to exist even when there are no apparent differences in the articulatory duration of words and nonwords (Thorn & Gathercole, 2001), or even when nonword articulatory duration is actually considered to be shorter than word articulatory duration (e.g. Hulme et al., 1991). Additionally, under articulatory suppression, although the word-length effect is diminished, the lexicality effect is not (Besner & Davelaar 1982) – a further indication that a process other than rehearsal mediates performance for items of differential familiarity. Consequently, redintegration theorists propose that the reason recall performance is much poorer for nonwords than words is due to nonwords not having any lexical representation in long-term memory to aid their reconstruction and recall. Furthermore, increasing the phonological familiarity of nonwords by using repeated repetition of items has been shown to increase their memorability, as has teaching participants the meaning of novel words (e.g. Brown & Hulme, 1993). These findings suggest that increasing the familiarity of items results in more available long-term representations to aid immediate serial recall (Roodenrys, Brown & Mercer, 1995). Thus, ones prior knowledge of language is believed to be an important initial determinant of serial recall performance.

#### 1.3.1.2 *Word Frequency Effects*

Word frequency effects – the more frequent an item in ones language the better recall performance than an item which occurs less frequently in a language – have also been observed in the absence of any notable differences in the articulatory length of the high and low frequency words (Hulme et al.,1997). Unlike nonwords, both high and low frequency words should still have a representation in phonological long-term memory, consequently the effect of frequency is interpreted not so much in terms of the availability of item representations but rather in terms of the accessibility of the item representations, with high frequency word representations being more accessible to aid reconstruction, than low frequency words which are used less often (Hulme et al., 1997).

However, it has since been proposed that word frequency exerts an influence not only on redintegration at the level of individual items but from associations made between items in long-term memory (Stuart & Hulme, 2000), In their study, Stuart & Hulme (2000) pre-exposed participants to high and low frequency pairs of items before a serial recall task and it was found that exposure to low frequency pairs led to enhanced recall performance for low frequency lists. This finding was interpreted as the associative links in long-term memory being able to further aid recall, with high frequency items benefiting from a greater level of existing inter-item associations in long-term memory than the low frequency items (see also Deese, 1960). Although it has since been argued that familiarising participants with individual items resulted in an equal level of improvement for low frequency lists (Saint-Aubin & Poirier, 2005), further supporting the idea that it is just familiarity with the items, not their co-occurrence which affects serial recall performance. This issue of association will be returned to in Chapter 2.

*1.3.1.3 Language Familiarity Effects; Bilingual Studies*

Further support for a long-term memory contribution and redintegration process in short-term memory performance comes from the language familiarity effects which are observed in bilinguals' recall. Language-specific variation in bilinguals immediate recall accuracy is well established at a number of different levels, typically bilinguals exhibit more accurate recall for items in their first or more familiar language than their second language (Chincotta & Hoosain, 1995; Thorn & Gathercole, 1999, 2001). Even nonwords in an individual's first language have been found to be more accurately recalled than nonwords in their second language (Thorn, Gathercole & Frankish, 2002) Since these differences remain when items are supposedly matched on articulatory duration and when rehearsal is prevented, it has again been argued that the effect cannot solely be the result of differences in subvocal rehearsal (Chincotta & Hoosain, 1998). Instead, in a bilingual individual, first language superiority has been attributed to the differential availability of long-term knowledge to support each language, with support greater for the more familiar language than the second language. Consistent with this is one study whereby bilingual adults who used their mother tongue both at home and at university were found to have a larger digit span in their mother tongue than their second language, whereas bilingual adults who used one language at home and another language at university showed no difference in digit span between their two languages (Chincotta & Underwood, 1996).

1.3.1.4 *Sublexical effects of redintegration*

There is increasing evidence for the influence of familiarity with a language, on verbal short-term memory capacity, particularly as they relate to the lexical knowledge of words. Thus, memory is enhanced by prior phonologically-based knowledge of a to-be-remembered item. Recent research into the contribution of long-term memory to short-term recall performance has shifted to focus on the internal structure of individual words, and the familiarity of sounds within words to try to establish whether redintegration works at a sublexical as well as a lexical level. It has been proposed that this second type of long-term memory support relates to knowledge concerning the sublexical or phonotactic properties of language.

This suggestion has arisen from a number of studies that have manipulated the 'wordlikeness' of nonwords required for recall. One such study found that nonwords that are considered more 'word like' are recalled better and repeated faster than nonwords considered less 'word like' (Gathercole, 1995). Other studies have varied the phonotactic frequency of nonwords, which has resulted in better recall performance for items containing phoneme pairs that have a high probability of occurrence in a language than item containing less probable phoneme pairs (Gathercole et al., 1999; Gathercole, Willis, Emslie & Baddeley, 1991; Roodenrys & Hinton, 2002; Vitevitch & Luce, 1999). Thus, familiar sound patterns are believed to be more readily represented than less familiar sound patterns in long-term memory (Gathercole & Martin, 1996).

Further evidence for a sublexical basis to redintegration comes from word neighbourhood effects whereby words with high density neighbourhoods are recalled more accurately than those from low density neighbourhoods (Roodenrys & Hinton 2002). A word's neighbourhood is classed as the set of words that differ from the target word by just one phoneme. This effect is interpreted in terms of the phonological information needed to reconstruct the degraded word representations that have many neighbours, being more available than those items with fewer neighbours. Also manipulations involving the biphone frequencies of nonwords have shown that nonwords with high biphone frequencies (items consisting of frequent biphones found in real words) are recalled more accurately than those with low biphone frequency (Roodenrys & Hinton, 2002; Thorn & Frankish, 2005).

However, whether or not the long-term contribution is believed to be lexical or sublexical, all these effects have contributed to the theory that existing knowledge of items in a language and its phonotactic regularities can lead to better recall performance as the phonological knowledge for these more familiar items is more available enabling a more efficient redintegration process, for item representations that are retrieved from a temporary short-term store. Nevertheless, while offering an indication of how linguistic familiarity impedes serial recall performance, redintegration accounts apparently ignore the intrinsic articulatory factors involved in whole sequence production. It is possible that there are articulatory differences between items that differ on familiarity but which only show up when the articulation of whole sequences is taken into account. Such a method of measuring articulation is rarely used, but would possibly include a measure of how easy items are to assemble and produce in sequence, which is typically what is needed for a serial recall task response. The importance of sequence level factors is typically ignored in favour of item based factors when it comes to the explanation of standard serial recall phenomena. Contemporary models of serial recall performance, which incorporate a redintegration process also predominantly concentrate on individual to-be-remembered items.

### 1.3.2 Models of memory for serial order

A number of computational models of immediate serial recall performance have been proposed to account for certain features of short-term memory that the working memory model does not explain including the effects of familiarity and how memory for serial order is encoded. A number of these contemporary models of immediate serial recall performance, incorporate a trace reconstruction or redintegration process to account for the long-term memory effects discussed above (e.g. Schweickert, 1993; Hartley & Houghton 1994; Lewandowsky & Farrell, 2000; Nairne, 1990). These models share the notion that redintegration involves the comparison of degraded traces in a short-term phonological store with a set of long-term memory traces, whereby the item that best matches the degraded item is selected. For example Schweickert's (1993) multinomial processing tree model of immediate serial recall of single items, includes the addition of a redintegration stage. The model proposes that there are two possible ways to achieve correct recall of an item. Firstly, an items trace is either intact so it has been maintained and can be directly accessed (possibly from rehearsal) and can be recalled correctly from the short-term store, or it is partially degraded. If the item traces are degraded than the degraded traces are used as cue to access long-term phonological knowledge of items, then a redintegration process reconstructs the item from the phonological store using the remaining information in the trace as a cue.

More generally though, the phonological loop model has been criticised for its lack of computational specification and how it is unable to explicitly account for how order is encoded. Serial recall tasks, as well as allowing for the identification of the different characteristics of to-be-remembered stimuli, which affect recall performance, they also identify distinctive patterns of recall and types of errors made. Tests of serial recall not only require the immediate recall of items they also require the order of the items to be encoded as well. It has been consistently shown that when recall performance is plotted by serial position, a distinctive serial position curve is achieved showing an advantage for items at the start of a list (the primacy effect) and a similar albeit smaller advantage for the last item in a list (recency effect). In addition, some patterns of errors (e.g., item transpositions) are more likely than others. These issues are not explicitly addressed in the phonological loop model. Consequently, a number of computational models have been proposed to account for how memory for serial order is represented, some of which integrate the main assumptions of trace decay and rehearsal mechanisms (Hartley & Houghton; 1994; Burgess & Hitch, 1999; Henson, 1998). Such models of serial recall performance attempt to explain the difficult problem of how order is encoded, as well as predicting typical response patterns in serial recall task.

Two classes of computational models have been proposed – associative and non-associative. Associative models assume that serial order is retained by encoding associations between items, thus, learning a sequence involves the formation and strengthening of associations between items, these are known as chaining models. The simplest chaining model assumes that an item cues the recall of the adjacent item, and recall performance is made up of a number of pairwise associations. However such models have been widely criticised for their simplicity and inability to common serial recall errors and how when one item in a list is recalled incorrectly, it does not necessarily mean that the rest of the list will be recalled incorrectly. Consequently chaining models of serial order are relatively unpopular even though more complex models have addressed some of the problems (e.g. Lewandowsky & Murdock, 1989).

In contrast, more accepted serial order models are non-associative, in these models, items exist in relative isolation of one another in memory. Such models assume that order is retained by encoding subsequent items with differential strengths of activation (e.g. Primacy model, Page & Norris, 1998) or by associating items with a context signal (e.g. Brown, Preece & Hulme, 2000; Burgess & Hitch, 1999). The network model of Burgess & Hitch (1999) incorporates the main features of the phonological loop model as well as offering an explanation for how memory for serial order is achieved. In this model each to-be-remembered item is associated with the position in which it was presented, a context signal, which starts at the beginning of the list and then proceeds to the end. At recall, the context clock is rewound and each item associated with each context signal is reproduced. A competitive queuing mechanism is also initiated at recall whereby the representation with greatest activation is chosen and then suppressed. Common positional errors such as transpositions are believed to result from confusions between similar/close context signals.

Another model based on competitive cueing is the primacy model (Page & Norris, 1996), in this model the position of an item is achieved from the relative pattern of activation strengths between the items (which are represented by nodes). Activation strength is greatest for the node representing the first item in a list, and reduces with each successive item node. This pattern of activations results in a primacy gradient which corresponds to the relative position of items in a list and thus, order is represented in this primacy gradient. During retrieval the primacy gradient is reinstated and a competitive queuing process is initiated which involves the successive selection and subsequent suppression of the node with the greatest activation level. Similar to the phonological loop, the primacy model posits that activation of a node begins to decay immediately after the list has been presented, but if rehearsal occurs then decay is reversed and the activation levels of the nodes are reinstated. Once an item has been selected it is suppressed and the next most active item is recalled, this pattern is repeated until the whole list has been recalled.

In order to account for language familiarity effects (e.g. lexicality, and frequency effects) and to enable the accommodation of how long-term memory affects short-term memory performance, these models typically incorporate a second stage of processing, whereby the retrieved items, which are partially degraded, are automatically compared to secondary or long-term memory representations. This is similar to a redintegration stage, so the item that is the nearest match to the retrieved item is selected for recall. This second stage is required to compare the impoverished item representation of the first stage to its most likely candidate. The inclusion of two stages in these models has allowed for not only a description of how order is represented (first stage) but also item error such as omissions and phonological confusions can be accounted for, as well as the influence of long-term memory, by the second stage. In both these models of memory for serial order again the main focus is on the independence between all items represented in memory.

### 1.3.3 Discussion: Preoccupation with item in accounts of short-term memory phenomena

Hitherto, the accounts of serial short-term memory which have been discussed predominantly focus on how the properties of individual items affect the memorial strength of each item independent to all other items in the to-be-remembered list. However, it is possible that the articulatory fluency involved in assembling the to-be-remembered items into an output sequence could also have an influential role in serial recall performance. One of the main aims of the present thesis is to examine whether linguistic familiarity at the sequence level may also have an influential effect on serial recall performance. Sequence level factors have been largely overlooked when explaining such serial recall phenomena as linguistic familiarity effects.

Current descriptions of short-term memory performance rarely acknowledge the possible influence of the articulatory processes, which are involved in assembling items into sequences. Although the phonological loop model has rehearsal at its core the process is largely underspecified in the model. The conventional account being that subvocal rehearsal is a way of refreshing individual item traces in the short-term store, so they can be retrieved at recall. The redintegration process can also be predominantly classed as an item-based account, in that it focuses on how ones prior knowledge of an individual item is used to reconstruct the decayed traces rather than on features of a whole sequence. Similarly, models that incorporate such a redintegration process either operate at the lexical level of the item or the sublexical level of the individual phonemes making up the item, *not* the level of the sequence.

Contemporary, computational models of memory for serial order, rather than concentrating on the processes that which underpin the relationships between and among items within sequences, also primarily focus on the activation levels, retrieval and recall of individual items. The next section will discuss the possibility that there are articulatory factors involved in planning, assembling and producing sequences, which may have an influencing role in serial recall performance. Prior to this the argument for a shift in focus from mnemonic constructs such as the phonological store, interference and decay to the importance of a perceptual and gestural influences on serial recall performance will be addressed.

### 1.4 Perceptual/Gestural Account of Short-term memory performance: An alternative to the phonological loop model.

More recently it has been suggested that there should be more of a focus on the processes underpinning the relationships among items within sequences rather than purely focussing on the characteristics of to-be-remembered items, when explaining serial recall performance (Macken & Jones, 1995; Jones, Macken & Nicholls, 2004). In the standard view of short-term memory, recall performance is typically explained in terms of a short-term memory system, made up of a number of components which are often regarded as entirely separate from earlier perceptual processes, typically memory models focus on what happens to an item once encoded.

However, a departure from this view has been suggested in the form of an account that highlights the importance of perceptual organisation and gestural skills in explaining short-term memory performance. Such a perceptual organisation account focuses on how auditory perception and gestural processes usually utilised in language perception and production are used to support the serial recall of items from short-term memory. There is an expanding body of evidence suggesting that some short-term memory phenomena can be better understood as reflecting auditory perceptual organization or speech/gestural skills rather than being the result of specialised mnemonic processes. Specifically it has been proposed that such skills can be used to impose order on to-be-remembered material (Macken & Jones, 2003; Jones, Macken & Nicholls, 2004). This is similar to seeing cognitive performance as a set of skills rather than a collection of separate components and structures (e.g. Glenberg, 1997).

Typically, the role of perception and gestural processes in the retention of serial order are either ignored or regarded as less important than mnemonic constructs such as decay and interference in the phonological store. Current models of serial short-term memory primarily focus on how the phonological loop and temporary store are specialised for the retention of material in the short-term, rather than on the perceptual processes involved in encoding order. The standard model of verbal short-term memory is described as an interaction between a passive short-term store and the phonological loop. The phonological store is the component of memory where items are stored in a phonological code, but this store is open to decay and/or interference. The phonological loop is used to first recode visual stimuli into phonological form, and second as a subvocal rehearsal mechanism used to refresh decaying representations in the phonological store. When articulatory suppression is carried out the phonological loop is engaged so visual items cannot be recoded and auditory items cannot be rehearsed.

The main evidence for such an interaction comes from the effects of phonological similarity and irrelevant sound. The locus of the phonological similarity effect is within the phonological store, where it is thought that the phonological codes of similar sounding items get confused within the short-term store leading to less accurate recall performance. Additionally, irrelevant sound is thought to add interference to the items in the phonological store as irrelevant sound (being auditory) has obligatory access into the phonological store where it can interfere with to-be-remembered item representations. This is given as the reason for the finding that under articulatory suppression the phonological similarity effect disappears in the visual modality (as items were prevented from entering the phonological store in the first place) but remains when mode of presentation is auditory. This interaction has been consistently presented as evidence for the phonological loop model.

Much of the evidence for a perceptual /gestural basis to short-term memory has focussed on how auditory perceptual organisational skills can account for some salient features of short-term memory such as the phonological similarity and irrelevant sound effects without implicating specific mnemonic processes or constructs such as the phonological store (Hughes & Jones, 2005; Jones, Macken & Harries, 1997; Jones et al., 2004, 2006; Macken & Jones, 2003). It is proposed that the phonological similarity effect arises primarily due to articulatory confusions, when rehearsal is allowed. However, when rehearsal or gestural skills are unavailable, under conditions of articulatory suppression, this is when auditory perceptual organisation skills are applied onto the acoustic stimuli (Jones, Hughes, Macken, 2006). Thus, the interactions observed between phonological similarity, articulatory suppression and modality have been explained more simply in terms of the ability to apply perceptual organisational skills onto acoustic material, especially when one is unable to use their gestural skills (rehearsal processes) to impose order on the material. Thus rather than using specific mnemonic constructs such as interference and phonological storage, serial recall performance can be more simply seen as a collection of perceptual processes which organise incoming information (Macken & Jones, 1995; Jones, Macken & Nicholls, 2004; Jones, Hughes & Macken 2006).

### 1.4.1 Articulatory Determinants of Serial Short-term memory

Rather than concentrating on how memory for order is achieved when rehearsal is prevented, it is the articulatory nature of serial recall performance which is the most interest to the present thesis. The experiments in the present thesis aim to examine how gestural and speech processes can be used to aid the retention of order in the short-term when rehearsal is permitted. Specifically, I will focus on how speech production and planning mechanisms involved in articulating a list of items together could be an important determinant of serial short-term memory. Thus, this next section will assess how processes which exist primarily for the production of language could constrain memory performance. In particular, the importance of sequence-level factors, specifically those processes involved in rehearsing items together, and how these could possibly constrain short-term memory performance will be examined. This idea will now be explored along with the idea that short-term memory performance is somewhat parasitic upon language production processes.

*1.4.1.1 Speech Errors*

Evidence that language production processes are an important determinant of memory performance is not a new proposal. Early evidence that memory performance is highly dependent on language production processes has come from studies examining speech errors. It has been found that the typical errors made on serial recall tasks have a corresponding error in natural speech. For example, Ellis (1980) carried out an extensive study comparing errors made in serial recall performance and found that they were consistently the same as errors seen in speech production. Common errors observed in serial recall tasks include transposition errors where initial consonants of different items are transposed — a typical characteristic of spoonerisms in natural speech (Mackay, 1970). The results were explained by of what Ellis (1980) called a 'response buffer' where pre-planned stretches of speech could be briefly held. The primary function of the buffer was supposed to be the production of speech, but it is also able to be utilised in immediate serial recall tasks where it is also necessary to assemble the to-be-remembered items into a speech plan. This is an indication that speech production and rehearsal in serial recall tasks use the same language skills, and further evidence that during serial recall tasks participants use what processes they have available to them to retain serial order.

*1.4.1.2 Rehearsal*

Although models of short-term memory highlight the importance of rehearsal in serial recall performance, often the precise mechanisms and production processes needed to plan and rehearse items in sequence are unspecified. The phonological loop model (Baddeley, 1986, 2000) stipulates that rehearsal is the specialised process by which the phonological codes that are stored in the phonological store are revivified, to decrease the likelihood of the item decaying from the store before retrieval. Neuropsychological studies of patients with different language impairments have shown that actual overt articulation is not necessary for rehearsal occur, what is important is the motor planning and sequencing of sounds (Bishop & Robson, 1989; Caplan et al.,1992; Waters et al.,1994). Patients with dysarthria, a disorder characterised by severe disturbances of articulation, typically show normal memory span (Bishop & Robson, 1989). However patients with apraxia of speech whereby the motor planning of speech is disturbed have impaired memory performance (Caplan et al., 1992, Waters et al., 1994). It is possible then that rehearsal and spoken recall can be derived from what is primarily a motor output plan for the vocal tract. Furthermore, rather than to-be-remembered items being articulated individually they are articulated in sequence. By examining the characteristics and demands of typical serial tasks, the next section will propose the importance of articulatory fluency in assembling and producing the items sequence.

*1.4.1.3 Demands of Serial Recall Task*

Typically, immediate serial recall tasks involve the rapid presentation of unrelated items in quick succession, which is immediately followed by a cue to recall/reproduce them. The task demands that items are recalled in the order that they were presented. Typically, the stimuli in serial recall tasks are unrelated and devoid of any meaning or prosody to aid reproduction. It has been suggested that given the rapid successive presentation of items, speech skills are used to impose order on the to-be-remembered items in sequence (Jones, Macken & Nicholls, 2004; Macken & Jones, 1995). Thus, rehearsing the items by assembling the items into an output sequence which can then be rapidly rehearsed and then reproduced at recall seems the most efficient way to carry out the task. Furthermore, it is more probable that rather than each item being recalled and rehearsed independently of all other items, what is assembled and reproduced at recall is the whole output plan. The easier items can be assembled into a speech plan then the more efficient rehearsal and recall should result. As mentioned previously, current models of immediate serial recall overlook any sequence level differences which could occur between different types of stimuli.

Construing rehearsal as a process of planning the articulatory gestures needed to produce the sequence means that processes that constrain the planning and production of articulatory sequences should also constrain serial recall performance. It has already been established the complexity of articulatory gestures within an item can affect its duration and possible recall (e.g. Caplan et al., 1992); however the complexity of articulatory gestures needed to negotiate the boundaries between items is possibly just as significant. If the same processes that underlie language production also underlie memory than constraints of language production should also constrain short-term memory performance. The next section will examine one aspect of connected speech which is involved in sequence production and possibly be an important determinant of immediate serial recall performance, namely coarticulatory fluency. Sequence production and therefore rehearsal during immediate serial recall requires participants to co-ordinate the articulators to output a whole planned motor sequence.

## 1.5 Possible role of (co) articulatory fluency in serial recall performance

### 1.5.1 Coarticulation

Thus, aside from the articulatory character of the items themselves, the other important factor in determining articulatory complexity could arise from the process of the coarticulation of adjacent items. Coarticulation is a process which is involved in both fluent word and sequence production, whereby the articulatory apparatus initiates the articulation of one phoneme while still producing the previous one. Fluid, accomplished, sequence production is underpinned by extensive planning, not just of the order of the items and their associated gestures, but the compromises and accommodations in articulatory planning that have to be made between items. Coarticulation between items in an utterance occurs when articulatory movements or gestures needed for adjacent gestures accommodate and anticipate each other, so during fluent speech the final phone of one word is able to assimilate the characteristics of the first phone of the following word. Despite the adjustments made by speech planning processes, it remains the case that some transitions are more complex and time consuming than others. Some items are easier to say together in sequences than others which involve more articulatory movement and are less able to be smoothly coarticulated without a gap between items.

Despite coarticulation playing an important role in the planning and production of sequences, it is typically disregarded when describing serial recall constraints. A study into Welsh and English digit span found that when spoken in list form Welsh digits were articulated slower than English digits this corresponded to the finding that digit span was greater for English than Welsh digits (Ellis & Hennelly, 1980). This is cited as strong support for the phonological loop model, with the shorter items benefiting from more rehearsal before decay than items that take longer to say. However in a re-evaluation of the Ellis & Hennelly (1980) study Murray & Jones (2002) suggested that Welsh digits were actually shorter when articulated in isolation, it was only when digits were placed into sequences or list form that they took longer to articulate. Thus, the established differences between English and Welsh span was attributed not to the length of items *per se*, but to differences in complexity of planning or executing the articulatory gestures at the boundaries between digits. Specifically the authors suggested that Welsh and English digit sequences spoken in list form are subject to different structural constraints, to be precise; coarticulation is less likely in Welsh than English digit sequences.

Thus, measuring the duration of sequences not only reflects the duration of the constituent items but it also captures the time taken to execute the articulatory gestures necessary to negotiate the boundaries between words. The ability to coarticulate items in sequence reduces effort and increases the speed of an utterance, which is arguably what is crucial during rehearsal in serial recall tasks when items are being rapidly presented. In a further study Murray & Jones (2002) constructed two lists of items that differed in articulatory complexity but were matched on all other factors. The high complexity list consisted of words which were more complex to say together in sequence (e.g. *tape, knife, turf, deaf, deep*), these words involve complicated movement of articulators when they are said in sequence. The low complexity list were (e.g. *rail, rice, nurse, wren, ran*) which are easier to say fluently. Importantly, the complexity of the co-articulation had an impact on serial recall performance. Words that were easier to say in sequence together, by virtue of containing less complex between-item articulatory transitions, were better recalled than words that are less easy to produce in sequence, even when individual items were matched for duration and frequency (Murray & Jones, 2002). This is further evidence that coarticulation is perhaps an important factor underpinning serial short-term memory performance. Therefore immediate serial recall memory may not be mediated solely by the phonological store but also by the processes that underpin speech production and perception.

The purpose of the present thesis is to address the role of (co)articulatory fluency in both speech production and immediate serial recall performance, particularly with regard to linguistic familiarity effects, which are largely attributed to the item-based process of redintegration. This thesis contends that both in particular and in general, the co-articulations required during a short-term memory task are relatively unfamiliar to the participant. In general because, items are usually drawn from the same syntactic class, and therefore seldom encountered adjacently in everyday speech, and in particular because they will be encountered infrequently even within a study.

It seems reasonable to expect, just as with any other skilled task involving gestures, that the fluency – and hence duration – of the gestures at the boundaries of words will improve markedly with familiarity. If articulatory duration is a determinant of short-term memory performance we may further expect improvements in fluency to be associated with improvements in recall performance. Articulation of a sequence of familiar items could involve more familiar and less complex movement of articulators (mouth, tongue and lips) between items in a sequence than unfamiliar sequences, leading to faster and more effective assembly of items into a sequence for rehearsal. The importance of co-articulatory fluency has been underestimated in studies assessing the contribution of articulation to verbal serial short-term memory.

The experiments in the present thesis aim to see how coarticulatory fluency and familiarisation affect immediate serial recall performance. Instead of focussing on the articulatory fluency or familiarisation, of individual items, speech processes involved in sequence planning and production are examined. Before describing the first experiments in this thesis, the methods that have previously been used to examine articulatory rate and articulatory duration are discussed in relation to how appropriate they are to capture coarticulation effects, particularly seen in immediate serial recall task. It is suggested presently that redintegration accounts of serial recall phenomena which question the role of articulatory duration differences may have overlooked the coarticulatory influences resulting from sequence production. It has been noted that some speech phenomena only occur during connected speech (Wheeldon, 2000) and connected speech is what occurs during sequence production but is rarely measured when obtaining an articulatory duration or articulation rate measure.

### 1.5.2. Inconsistencies in the measurement of articulatory duration and rate

One of the main reasons articulatory factors have been ruled out in fully explaining linguistic familiarity effects is that performance differences between the two classes of items (e.g. low vs. high frequency words, words vs. nonwords) still exist even when the items have been apparently matched on articulatory duration. However, it is possible that the complete role of articulatory factors in familiarity effects, especially at the sequence level, have not been fully captured by measurements of articulatory duration that are confined to the item level. A growing body of conflicting results have arisen with regard to the relationship between speech rate and memory span, much of this controversy could be attributed to the array of different methods of measurement, which have been employed to calculate speech rate and articulatory duration of to-be-remembered stimuli.

Furthermore it has been suggested that the controversy over the nature of the word length effect is also due at least in part to the inaccurate measurement of short-term serial recall stimuli for word-length experiments (see; Mueller et al., 2002). The different methods which have been used to measure articulatory duration can be criticised for typically failing to capture the full effect of coarticulation, the different methods employed to measure articulatory duration and speech rate will be considered presently with regard to how likely they are to capture coarticulation effects and any problems involved.

#### *1.5.2.1 Individual Items*

Serial recall tasks are the key way to measure serial recall performance, since rehearsal has been considered to be an influential factor in memory performance, researchers often measure the articulatory duration of their experimental stimuli and/or measure the articulation rate of their participants in an attempt to control for rehearsal differences which may arise in the different types of recall stimuli. There are massive inconsistencies in the way which this has been done and the conclusions obtained from such measures.

Some studies which have claimed to match or differentiate their stimuli on articulatory duration have measured the duration of individually articulated items, although in some cases the measurement for articulatory duration in stimuli comes from entirely separate participants to the actual participants who are required to do the serial recall task (Baddeley & Andrade, 1994; Cowan et al., 1992). With such a method the experimenter measures how long it takes just one person - sometimes even themselves (Caplan et al., 1992) - to articulate each word on its own. This method can be criticised for being unable to account for the individual differences in speech production of different participants. In addition, only having the measurement for one speaker could mean that the duration measurement is less accurate than if a number of people were measured. In addition, measuring the duration of individual words excludes any time required to pre-programme the utterance that might occur as a gap between words –this has been suggested to be an important factor in determining the rate of rehearsal in to-be-remembered sequences (see Zhang & Simon, 1985). Alternatively, when individual item duration is measured the time taken to plan and produce the articulatory gestures needed to coarticulate the items in sequence together is completely overlooked. In serial recall tasks, items are not produced in isolation, completely independent of other items in the list.

There are obvious problems then with the measurement of the articulatory duration of individual words, as the result such methods are being used less often to control the articulatory duration of serial recall experiments. Thus, another method involves the rapid repetition of individual words (Hulme et al., 1997; 2002). This method typically involves all the items which are used in the serial recall task being presented one at a time and the participant is required to rapidly repeat each item ten times, then words spoken per second is worked out. This method has an advantage over the individual item measurement above as the utterance is much faster when being repeated and this is arguably closer to what occurs during rehearsal. However, it can still be criticised as being insensitive to coarticulatory fluency, as only one coarticulation is needed and in addition it will probably not be one that would occur in serial recall responses as typically words are not repeated in one serial recall trial.

*1.5.2.2 Pronunciation Duration*

Other studies have employed a method of measurement known as 'pronunciation duration' or 'list reading' (Baddeley, 1986; Schweickert & Bouruff, 1986; Dosher & Ma, 1998). This method involves the simultaneous presentation of items this time in list form arrayed from top to bottom where the participant has to read out as quickly as possible. Although this measures the duration of more than one item, it is quite possible that this method is not completely accurate, especially when it comes to capturing coarticulation. For example, it is possible that by having one item on each line does not encourage one to coarticulate an item with the following item which is presented on a separate line, possibly encouraging pauses between items. In addition, the lists are usually longer than the lists they are required to recall.

Occasionally, a speech rate task may be made up of completely separate items to the stimuli used in the immediate serial recall task. Such methods of measuring pronunciation rate include the measurement of counting rate (e.g. Standing & Curtis, 1989; Cowan et al.,1988) or the measurement of the articulation of over learned sequences such as the alphabet or digits 20-40 (e.g. Tehan & Lahor, 2000). Such methods measure a participant's pronunciation rate, so how long it takes to articulate a sequence of items, but such measures can be criticised, as they do not give any indication of the rate of articulation of the actual to-be-remembered items. In addition, over learned sequences probably involve very little planning as they are so common to the speaker, this is perhaps not representative of the motor planning of sequences which is likely to be involved in immediate serial recall tasks of sometimes unfamiliar items.

*1.5.2.3 Pairs of stimulus items*

Hence, it is argued that a more accurate measurement of articulation rate can be obtained from the measurement of the rapid repetition of pairs of to-be-remembered items (Baddeley & Andrade, 1994; Gathercole & Adams, 1993; Hulme, Roodenrys, Brown & Mercer, 1995; Jarrold, Hewes & Baddeley, 2000, Thorn & Gathercole, 2001). This commonly used method involves the presentation of pairs of items (which will be used as stimuli in the serial recall task) and the participant is required to rapidly repeat the pair ten times before being presented with another pair where the process is repeated. This method is more accurate as more than one item is being articulated and the utterance is speeded. This method can still be criticised on the grounds that only a small number of the actual items are used and additionally it has been suggested that the rapid repetition of items could result in tongue twisters effects, making it less representative of articulation rate (see Caplan et al., 1994) and a less accurate measurement. Furthermore studies which base articulatory duration and rate measurements on pair repetition are only taking into account three word boundary coarticulations compared to about six boundaries which need to be negotiated in a typical span-length list of about six items.

*1.5.2.4 Sub-span Lists*

Articulation rate or the measurement of articulatory duration of a set of stimuli has sometimes been measured in a separate pronunciation task using subspan lists of three of four items (Cowan, Wood, Wood, Keller & Nugent, 1998). Although this measurement does take into account the spoken rate of a short sequence and it has been found that single word speech rate is more weakly correlated with memory span than the rate of repeating word triplets is. (Lovatt, Avons & Masterson, 2000) Yet, this method still does not capture all the coarticulation involved in a typical serial recall task unless the recall task involves 3 or 4 item lists.

*1.5.2.5 Duration of recalled responses*

Finally, there have been a few studies which have involved measuring response duration at recall or after being told to learn a sequence of words, the sequence is taken away and the list has to be recalled from memory (e.g. Schweickert et al.,1990; Schweickert & Bouruff, 1986; Mueller et al., 2003). Although more representative of the immediate serial recall task, this method of actual rate of articulation could be confounded by the memory load. It is also possible that when a sequence is recalled it is done slightly slower than when a sequence is rehearsed, which involves much faster articulation rate, and probably more coarticulation as the sequence does not have to be as intelligible. One final point, before proceeding on to the method that will be used in the present thesis, is that many previous methods have used a stopwatch to measure articulatory duration which is a fairly imprecise form of measurement when it comes to rapid speech measurement.

It is possible that the role of co-articulatory fluency in familiarity effects at the sequence level have not been captured by measurements of articulatory duration restricted to the item level. If coarticulatory fluency is a key determinant of efficient rehearsal, measuring duration of individual items, pairs or subspan lists are likely to minimise the estimate of its contribution, as most serial recall tasks require the recall of many more items. For this reason the experiments in this thesis will compare the measurements of articulatory duration of sequences of items at the length of the to-be-remembered items (6-item) with individual item duration. Furthermore, the influence of linguistic familiarity will be examined at both the item and sequence level.

## 1.6. Prelude to Empirical Series 1

In summary, Chapter 1 has noted that the general accounts of immediate serial predominantly focus on the properties of the individual item, with little reference to how sequence level factors can affect serial recall performance. Specifically, little attention has been focussed on the speech processes involved in articulating a list of to-be-remembered items together. In addition, although the standard working memory model has the process of rehearsal at its core, the process is largely underspecified. Furthermore, linguistic familiarity effects have not been attributed to the process of rehearsal, but rather they have been attributed to the contribution of long-term memory, in the form of the item-based process of redintegration. Articulatory and (co)articulatory fluency has been ruled out of explaining such effects, but empirical Series 1 endeavours to identify whether previous methods of measurement of articulatory duration and articulation rate fail to take into account sequence level factors in rehearsal such as coarticulatory fluency at the word boundaries. Furthermore empirical Series 1 attempts to investigate whether linguistic familiarity effects may be partially attributed to a measurable sequence level factor such as coarticulatory fluency rather than just the more abstract, item-based process of trace redintegration.

# CHAPTER 2:

# Linguistic Familiarity Effects: Coarticulation or Redintegration?

## 2.1 Abstract

Serial recall is better for familiar words than unfamiliar words. This is usually attributed to a process of redintegration whereby partially-decayed representations of verbal items in short-term memory may be reconstructed from long-term lexical knowledge. An alternative tested in the present five experiments is that familiarity influences memory at the sequence (rather than the item) level by enhancing the efficacy with which items may be assembled into sequences, especially in relation to the process of coarticulation. Experiment 1 found that with practice serial recall of nonwords improved more than that of words. Experiments 2 and 3 found that the improvement in recall with practice was due to increasing coarticulatory fluency in producing the sequence rather than greater fluency in producing the items with both visual and auditory presentation. Experiment 4 suggested that coarticulation, and not the formation of associative links between items in a set, led to faster articulation rates and improved recall for familiar lists. Finally, Experiment 5 demonstrated that there were larger differences between high and low frequency stimuli when sequence duration rather than item or pair duration was measured These results suggest that linguistic familiarity effects in short-term memory are, at least in part, due to articulatory fluency, not just redintegration.

## 2.2. Introduction to Empirical Series 1

The preceding chapter noted that within short-term memory research there is a pre-occupation with the characteristics of the individual item when explaining various immediate serial recall phenomena including linguistic familiarity effects (e.g. frequency, language familiarity, lexicality effects) As a result the possible influencing role of articulatory factors in assembling items into a gestural sequence may have been overlooked. Furthermore, there has been an accumulation of evidence which largely dismisses the role of articulation in favour of a main role for long-term memory processes. Specifically, redintegration is typically used to explain the differential levels of immediate serial recall performance for familiar and unfamiliar stimuli.

Classically such a hypothesis stipulates that when a to-be-remembered item is retrieved it may be partially degraded. If this is the case then the long-term knowledge of an item's phonological structure is used to fill in the missing gaps, to reconstruct the degraded representation (e.g. Schweickert, 1993; Brown & Hulme, 1995). This process of redintegration is believed to be more efficient for familiar items as the long-term memory representations are more accessible and/or available than representations of unfamiliar item representations. For example nonwords supposedly have no previous representation in short-term memory, which can aid their recall (Brown & Hulme, 1995; Thorn & Gathercole, 1999; Thorn, Gathercole & Frankish, 2002). In these dominant accounts of linguistic familiarity effects the emphasis is on the phonological characteristics of the *item*, consequently, articulatory features involved in *sequence* production have either been overlooked or dismissed as having a trivial role in immediate serial recall performance.

Thus far, little attention has been focussed on articulatory factors involved in the assembly of items into a sequence, which can then be rehearsed and reproduced at recall. Furthermore, this pre-occupation with the item rather than the sequence in short-term memory research is reflected in the way articulatory duration has been measured. Rarely is the whole spoken duration of all items required for recall measured, instead spoken duration of individual or pairs of items is usually taken as the accurate articulation measure (e.g. Baddeley & Andrade, 1994; Gathercole & Adams, 1993; Hulme, Roodenrys, Brown & Mercer, 1995; Jarrold, Hewes & Baddeley, 2000, Thorn & Gathercole, 2001). However, arguably participation in a serial recall task requires the rapid reproduction and rehearsal of not one item but a whole sequence of ordered items. If this is the case, it should make more sense that the measurement of a participant's articulation rate or the articulatory duration of stimuli used in immediate serial recall tasks should involve the items being articulated in sequence, as required by the serial recall task, not, as is the norm, in pairs or even individually measured.

In Chapter 1, coarticulation was identified as being one feature of fluent speech, which may have been overlooked when discussing the articulatory duration of immediate serial recall stimuli. Although necessary to the smooth combination of sounds within an individual item, coarticulation is also an important part of connected speech, necessary for fluent sentence and sequence production. The complexity of the coarticulations needed between items, has already been shown to influence serial recall performance, with sequences of items which involve less articulatory movement from the end of one word to the beginning of the other, leading to better recall performance than high complex lists (Murray & Jones, 2000). However, previous research has not examined how the familiarity of co-articulatory gestures between words could affect the production of ordered sequences and subsequent recall performance.

Thus, the predominant focus of the experiments in the present series is to evaluate first, whether there are differences in articulatory duration of items that differ in linguistic familiarity, which only show up in the measurement of sequences rather than in individual or pairs of items and second, to see whether coarticulatory effects can constrain serial recall performance. A relatively novel way of measuring articulatory duration will be employed where the spoken duration of 6-7 item sequences (the required length of each serial recall trial in the experiments) will be measured, arguably with this method the effects of coarticulatory differences in sequences should become manifest. Moreover the affect of increasing the familiarity of coarticulations between items will be examined.

Thus, the purpose of the experiments that follow is to assess the contribution made by increased coarticulatory fluency to improvement in serial recall – independent of redintegration – when participants become more familiar with the to-be-remembered sequences. The experiments test the novel proposition that the articulatory gestures needed to produce items in unpracticed sequences may be less familiar and hence less fluent than those needed for practiced sequences. Results supporting this view would suggest diminished prominence for mnemonic factors related to redintegration in serial recall. It may become unnecessary for short-term memory models to include an item-based process of redintegration to explain linguistic familiarity effects, as rehearsal-based articulatory factors involved in producing whole sequences could be sufficient, or at least have an important role in explaining these effects.

The present experiments take a different approach to examining linguistic familiarity effects in serial recall to those commonly reported in the literature (e.g. Gathercole et al., 2001; Roodenrys et al., 1993). With the exception of Experiment 1, instead of using items with different levels of pre-experimental-familiarity (words/nonwords, high/low frequency words, etc.), the familiarity of stimuli is manipulated within the experimental setting. In this sense, the experiments are a microcosm of language learning. All the experiments followed the same basic methodology. Initially, a baseline measure was taken of the articulatory duration of items spoken in isolation and in sequence (Stage 1). This is invariably followed by a familiarisation phase (Phase 2) that involved familiarisation with articulating sequences of these items, either through rehearsal during serial recall or reading. The familiarisation phase was followed by a post-familiarisation stage (Stage 3) in which articulatory duration measurements were again taken for items in isolation and in sequence (Stage 3). Finally, a serial recall task tested the memorability of different types of sequence (Stage 4).

Interest is focussed on two issues in relation to these experimental phases; firstly, whether familiarity with the articulation of sequences would affect the duration of items or sequences, and secondly, whether familiarity with the items or sequence will have an impact on serial recall performance. If coarticulatory fluency is a key factor in serial recall performance it is expected that as participants become more familiar with articulating the items in sequence, their ability to produce and recall sequences containing these practised coarticulations would improve. If, however, redintegrative processes were dominant it would be expected that even sequences containing unpractised coarticulations would benefit from familiarisation with the items themselves, resulting in faster production times and improved recall performance. In this case, the level of redintegrative support would be similar for all items.

It should be noted that for all the experiments in the current chapter a great deal of time and effort was required to take all the separate measurements from each participants data needed for the analyses. For example in Experiment 3 a total of 288 time consuming measures per participant (5760 measures in total) needed to be taken by hand from the waveforms produced from the audio editing software *SoundForge 5.0,* in order to determine accurately the duration lengths of the different item types.

### 2.3. Experiment 1: Words and Nonwords

The first experiment focuses on the lexicality effect and sets out to examine the effect of familiarisation on the rate of production of words and nonwords spoken both in isolation and in sequence, as well as recall for such word and nonword sequences. The lexicality effect (better recall of words than nonwords) is commonly regarded as the most compelling evidence for a crucial role for long-term memory representations in short-term serial recall. The dominant view of the lexicality effect is that word sequences are recalled more accurately than nonword sequences because words unlike nonwords have a representation in long-term memory with which to aid their reconstruction at recall (Hulme, Maughan & Brown, 1991; Hulme, Roodenrys, Brown & Mercer, 1995; Roodenrys, Hulme & Brown, 1993). As nonwords are unknown to participants they do not have the benefit of a long-term representation with which to aid their recall. Critically, it has been claimed that the lexicality effect cannot be explained in terms of differences in rehearsal and articulatory duration and rather it is independent of any articulatory factor. Despite suggestions that nonwords as they are unknown to individuals take longer to say, articulatory differences have been dismissed as trivial significance in favour of redintegration explanations (e.g. Hulme et al., 1991; 1995; 1999; Roodenrys, Hulme & Brown, 1993).

In the present experiment participants were familiarised with the to-be-remembered items during a block of serial recall trials. The impact of this on the speed of production of items and sequences without a memory load – the articulatory fluency – was assessed by measuring articulatory duration of single items (a common method of articulatory duration measurement) and items spoken in sequences. Measurements were taken both before and after the memory test. Analysis of the memory test was split into three blocks to monitor any improvement made on both word and nonword lists as participants progressed through the trials. In particular, the experiments investigated whether the words or nonwords would benefit more from practice and whether any such benefit is manifest at the *item* or *sequence* level of production.

### 2.3.1 Method

#### *2.3.1.1 Participants*

Twenty-five undergraduate and postgraduate students at Cardiff University participated in the experiment in return for payment or as part of their course credit. All were native English speakers reporting normal hearing and normal or corrected-to-normal vision. They were 15 female and 10 male native English speakers aged between 18 and 24.

#### *2.3.1.2 Apparatus and Materials*

The items varied in lexicality (words and non-words). All items were one-syllable consonant-vowel-consonant (CVC) stimuli, which were randomly drawn from the stimulus pool used by Gathercole et al. (2001). Two different sets, each of words and non-words, were randomly chosen. Participants were randomly assigned a set. Each participant always encountered the same six words and six non-words throughout the experiment. The items were either, Set 1, (Words: *dog, birch, warm, soot, kerb, chuck.* Non-words: *lod, chorg, dook, jit, tudge, mern*) or Set 2, (Words: *bark, torch, learn, nod, chat, dig.* Non-words: *gerch, jal, chig, padge, darp, gan*). Six-item sequences were used for serial recall: pilot studies had found that memory performance for 7-item nonword sequences was extremely poor and at 5-item length, memory for word sequences was at ceiling.

Sets 1 and 2 were used for the familiarisation stage (Stage 2), which took the form of a serial recall task. The stimuli were from natural male speech recorded digitally to 16-bit resolution at a sampling rate of 44.1 kHz using the audio editing software *SoundForge 5.0.* (Sonic Foundry Inc., Madison, WI). All items were compressed digitally to 400ms, which did not alter the pitch, using the same software. The lists were six items in length with no items being repeated in any one trial. Items did not appear in the same serial positions in successive trials and there were no identical trials. The word and nonword trials were presented in a quasi-random order, with the restriction that there were no more than two of the same type of trials in succession. The sequences were presented on a Macintosh computer using the *PsyScope* experiment control system (Cohen, MacWhinney, Provost & Flatt, 1993), at the rate of one item per second. All spoken responses were recorded using a microphone and the audio editing software *SoundForge 5.0.*

*2.3.1.3 Procedure*

All participants were tested individually in a soundproof laboratory. During the first baseline reading stage (Stage 1) participants were instructed first, to read aloud each word or nonword that appeared in front of them as quickly and accurately as possible, before pressing the spacebar for the next individual item. All items were shown and each item was presented three times. Next, six-item sequences, consisting of either words or nonwords were presented simultaneously on the screen. On separate trials three, six-item-word sequences and six, three-item nonword sequences were displayed, one at a time, in the centre of the screen. The order of the items in the sequence was random on each occasion. Participants were required to read aloud the sequence from left to right, as quickly and accurately as possible, before proceeding on to the next sequence. There were three sequences of each type, which were presented in a random order.

Following the baseline reading stage (Stage 1), was the familiarisation phase and participants were given instructions for the serial recall task (Stage 2). Participants were told that they would hear sequences of six words or non-words, spoken over the headphones. Immediately after presentation, the computer screen flashed; this was the participants' cue to recall, vocally, the items in sequence. Participants were informed that it was important that they preserved the order of the items, so that at any place in the sequence where they were unsure of the correct item they should respond 'blank'. When the 10 s recall time was up, a tone was sounded to signal the beginning of the next trial within 2 s. The serial recall task consisted of 60 trials (30 word lists and 30 nonword lists), along with two practice trials, taking just over 20 minutes to complete. All responses were recorded onto the computer in SoundForge. After the serial recall task, participants were again presented with the individual item and sequence reading task (Stage 3), which was identical to Stage 1. The procedure took just under an hour to complete.

### 2.3.2 Results and Discussion

*2.3.2.1 Articulatory duration (pre-and post-familiarisation)*

The sequences and item recordings were labelled and saved for each participant then the duration of each utterance of each individual item was measured in milliseconds from the beginning to the end of the utterance using *SoundForge* software. Using *SoundForge* software the duration of items can be measured with millisecond accuracy by identifying the endpoints of a waveform by eye. The accuracy of placement can then be further judged by using the endpoints to replay the sound and judging whether the full utterance was captured. Utterances were replayed several times to ensure accuracy of measurement and care was taken to ensure the whole item was isolated and captured.

Mean item duration was calculated for words and nonwords. Similarly, for the sequence recordings the duration from the start of the sequence until the end of the sequence was measured. There were three sequences of each type, and the average duration for each sequence type was divided by six, thus a mean duration per item in a sequence was calculated for both words and nonwords. Table 1 shows the mean duration of words and non-words spoken in isolation and in sequence, before (Stage1) and after (Stage 3) the serial recall task (Stage 2). There was very little difference in duration between isolated words and nonwords before familiarisation (Stage 1) and little decrease in articulation time for either type after familiarisation (Stage 3). The articulatory duration of words and nonwords spoken in sequences showed a different pattern of results. The duration of an item was much shorter when articulated within a sequence than when articulated in isolation. Additionally, participants got quicker at articulating both word and nonwords in sequences, after completing the serial recall task.

A repeated-measures ANOVA carried out on the single-item duration data containing the factors item type (word vs. nonword) and stage (Stage 1 vs. Stage 3), established no main effect of item type on articulatory duration when spoken in isolation, $F(1, 24) = .000$, $MSE = 253$, $p > .05$, and no main effect of stage $F(1, 24) = 1.245$, $MSE = 357$, $p > .05$ and no interaction between stage and type.

Table 1

*Mean articulatory duration in milliseconds of an item spoken in isolation and within a sequence, before (Stage 1) and after (Stage 3) familiarisation on a serial recall task*

| | Isolation (ms) | | | | Sequences (ms) | | | |
|---|---|---|---|---|---|---|---|---|
| Item | Before | | After | | Before | | After | |
| | M | *(SD)* | M | *(SD)* | M | *(SD)* | M | *(SD)* |
| Words | 511 | *(54)* | 508 | *(53)* | 425 | *(74)* | 411 | *(64)* |
| Nonwords | 512 | *(51)* | 508 | *(57)* | 458 | *(79)* | 425 | *(63)* |

*Note. Sequence duration is calculated by dividing whole sequence duration by six (the number of items in a sequence)*

Thus, when items were articulated in isolation, word and nonword stimuli duration was equivalent. Participants also did not get significantly faster at saying items in isolation after familiarisation. However, the ANOVA on the sequence data established a significant main effect of item type, $F(1, 24) = 18.11$, $MSE = 742$, $p < .001$, indicating that it took longer to articulate a nonword in sequence than it did to articulate a word in sequence. The analysis also found a significant main effect of

Stage, $F(1,24) = 7.977$, $MSE = 1736$, $p < .01$ as well as a significant item type by stage interaction, $F(1,24) = 5.478$, $MSE = 447$, $p < .05$, indicating that nonword articulation rates improved more in sequence between stages than did word articulation rates. Pairwise comparisons for simple effects with Bonferroni adjustment for multiple comparisons showed that for word sequences the mean difference of 13.64ms between stage 1 and stage 3 was not significant $p > .05$, whereas for nonwords the mean difference of 33.40 between stages was significant $p < .01$. In summary, after the serial recall task, improvement in speech rate was greater for nonword than word sequences

*2.3.2.2 Familiarisation (Stage 2)*

The serial recall responses were recorded and then these were transcribed and scored with respect to serial position. The criterion for scoring was strict: only items that had been recalled in the presentation serial position were scored as correct. The serial recall task was split into three blocks of 20, with 10 word and 10 nonword sequences in each, so that the average number correct in a block could be compared for both the words and the non-words. The number of items correctly recalled in each serial position was scored for each participant as a function of item type and block. These data are summarised in Figure 1, which shows the mean proportion of items correctly recalled in each block as a function of lexicality.

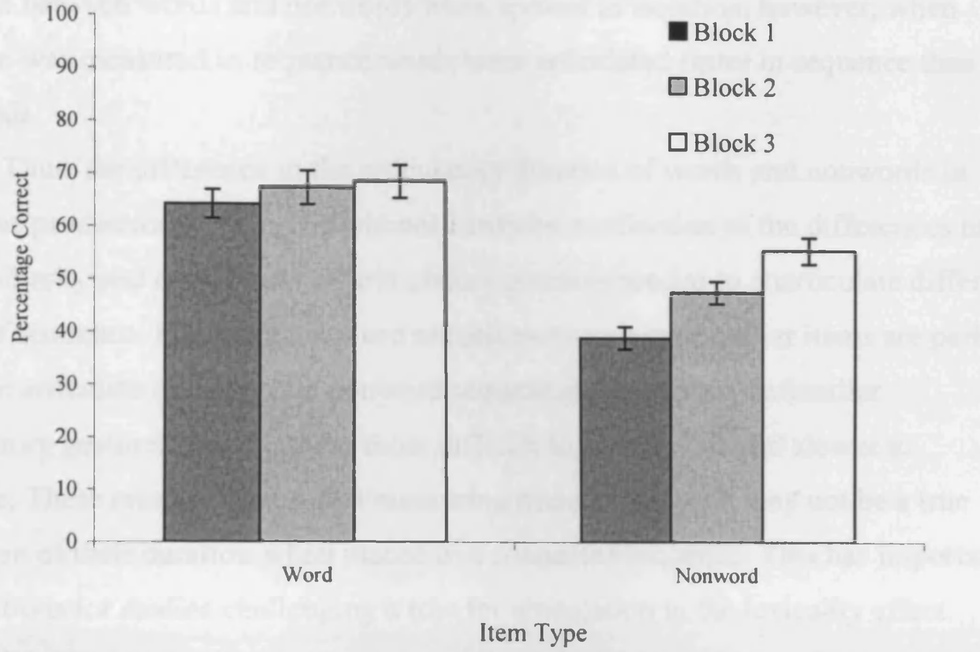


*Figure 1.* Percentage of correctly recalled words and nonwords for each block of ten trials. Error bars show standard error.

An effect of lexicality is clear from these data; words were better recalled than nonwords, $F(1, 24) = 117.4$, $MSE = 125$, $p < .001$. An ANOVA also showed that there was a main effect of block, $F(2, 48) = 17.64$, $MSE = 62$, $p < .001$, reflecting the fact that recall of items improved with block. There was also a significant interaction between item and block, $F(2, 48) = 9.17$, $MSE = 46.9$, $p < .001$, showing that overall, the improvement between blocks was much greater in the nonword trials than the word trials. Pairwise tests of simple effects with Bonferroni adjustment showed that whereas the mean difference of 3.488ms for word recall between blocks 1 and 3 was not significant $p > .05$, for nonwords the mean difference of 15.20ms between bocks 1 and 3 was significant $p < .001$.

To summarise the main findings of Experiment 1: Firstly, item duration was longer for items spoken in isolation than when spoken in a six word sequence – this finding illustrates how coarticulation enables the articulatory programme to be shortened when they are spoken in sequence. For example the endings of items are truncated as they assimilate into the pronunciation of the next item in the sequence, this only occurs in rapid connected speech, and not when items are spoken in isolation (e.g. Wheeldon, 2001). Furthermore, there was no difference in the articulatory duration between words and nonwords when spoken in isolation, however, when duration was measured in sequence words were articulated faster in sequence than nonwords.

Thus, the difference in the articulatory duration of words and nonwords in sequence production seen in Experiment 1 may be a reflection of the differences in the familiarity and complexity of articulatory gestures needed to coarticulate different types of sequence. For example, word sequences containing familiar items are perhaps easier to articulate quickly than nonword sequences that contain unfamiliar articulatory gestures making them more difficult to coarticulate and slower to produce. These results suggest that measuring items in isolation may not be a true reflection of their duration when placed in a connected sequence. This has important implications for studies challenging a role for articulation in the lexicality effect. Typically, these studies have not measured the articulatory duration of sequences; rather they have used isolated words or, at best, repetition of word-pairs (Baddeley et al., 1975; Baddeley & Andrade, 1994; Gathercole & Adams, 1993; Hulme, Roodenrys, Brown & Mercer, 1995; Hulme et al., 1997; 2002,; Jarrold et al., 2000, Thorn & Gathercole, 2001).

Secondly, familiarisation was shown to have an effect on the articulatory duration of words and nonwords when they were spoken in sequence. However, there was no corresponding decrease in articulatory duration for either words or nonwords when the items were spoken in isolation. The improvement in articulatory duration observed for both words and nonwords spoken in sequence, resulting from familiarisation, indicates that it is the increase in the familiarity of the items at the sequence level which enhances fluency. Furthermore, after familiarisation the duration of the nonword sequences decreased more in articulatory duration than the word sequences, suggesting that the nonword sequences involving unfamiliar articulatory gestures benefited more from familiarisation than the word sequences. The results of Experiment 1 have shown that there are effects of familiarisation on articulatory processing that are revealed only when measuring the duration of items spoken in sequences rather than in isolation, which in turn can determine how well they are recalled.

Finally, the serial recall data showed an effect of lexicality with word recall performance being superior to nonword recall, a finding that has been replicated many times (Gathercole et al., 2001; Hulme et al., 1991; 1995; 2003; Roodenrys, Hulme & Brown, 1993). However, the influence of familiarisation on articulatory duration of sequences is also reflected in the serial recall results. There was a significant improvement in the recall of word and nonword sequences with practice, nonword recall improved significantly more than word recall. Thus, the improvement in the serial recall of nonword sequences is mirrored by the increased speed of articulation for nonword sequences after familiarisation. Taken together, these findings suggest that as the gestures involved in articulating a sequence become more familiar to the participant, the greater the ease with which they can assemble items into a sequence for rehearsal, having knock-on effects in the form of faster articulation rates and improved rehearsal efficiency.

However, from this experiment it is unclear what exactly is being learnt with practice, the individual items or the sequence? The results of Experiment 1 seem to suggest that practice with articulation of sequences is one reason nonword recall performance increases. However, from a redintegration standpoint it could be argued that the reason recall of nonwords improved more with practice is that long-term phonological knowledge of nonword items is being built up, which can then support the nonword item recall. Initially, participants would have had no lexical representation of the nonwords, but as they become more familiar with these items, the redintegrative support improves for the nonwords, leading to increased improvement in recall performance. Nevertheless, one might expect such an account to predict an effect of familiarisation on the spoken duration of nonwords in isolation, which was not the case in this first experiment. The question of what, in the case of nonwords, is being learned with practice is addressed in Experiment 2.

### 2.4 Experiment 2: Coarticulation or Redintegration?

In Experiment 1, it was shown that after familiarisation articulatory duration decreased for items spoken in sequence, but not items spoken in isolation. The decrease in duration was greater for nonwords and with practice during the serial recall trials: performance improved more for nonword than word sequences. However, the change in articulatory duration and improvement in nonword recall could be the result of increased redintegrative support rather than as argued the increased (co-) articulatory fluency for the sequences. Thus, during the experiment participants could either have become more familiar with the items, leading to the increased efficiency of redintegrative support. Alternatively, the increased articulatory fluency from practising coarticulations between items in a sequence could be equally responsible for the results.

Previous studies examining language familiarity effects in bilingual individuals have shown that recall performance is better for items in a participants' first rather than the second language (Thorn & Gathercole, 2001; Chincotta & Hoosain, 1995). This is not thought to be due to rehearsal being more efficient in the first language (because items were supposedly matched for articulatory duration or the differences in articulation of pairs or individual items is minimal) but that redintegrative support is more available for first language items as they have been experienced more often (Thorn & Gathercole, 2001). Such redintegrative support is thought to operate at a lexical level, so it is the availability of item-specific information which is critical. The purpose of Experiment 2 was to try to distinguish between these two explanations of how familiarisation influences articulatory processes and memory: Is it purely the familiarity of an item, as the redintegrative account would suggest, or does the familiarity with the linguistic/articulatory gestures used in coarticulating a sequence also play a role in determining short-term serial recall performance? In Experiment 2 only nonwords were used, for the reason that they do not have any lexical entry in long-term memory that could initially aid recall through redintegration.

In Experiment 2, the experimental procedure employed was similar to that used by Stuart and Hulme (2000) who looked at the effect of word co-occurrence on short-term memory. In their study they divided high and low frequency words into two groups (A and B) and found that pre-exposure to low frequency pairs of 'A' words and 'B' words resulted in increased memory performance for sequences containing the familiarised pairings of items, but not when the sequences contained items from alternating sets. Similarly, in the present study each participant was presented with 12 different nonwords. The nonwords were taken from two closed sets of six items each (A items and B items). In the reading stages, (Stage 1 & 3) participants were required to articulate different types of sequence. The types of sequence either comprised all nonwords in a set (either all A items or all B items), these were called 'Pure' lists, or sequences consisting of alternating items from set A and set B words, known as 'Mixed' lists. Of course, in Stage 1 these sequence types were from the standpoint of the participants, undifferentiated. In the familiarisation stage (Stage 2), participants were tested on serial recall sequences of only pure lists (comprising either only-A or only-B items). Then they were given the sequences to articulate again in Stage 3 (after familiarisation), and finally Stage 4 was another serial recall task comprised of both pure and mixed lists, in order to study what affect familiarisation had on memory for the different types of sequence.

If familiarisation with coarticulating the items in sequence together is important it would be expected that after the familiarisation stage (Stage 2), participants would be faster at reading the pure sequences (practiced coarticulations) than the mixed sequences (unpracticed coarticulations), even though the items in each type of sequence will have been encountered equally often during the familiarisation stage. One would also predict better recall of the pure sequences in the final serial recall task (Stuart & Hulme, 2001). However, if only familiarity with the items is important then there should be no difference between the pure and mixed lists, as the participant will have encountered all the words the same number of times in the familiarisation phase.

### 2.4.1 Method

*2.4.1.1 Participants*

Twenty-three undergraduate and postgraduate students at Cardiff University participated in the experiment, in return for payment or course credit. All reported normal hearing and normal or corrected-to-normal vision. They were 17 female and 6 male native English speakers, aged between 18 and 22. None of the participants had taken part in the previous experiment.

*2.4.1.2 Design and Materials*

Thirty-six nonwords from the Gathercole et al. (2001) study were assigned randomly to one of three groups comprising two sets – A and B – each of six words. Each participant experienced only one of the three groups. From each group, three types of sequence were constructed: pure A, pure B, and mixed (AB). The sequences consisted of either, all set A items, all set B items (pure lists) or alternating items from Sets A and B (mixed lists). The stimuli for the memory task were from natural male speech recorded digitally with a 16-bit resolution at a sampling rate of 44.1 kHz using the audio editing software *SoundForge 5.0*. All items were compressed digitally to 400ms using the same software, so that they were all the same duration. The serial-recall task (Stage 2) consisted of 60 trials altogether (30 pure A sequences and 30 pure B sequences) randomly presented. The lists were six items in length with no item being repeated in any one trial. All the items in any set were used in each trial.

*2.4.1.3 Procedure*

Participants were tested individually in a soundproof room. Stage 1 involved the baseline measurement for reading the nonwords from a screen either in isolation or as a sequence. Firstly, all single items from the set a participant had been allocated were displayed on the screen one at a time, participants were requested to read aloud each one as quickly as possible before pressing the spacebar and proceeding to the next item. Items to be spoken in sequence were then presented simultaneously and participants were asked to read each sequence aloud as quickly and accurately as possible from left to right, before the next sequence appeared. There were 12 sequences altogether, all six items in length: four pure A sequences, four pure B sequences and four mixed (AB/BA) sequences, which were presented in a random order for each participant.

The familiarisation stage (Stage 2) comprised the serial recall task, as in Experiment 1. The to-be-remembered-items were presented at a rate of one item per second. Only pure sequences (A and B) were presented for recall. Stage 3 of the experiment was identical to the first stage; here, participants read the nonwords both in isolation and in sequences. Finally Stage 4 involved a similar serial recall task to the second stage but this time there were only 24 sequences, 12 sets of 'pure trials (6

'A', 6 'B') and 12 sets of mixed trials in which to-be-remembered sequences were made up of items from both sets.

**2.42 Results and Discussion**

*2.4.2.1 Articulatory duration (pre-and post-familiarisation)*

Articulatory duration was measured using *SoundForge 5.0* software as described in Experiment 1. The mean articulatory duration of all items spoken in isolation was taken to get an average duration for a nonword uttered in isolation. The average duration of an item in a sequence, either pure or mixed, was reached by dividing the average duration of each kind of sequence by 6 (the number of items in a sequence). The pure-A sequence and pure-B sequence durations were averaged to get one 'pure' sequence duration. This was done for both Stages 1 and 3.

The average isolated item duration was 517ms in Stage 1 before the familiarisation in Stage 2, and 511ms in Stage 3 after familiarisation. As in Experiment 1 there was no significant difference between the isolated item duration before and after familiarisation of the items on the serial recall task, $t\ (22) = 0.88, p = 0.389$. This indicates that familiarisation with the material during the serial recall task did not affect the speed of articulation for words in isolation. Figure 2 shows the average duration of an item in sequence, before and after familiarisation for both pure and mixed lists. The articulatory duration of an item spoken in pure and in mixed sequences was very similar in Stage 1, that is, before the familiarisation stage. However, in Stage 3 – after the familiarisation stage – there was a large decrease in the duration of items spoken in pure sequences that is not observed in the duration of items spoken in mixed sequences.

A repeated measures ANOVA established there was no significant main effect of list type (pure/mixed), $F\ (1,22) = 1.48$, $MSE = 171, p > .05$ or stage (before or after the serial recall task), $F\ (1,22) = 2.36$, $MSE = 1749, p > .05$. However, there was a significant interaction between list type and stage, $F\ (1, 22) = 9.388$, $MSE = 362, p = .006$. Post-hoc paired t-tests with Bonferroni correction were performed to analyse duration for each word type across stages, where $\alpha$ was set at 0.025 (two tailed) to control for the increased probability of committing a Type 1 error, these showed a significant decrease in articulatory duration for the pure sequences after familiarisation, $t\ (22) = 2.58, p < .\ 0.025$, which was not the case for mixed sequences, $t\ (22) = 0.13, p > .05$.

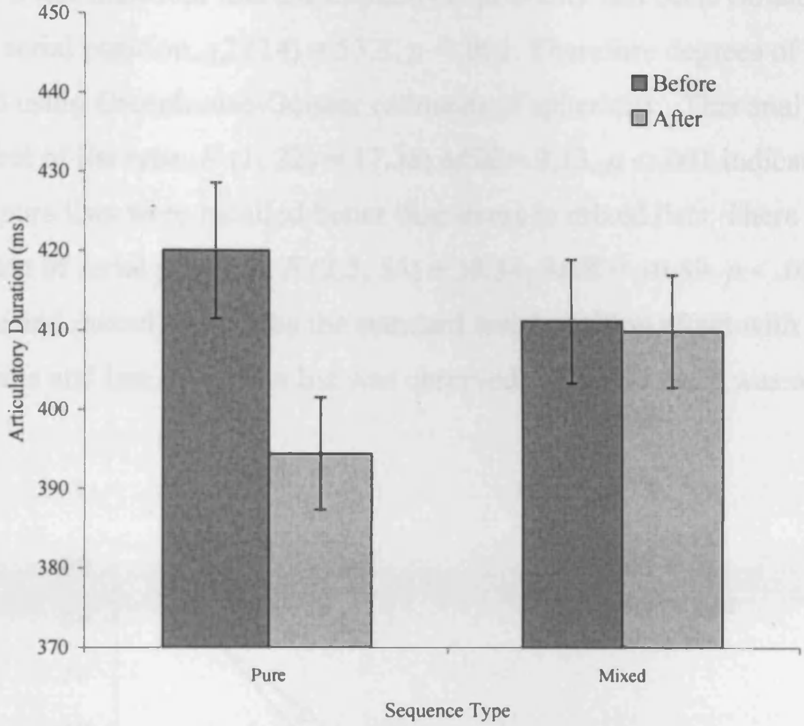


*Figure 2.* Articulatory duration of pure and mixed lists before and after the serial recall task Error bars show standard error.

So, even though each item in both pure and mixed lists was encountered equally often during the familiarisation stage, this familiarity only led to a decrease in articulatory duration when the sequences contained items that had been practised together (pure lists).

*2.4.2.2 Serial Recall (Stage 4)*

The serial recall responses after familiarisation were transcribed and only items that were recalled correctly in the correct serial position were marked as correct. Figure 3 shows serial position curves for recall of both pure and mixed lists. Overall, recall performance was better for the pure lists than the mixed lists. These results are an indication that what is learnt with practice is not familiarity with the individual items, as all A and B items were presented the same number of times and therefore equally familiar, but rather familiarity with the sequence and whether coarticulations between items had been experienced the same number of times. A repeated measures ANOVA with factors type of list (pure/mixed) and serial position was carried out. Mauchly's test indicated that assumption of sphericity had been violated for the main effect of serial position, $\chi2$ (14) = 53.3, $p < .001$. Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. This analyses showed a main effect of list type, $F$ (1, 22) = 17.38, $MSE$ = 2.13, $p < .001$ indicating that overall items in pure lists were recalled better than items in mixed lists. There was also a main effect of serial position, $F$ (2.5, 54) = 38.34, $MSE$ = 10.89, $p < .001$, thus for both pure and mixed sequences the standard serial position effect with better recall of initial items and last items in a list was observed. However there was no significant

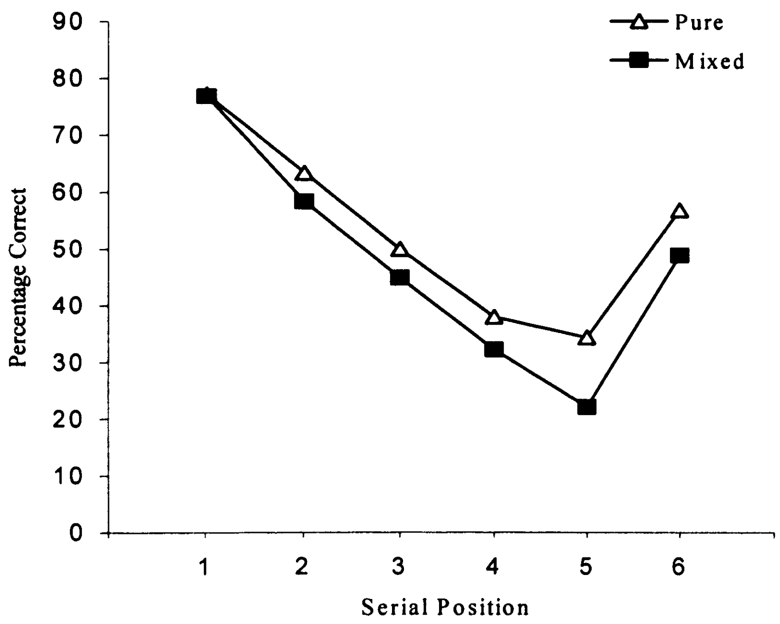


*Figure 3*, Serial position curves for percentage of items correctly recalled in each serial position for pure and mixed sequence trials in Stage 4

interaction between type and serial position, $F$ (5,110) = 1.50, $MSE$ = 1.70, $p > .05$.

In summary, as with Experiment 1, the articulatory duration results of Experiment 2 showed that an item spoken within a sequence was articulated faster than an item spoken in isolation. However, this time item familiarity was controlled across the conditions, as only nonword items were used, which did not have any lexical representation in long-term memory. The rehearsal-based factor that was varied here was the familiarity with executing the coarticulations between items. As in Experiment 1, there was no significant difference in articulatory duration between the items spoken in isolation before and after the familiarisation stage, additionally; there was no significant difference between sequences of pure lists and sequences of mixed lists in the baseline stage of the experiment (Stage 1). After familiarisation with the pure sequences in the serial recall task, participants showed a significant decrease in articulatory duration of the pure lists which was not matched by the articulatory duration of the mixed lists (in which the coarticulations had not been practised). All the items had been practiced the same number of times, so the degree of lexicality and redintegrative support should be the same within pure and mixed lists, but what varied was the articulatory fluency of the sequences – the coarticulations involved between items had been practiced in the pure sequences but not the mixed sequences.

In the final stage of the procedure, participants were tested on recall of both pure and mixed lists. The results showed that serial recall of sequences containing practised coarticulations (i.e. pure lists) was better than that of mixed lists (unpractised coarticulations). If, as Thorn & Gathercole (2001) and others have argued, item familiarity is the essential factor, then the recall of all lists (pure and mixed) should have benefited from familiarisation to the same degree, as all items had been experienced the same number of times. This was not the case as the practised items in practised sequences were recalled more accurately than the practised items in the unpractised sequences.

The present finding is similar to that of Stuart & Hulme (2000) who showed that participants familiarised with pairs of low frequency items performed better on a serial recall task than participants who had not been familiarised with saying the items in pairs. However, they attributed their finding to associative support, as opposed to the coarticulatory account being developed here; they argued that familiarisation created inter-item associations between items in long-term memory aiding serial recall performance via item redintegration. In contrast it has also since been argued that the same degree of improvement in recall of low familiarity lists can be achieved just through familiarising participants with individual items, which is thought to increase the level of redintegrative support of the items (Saint-Aubin & Poirier, 2005), although the present experiments suggest that item familiarity is not enough to significantly enhance serial recall performance. I will return, in Experiment 4, to this issue of association.

Firstly Experiment 3, will be described; the method of which is almost identical to Experiment 2, but with three notable exceptions. First, presentation of the familiarisation phase will change from auditory (as in the preceding experiments) to visual. Second, the time taken to initiate the spoken item and sequence responses in Stages 1 and 3 will be examined. Lastly, the time taken to utter pairs of items (a measure of articulation rate that is prevalent in short-term memory research) will also be measured, to see whether this is affected by familiarity as well as sequences.

## 2.5 Experiment 3

Experiment 2, indicated that what was improving with practice/familiarisation from the serial recall task was not so much the level of redintegrative support for the individual items, rather the articulatory fluency involved in planning and producing whole sequences of items was improving. However, one factor not examined in the preceding Experiments 1 and 2 but likely to be related to articulatory processes was how long it took participants to start articulating the items in isolation and in sequences. The previous two experiments found that the familiarisation of items in sequence had no effect on the articulatory duration of items spoken in isolation. However, differences resulting from familiarity may have been concealed in the time taken to plan spoken output.

It is likely that the time taken to plan an item for spoken output may get shorter after practice with articulating the items. In a series of studies, Sternberg, Monsell, Knoll and Wright (1978) found the mean latency to start saying well-learned sequences of items increased linearly with the number of words in a sequence. This is attributed to the whole utterance having to be planned before execution. Similarly, Caplan, Rochon, & Waters (1992) argued that word-length effects are actually the effects of speech planning, which varies with complexity of the items to-be-remembered. Thus, it has been suggested that ease of planning and/or executing an output response may place an additional constraint on verbal short-term memory performance (Cowan et al., 1998; Sternberg et al., 1980). Therefore, included in Experiment 3, was a measure of the time it takes to start reading items in isolation and sequence, in order to examine any differences in speech planning times that may occur after familiarisation with the items.

Only a few studies have measured the time taken to start articulating items when examining articulatory duration. However, a number of studies have looked at the time taken to initiate recall responses during a serial recall task. The preparatory interval (time between last item in a presentation list and the initiation of a recall response) has not been found to differ between words and nonwords (Hulme et al., 1999). Furthermore, preparation time of a recall response has not been shown to correlate with memory span in children (Cowan, 1992). However, the pauses between word and nonword items in a recalled list have been found to be longer for nonwords than words (Hulme et al., 1999), this result is regarded as further evidence for redintegration, as the process takes longer for nonword than word items. However, it is possible to argue from the two previous experiments in the current series, that these pauses may reflect articulatory fluency. For example, words may be easier to coarticulate together resulting in shorter pauses, but between nonwords there could be more complex articulatory gestures (which may show up as silences) to accommodate the next nonword item in a list.

Previous research that has shown no difference in articulatory duration of familiar and unfamiliar words has typically measured articulatory duration of the items by measuring the time taken to rapidly repeat pairs of items (e.g. Hulme et al.,1991, 1995, 1997, 2003, Roodenrys et al, 1993; 2002; Thorn & Frankish, 2005). Consequently, in Experiment 3, articulatory duration measurement of pairs of items were was also included in the baseline (Stage 1) and post-familiarisation (Stage 3) reading stages, to examine whether this duration would decrease for the pure item pairs after familiarisation (as was found for pure sequence duration in Experiment 2). Alternatively, articulation of pairs, which include fewer articulatory transitions, may not show such an improvement after familiarisation of whole, pure sequences.

Additionally, in Experiment 3, the sensory modality of presentation for the serial recall task changed from auditory to visual, to examine whether this would lead to the same degree of improvement in articulating pure sequences as seen in the auditory presentation of the previous experiments. One of the key assumptions of the working memory model and many other short-term memory accounts is that whereas auditory stimuli can be encoded into phonological form automatically, visual stimuli typically needs to be converted to phonological form (through some sort of articulatory process, e.g. rehearsal) to gain access (e.g. Baddeley, 1986; 2000),

The experiment was again split into three stages. Stage 1 was a baseline stage of articulating items in isolation, pairs and sequences, Stage 2 was the familiarisation stage which incorporated a serial recall task of pure A and pure B sequences. Finally, Stage 3 involved the post-familiarisation reading of items in isolation and in pure and mixed pairs and sequences. This time there was no final articulation stage (Stage 4) as the emphasis was only on the articulatory data.

### 2.5.1 Method

*2.5.1.1 Participants*

Twenty undergraduate and postgraduate students at Cardiff University participated in the experiment in return for payment or course credit. They were 12 female and 8 male native English speakers aged between 18 and 22 years of age. All participants reported normal hearing and normal or corrected-to-normal vision and had not participated in the previous experiments.

*2.5.1.2 Design and Materials*

The experiment used the same sets of nonwords used in Experiment 2. In addition to sequences of each type, pairs of items were also constructed and included in the reading task of Stages 1 and 3; four pairs of each type (A, B, and mixed AB/BA). As before all the responses were measured in *SoundForge.* Additionally, as each item, pair or sequence appeared on screen, a click – with an almost instantaneous rise-time – was registered on the sound recording software, so that the time from presentation of item(s) to the start of the utterance could be accurately recorded. The same stimuli as used in Stage 1 were then used in a serial recall task (Stage 2). The serial recall task had 60 memory trials as in Experiment 2, but this time the items were presented visually one at a time (one item a second) in the centre of the computer screen.

*2.5.1.3 Procedure*

The procedure was the same as in Experiment 2, with the addition of reading aloud pairs of items in Stages 1 and 3 and the serial recall part of the experiment used visual rather than auditory presentation. The final recall stage of pure and mixed lists (Stage 4) was also omitted from this experiment.

## 2.5.2 Results

Both the articulatory duration and latencies to begin output for the reading in Stages 1 and 3 were measured in *SoundForge*. An average duration of an item spoken in both pure and mixed sequence was calculated. Additionally, the articulatory duration of an item spoken in both pure and mixed pairs was calculated – by dividing the total articulatory duration of a pair by two. The onset time was measured from the time the item appeared on the screen (shown as a click on the waveform) to the initiation of the utterance. Each participant provided 288 separate measurements. Table 2 shows the average onset time and articulatory duration for items in isolation and in the pure and mixed pairs and six-item sequences, before and after the familiarisation that occurred in Stage 2.

*2.5.2.1 Onset Time*

The duration from stimulus presentation until the point when participants started to articulate the utterance was calculated for items in isolation, pairs and sequences, this data is shown in Table 2. Participants had the longest onset times for the sequences and the shortest for the items in isolation; this reflects the increasing complexity of the speech planning process as sequence length increases. It is well established that onset time increases linearly with list length (e.g. Sternberg et al., 1978; 1980). A decrease in onset time between the stages was observed when items were articulated in isolation. There was a large decrease in the onset time for items uttered in isolation from Stage 1 to Stage 3 after familiarisation (over 100ms), $t\,(19) = 3.99, p < .01$.

The onset data for the pairs and sequences is less clear, pair onset duration appears to decrease the same amount for pure and mixed pairs, before and after familiarisation, whereas in the sequence data there is little difference in pure sequence onset times before and after familiarisation, whereas onset times decreased slightly for mixed sequences. A repeated measures ANOVA with the factors length (two/six), stage (before/after familiarisation) and type (pure/mixed) only showed a main effect of length, $F(1,19) = 9.27$, $MSE = 42466$, $p < .05$, indicating that the onset times were longer for the sequences than the pairs of items. However, there was no main effect of stage, $F(1, 19) = 2.31$, $MSE = 16055$, $p > .05$, or item type, $F(1, 19) = 1.47$, $MSE = 7188$, $p > .05$. Thus, familiarisation with the items in sequences did not affect onset times for the spoken utterances in either the pairs or sequences, for pure or mixed lists. There was also no significant interaction between length and type, $F(1,19) = 1.93$, $MSE = 6141$, $p > .05$, no interaction between length and time, $F(1,19) = .623$, $MSE = 9226$, $p > .05$, and no interaction between length type and stage $F(1,19) = 1.97$. $MSE = 4461$, $p > .05$.

Table 2 *Summary of mean onset and duration times for items, pairs and sequences, before and after the serial recall tasks*

| | ONSET | | | | DURATION | | | |
|---|---|---|---|---|---|---|---|---|
| | Before | | After | | Before | | After | |
| | *Mean* | *(SD)* | *Mean* | *(SD)* | *Mean* | *(SD)* | *Mean* | *(SD)* |
| Isolation | 706 | | 604 | | 555 | | 551 | |
| Pairs | | | | | | | | |
| *Pure* | 752 | *(154)* | 718 | *(167)* | 408 | *(82)* | 415 | *(89)* |
| *Mixed* | 761 | *(194)* | 711 | *(175)* | 411 | *(93)* | 407 | *(94)* |
| Sequences | | | | | | | | |
| *Pure* | 849 | *(211)* | 853 | *(202)* | 405 | *(88)* | 370 | *(71)* |
| *Mixed* | 826 | *(204)* | 798 | *(212)* | 408 | *(86)* | 406 | *(87)* |

A significant decrease in onset time between stages was only seen in the isolated condition. This reflects the fact that when participants start the experimental session, all the nonwords had to be learned afresh, when each one is presented for the first time, the participant has to decide how it is going to sound and the articulatory gestures involved in producing it. This implicates the grapheme-to-phoneme route, which is involved in reading novel or nonwords versus the direct route to reading of real or familiar words (e.g. Coltheart, 1980). Novel words have to be planned out before output but familiar word reading is more automatic. Initially, the time spent planning how to say each item is longer, but by the time the participant gets to the post-familiarisation stage they have had ample experience of recognising and saying each item.

*2.5.2.2 Articulatory Duration*

The spoken articulatory duration for items spoken in isolation, pairs and sequence before and after familiarisation is also shown in Table 2. Despite the nonwords becoming more recognisable and more familiar, this is not reflected in an improved articulatory duration for the items themselves – it takes participants just as long to articulate a nonword in Stage 3 as it does in Stage 1– which has also been found in the previous two experiments. The articulatory duration data for the two types of lists (pure and mixed) replicated the results of Experiment 2, but this time instead of auditory presentation, the serial recall task was visually presented. There was no improvement in articulatory duration of the mixed lists but a large improvement for articulatory duration of the pure sequences between the pre- and post-familiarisation stages. There was no significant difference in the articulatory duration of items spoken in isolation before or after familiarisation, $t\ (19) = .567, p > .05$. A repeated measures ANOVA was carried out to establish whether there was an effect of familiarisation on pair and sequence duration for pure and mixed lists. The factors included were length (two/six), stage (before/after), and type of list (pure/mixed). This analysis established that there was a main effect of list type, $F\ (1, 19) = 5.2$, $MSE = 544$, $p = < .05$, but no main effect of either stage, $F\ (1,19) = 1.02$, $MSE = 2834$, $p > .05$ , or length, $F\ (1,19) = 1.85$, $MSE = 3930$, $p > .05$. There was also a significant interaction between length and type, $F\ (1,19) = 6.27$, $MSE = 732.5$, $p < .05$ and a significant interaction between length and stage, $F\ (1,19) = 5.78$, $MSE = 4404$, $p < .05$. There was a significant 3 way interaction of stage, length and type, $F\ (1, 19) = 20.14$, $MSE = 251$, $p = < .001$. Pairwise comparisons, Bonferroni adjusted, showed that there was no difference in articulatory duration between either pure pairs or mixed pairs between stages 1 and 3 (all $p > .05$) however for sequences the mean difference of 35.4ms between stages 1 and 3 for pure sequences was significant $p < .001$, whereas the mean difference of 2.5ms between stages 1 and 3 was not significant for mixed sequences, $p > .05$.

Crucially only the articulatory duration of items spoken in pure sequences decreased significantly after the familiarisation task, $t\,(19) = 5.47, p < .001$. There was no difference for articulatory duration of items spoken in mixed lists, $t\,(19) = .205, p = .840$. This finding further suggests that coarticulatory fluency could be a key factor in familiarity effects, and the measurement of the articulatory duration of pairs of items minimises its contribution (two coarticulations instead of five for a sequence of six items), and may mask any actual articulatory differences between the materials.

In summary, these results show that familiarity with each item does not improve individual item articulation times although it does improve pre-articulatory planning. It is possible that the majority of articulatory planning is carried out whilst the response is being articulated for the pairs and sequence data. There was no significant decrease in either onset or articulatory duration times for pure or mixed pairs before or after the familiarisation task. However, in the six-item sequences there was no improvement in articulatory duration of the mixed lists but a large improvement for articulatory duration of the pure sequences between the pre-and post-familiarisation stages. This replicates what was found in Experiments 1 and 2. The finding that practice only increased the articulation of six-item sequences without altering the duration of pairs of items is potentially significant; previous research concluding that lexicality effects exist in the absence of any difference in articulatory rates has commonly only measured the time taken to rapidly articulate item pairs without taking measurements from longer sequences. In conclusion, these experiments suggest that co-articulatory advantages do not become evident when only articulation rates of words in isolation and pairs is scrutinised.

### *2.5.2.3 Further Exploration of Pure Sequence Duration Measures*

The results of the present experiment and the preceding two experiments (1, 2 & 3) have all shown that after familiarisation with assembling items into sequences the articulatory duration of producing sequences containing the same items that had been practiced in sequence was reduced. As the duration of sequences containing the same items but in different sequence formation did not show such facilitation in articulation rate, the results have been attributed to increased coarticulatory fluency at the word boundaries for the practised sequences; however, hitherto this construct has not been directly explored. In all the previous experiments, the sequences have been measured as a whole and increases in the speed of articulation have then been attributed to coarticulation effects. However, it is possible that the shortening of individual items not just increased coarticulatory fluency between words could also be leading to shorter sequence duration after practice on the pure sequences. Specifically it could be possible that what may be also getting shorter is individual word duration as the vowel within each item is articulated much more quickly as the items become more practised. There is evidence that individual within-item segments are shortened in rapid speech. For example, it has been found that the acoustic duration of vowels within items is shorter for faster speaking rates (Gay, 1981).

Thus, the pure sequence articulatory duration data from a sample of 12 (just over half) of the participants in Experiment 3 was investigated further in an attempt to explore whether the individual words as well as the transitions between words were getting shorter after practice assembling items into pure sequences. As all the items used in the present experiment were short one syllable CVCs it proved very difficult to isolate individual sounds in connected speech, and it was not possible to accurately compare vowel duration of items before and after practice. Instead, an attempt was made to capture the beginning and end of each word in a pure sequence, so an average articulatory duration of an item at each serial position could be calculated for items in pure sequences before and after practice.

In addition to measuring the individual word duration, the inter-item pauses were also measured as accurately as possible for the pure sequence utterances. Any periods of silence that occurred between successive words in the sequence were measured, in order to examine whether these were also shortened after practice. Figure 4 shows the results of these extra measurements; Figure 4a shows the mean articulatory duration of an item for each of the six serial positions in the uttered sequences, before and after practice, for pure sequences, Figure 4b shows the average pause duration between successive items before and after practice for each serial position.

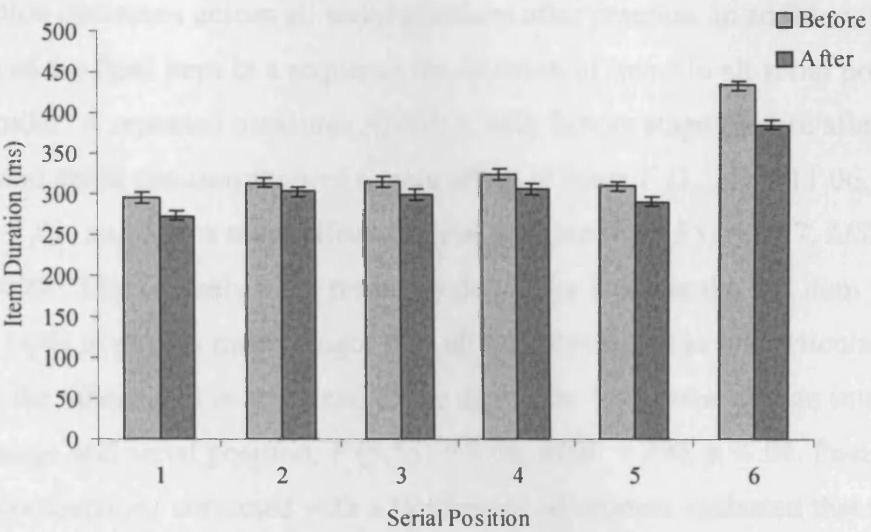


*Fig. 4a.* Average articulatory duration at each serial position before and after practice (Stage 2) with the 'pure' lists. Error bars represent standard error of mean

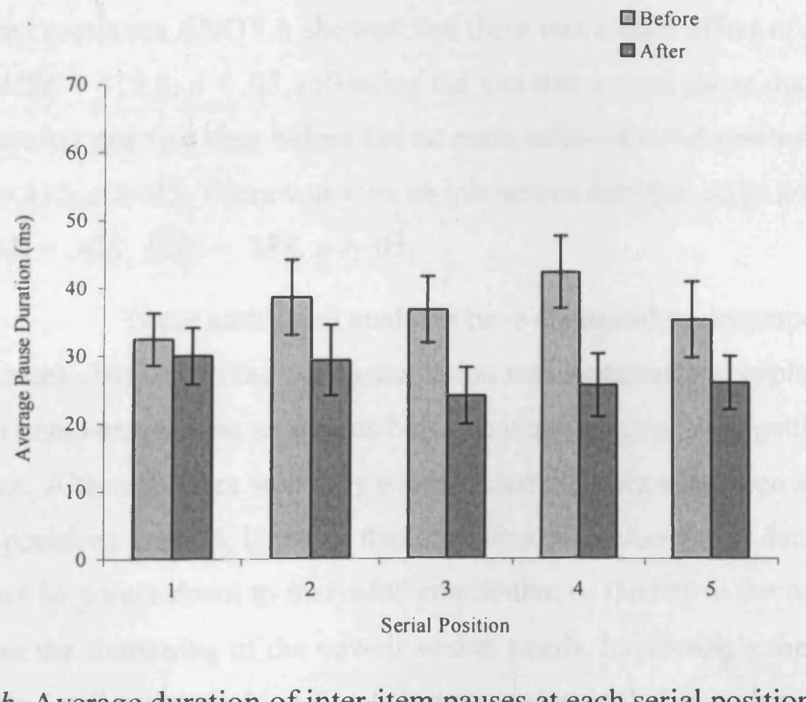


*Fig. 4b.* Average duration of inter-item pauses at each serial position before and after practice (Stage 2) with the 'pure' lists. Error bars represent standard error of mean

Firstly, from the item duration data in Figure 4a, it is evident that after practice item duration decreases across all serial positions after practice. In addition, with the exception of the final item in a sequence the duration of items in all serial positions is very similar. A repeated measures ANOVA with factors stage (before/after practice) and serial position showed a main effect of stage $F(1, 11) = 11.06$, $MSE = 1623$, $p < .01$, and also a main effect of serial position, $F(5,55) = 85.7$, $MSE = 568.4$, $p < .01$. This is likely to be primarily due to the fact that the last item in a sequence (sp6) is always much longer than all the other items as it is articulated more fully than the others as it is at the end of the utterance. There was also an interaction between stage and serial position, $F(5,55) = 3.66$, $MSE = 299$, $p < .01$. Post-hoc pairwise comparisons corrected with a Bonferroni adjustment indicated that there were only significant differences between stage 1 and stage 2 for serial positions 1 ($p < .05$) and 6 and for serial position 6 ($p < .001$). There was no significant differences between serial positions 2,3,4, & 5 before and after practice (all $p > .05$).

The mean inter-item pause duration data is shown in Fig. 4b. The pause durations involved are very small and there is a lot of variability in the scores but it is evident that after practice articulating the items in pure sequence, the pauses between items get shorter, indicating more rapid and fluent speech and coarticulation. A repeated measures ANOVA showed that there was a main effect of stage $F(1,11) = 7.28$, $MSE = 419.8$, $p < .05$, reflecting the fact that overall pause durations were shorter after practice than before but no main effect of serial position, $F(4,44) = .183$, $MSE = 415$, $p > .05$. There was also no interaction between stage and serial position, $F(4,44) = .423$, $MSE = 388$, $p > .05$.

These additional analyses have attempted to decompose the time differences obtained in the pure articulation rate measures and explore whether or not within item components as well as between item transitions are getting shorter after practice. Although there was only a significant difference between stages 1 and 3 for serial positions 1 and 6, it seems that individual item duration is decreasing, thus, this may not be purely down to increased coarticulatory fluency at the word boundaries but also the shortening of the vowels within words. Interestingly the items at serial position 1 and serial position 6 only have one coarticulation each as item 1 is not preceded by another item and item 6 is not followed by another item. The inter-item pause duration data suggests that after practice there is much shorter pauses between items which indicates that after practice assembling items into sequences, participants are more efficient and better able to coarticulate the items and blend the articulation of utterances together more efficiently.

Although degree of coarticulation is known to be lowest when spanning a word boundary, it has been found to be more pronounced during the production of rapid speech which was required in the articulation task of the present series (Byrd & Tan, 1996). In one study which examined the articulation of consonants spanning a word boundary, it was found that speaking faster decreased the articulatory duration of the separate components as well as increasing the temporal coarticulation of the tongue and consequently improving the coproduction or coarticulation between the successive articulations (Byrd & Tan, 1996). It was subsequently suggested by these authors, that speakers utilise a combination of overlap and shortened durations as speech rate increases, thus, it is possible in the present experiment that faster rate of pure sequence production after practice could be the result of a combination of increases in coarticulatory fluency both between items and shortened vowel durations within items.

### 2.6 Experiment 4a: Coarticulation or Association?

The results from the foregoing experiments demonstrate that familiarisation of items in sequences affects articulatory fluency and recall by increasing the readiness with which sequences of items can be assembled into a speech plan to prepare for recall. These results are very encouraging for the idea that improvements in memory are mediated by the fluency of speech habits; however, these results so far could be re-interpreted as reflecting more abstract associative processes.

Given that items from pure lists have been repeatedly presented together, the speedier production of pure lists could arise from the forging of stronger associative links between these items. Repeated presentation of item pairings has been found to result in better subsequent serial recall of low frequency items (Stuart & Hulme, 2000). The result was explained in terms of strengthened associative links between co-occurring items thereby enhancing the level of redintegrative support for individual items via activation from other, associated items. Accordingly it could be argued for the experiments in the current series, that the fact that pure A or B items had been presented for the serial recall task could have then strengthened the associative links between the items within each set, making it easier to articulate and recall pure sequences. Nevertheless, Experiment 2b of the current series here, showed that practising the articulation of sequences did not improve the articulation rate for pairs of items.

The purpose of Experiment 4 was to distinguish between association and coarticulation effects. The experiment was a within-participants design and the experiment consisted of two main sections, each section had the same three stages of the previous experiments. Firstly, a baseline reading stage (Stage 1), next a familiarisation stage (Stage 2) and a final reading stage (Stage 3). The aim was to compare familiarisation accounts involving coarticulation-plus-association with familiarisation involving association alone. This time, instead of a familiarisation stage incorporating a serial recall task, the familiarisation stage involved reading aloud the pure sequences. By contrasting two different types of reading of pure sequences, the experiment was designed to distinguish between the contribution of association and coarticulation. Participants were required to read out pure lists as quickly as they could (resulting in coarticulated sequences), then they were required to read another list in a paced fashion (where each item in a sequence appeared and is articulated in isolation, so coarticulation is prevented). The former allows for coarticulation and association of pure list items, whereas the latter has the same degree of association for pure items but no opportunity to coarticulate items in the sequence. If mere association is the critical factor, then sequence duration for pure lists should decrease after familiarisation with both paced and speeding reading. If, however, coarticulation is necessary to decrease sequence duration, only speeded reading should show a pure sequence duration decrease.

## 2.6.1 Method

*2.6.1.1 Participants*

Twenty-four undergraduate and postgraduate students at Cardiff University participated in the experiment in return for payment or course credit. They were all native English speakers with normal hearing and normal or corrected-to-normal vision. None of the participants had taken part in the previous experiments.

*2.6.1.2 Apparatus and Materials*

The same sets of nonword items, as used in Experiments 2 & 3 were used in this experiment. Participants were presented with two sets of 12 nonwords (one for each phase of the experiment). As in the previous two experiments each of the sets of items was split into two sets of six, Set A, and Set B. In the speeded-reading part of the familiarisation stage, pure sequences appeared for five seconds with all items appearing at the same time, and then the next sequence appeared. For the paced reading familiarisation stage each item in sequence was presented and remained on screen while the other items were being presented. The rate of presentation was one item per second. Once all six items had been presented the sequence disappeared and presentation of the first item of the next sequence appeared.

*2.6.1.3 Procedure*

Participants were seated in a soundproof booth in front of a microphone. Firstly, they completed the baseline articulation stage of items in isolation and sequence as before (Stage 1). Participants were then instructed to read aloud the pure sequences of nonwords that were presented. They were required either to read the sequence out as quickly as possible (speeded familiarisation), or each item in sequence would appear one after the other and each item had to be articulated as quickly as possible before the next one appeared (paced familiarisation). In the speeded reading part of the familiarisation stage, pure sequences appeared for five seconds with all items appearing at the same time, and then the next sequence appeared. For the paced reading familiarisation stage each item in sequence was presented and remained on screen while the other items were being presented. The rate of presentation was one item per second. Once all six items had been presented the sequence disappeared and presentation of the first item of the next sequence appeared. All sequences were presented three times and there were forty separate sequences. Following this reading task, participants were presented with the items in isolation again and in sequence to articulate as quickly as possible to get post-familiarisation duration measurements.

Participants were then offered a short break before continuing the experiment, the whole procedure was then repeated with a different set of nonword items and the opposite reading type (speeded or paced) from the one they did in the first part of the experiment. The order of paced or speeded reading being carried out first or second was counterbalanced across the participants. The whole procedure took an hour to complete.

### 2.6.2 Results and Discussion

The average duration of an item, for pure and mixed sequences, before and after paced and speeded reading, is shown in Figure 5. The speeded reading data show the same pattern as the previous experiments; there is a reduction in articulation time for pure sequences but not mixed sequences. However, the results for the paced reading data do not replicate this pattern, as there is no difference in articulatory improvement for pure or mixed lists.

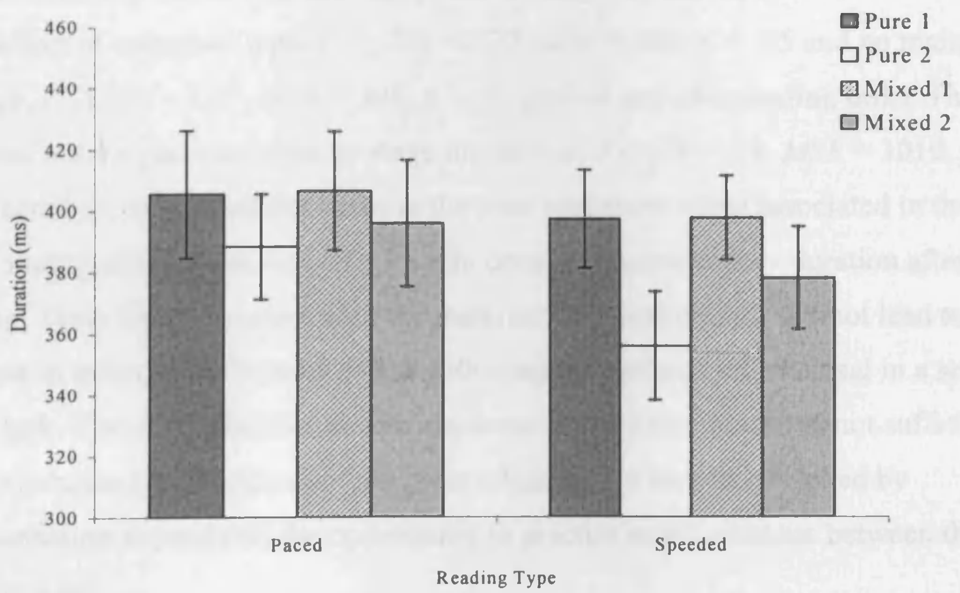


*Figure 5.* Articulatory duration of items spoken in pure and mixed sequences, before and after paced and speeded reading practice. Error bars show Standard error.

2.6.2.1 *Speeded Reading*

A repeated measures ANOVA on the articulatory duration data, of pure and mixed sequences before and after the speeded reading was carried out and showed a main effect of stage, $F(1,23) = 13.27$, $MSE = 1598$, $p < .001$. Articulatory rate got significantly faster after the speeded reading task. There was also a main effect of list type (pure and mixed), $F(1, 23) = 6.153$, $MSE = 528$, $p < .05$. There was also a significant interaction between list type and stage, $F(1, 23) = 13.12$, $MSE = 252$, $p < .001$. Employing the Bonferroni adjustment, pairwise comparisons showed that the articulatory duration of the pure lists decreased significantly more after the speeded reading task (mean difference was 41.5, $t(23) = 5.12$, $p < .001$) than the mixed lists where there was not a significant decrease in duration (mean difference 17.9, $t(23) = 1.9$. $p > .05$). This replicates what was found in the previous experiments.

*2.6.2.2 Paced Reading*

A repeated measures ANOVA on the articulatory duration data, of pure and mixed sequences before and after the paced reading was carried out. There was no main effect of sequence type, $F(1, 23) = 2.77$, $MSE = 308$, $p > .05$ and no main effect of stage, $F(1.23) = 2.77$, $MSE = 308$, $p > .05$ (before and after reading task). There was also not a significant type by stage interaction, $F(1,23) = 1.9$, $MSE = 3010$, $p > .05$. Therefore, despite all the items in the pure sequences being associated in the paced reading task, there was only a slight decrease in articulatory duration after reading, Thus, familiarisation with the material via paced reading did not lead to the increase in articulatory fluency found with speeded reading and rehearsal in a serial recall task. This indicates that mere association of the items in a set is not sufficient to lead to enhanced production of those items. Rather, the benefit conferred by familiarisation depends on the opportunity to practice coarticulations between the items in a set.

The results of this experiment sought to distinguish between coarticulation factors and associative factors. In both paced and speeded conditions, items within each set co-occurred equally often, what was manipulated was whether items were coarticulated or not. Only the pure sequences with practised coarticulations from the speeded reading were articulated faster. However, having determined that articulatory duration changes with practice on reading speeded lists, Experiment 4b was conducted to examine whether this would also result in enhanced recall for sequences that had been read in a speeded rather than paced fashion.

## 2.7 Experiment 4b

Instead of measuring articulatory duration, this experiment required participants to carry out paced and speeded reading of pure lists as before. However, this time, after each familiarisation task they performed a serial recall task of both pure and mixed lists. As a product of the improvement in articulation of pure lists where the coarticulations had been practised, it is hypothesised that memory performance for pure sequences should be enhanced in the speeded reading condition compared to the paced reading condition where coarticulations were unpractised.

### 2.71 Method

*2.7.1.1 Participants*

Twelve undergraduate students at Cardiff University participated in the experiment as part of their course credit. They were all native English speakers with normal hearing and normal or corrected-to-normal vision. None of the participants had taken part in the previous experiments

*2.7.1.2 Apparatus and Materials*

The same four paced and speeded reading nonword sets were used as in Experiment 4a. The serial recall part of the experiment consisted of 32 trials altogether, randomly presented (16 pure sequences and 16 mixed sequences). The lists were six items in length with no item being repeated in any one trial. The presentation rate was one item per second.

*2.7.1.3 Procedure*

Participants were seated in a soundproof booth, in front of a microphone. Participants were visually presented with sequences of nonwords, which they had to articulate as quickly as possible. All sequences were presented three times for the participant to articulate. They either read the sequences aloud as quickly as possible (speeded familiarisation) or each item in sequence would appear one after the other and each item had to be articulated as quickly as possible before the next one appeared (paced familiarisation). Once they had finished the reading task, instructions were given for the serial recall task. Sequences of six nonwords were presented one at a time on the computer in front of them. As before, recall was spoken, and participants were asked to recall the sequence of items immediately after presentation, preserving the order of presentation.

Both pure and mixed sequences were presented. Participants were then offered a small break before continuing the experiment. The second part of the experiment was identical to the first part except this time a different set of nonwords were used and participants did the opposite familiarisation task either paced or speeded, to the one they did in the first part, before carrying out the serial recall task. The order of paced or speeded reading being carried out first or second was counterbalanced across the participants and the whole procedure took just under one hour to complete.

### 2.7.2 Results & Discussion

The serial recall responses were recorded and only items that were recalled correctly in the right order were marked as correct. Figure 6a shows the overall percentage of items correct for pure and mixed lists in both conditions (paced and speeded reading) and Figure 6b shows serial position curves for the pure and mixed sequences in each reading condition.

It is evident that there was a bigger difference in serial recall performance between pure and mixed sequences in the speeded reading condition than in the paced reading condition with pure sequences being recalled better than mixed sequences. In the paced reading condition overall performance was slightly better for the mixed than the pure sequences

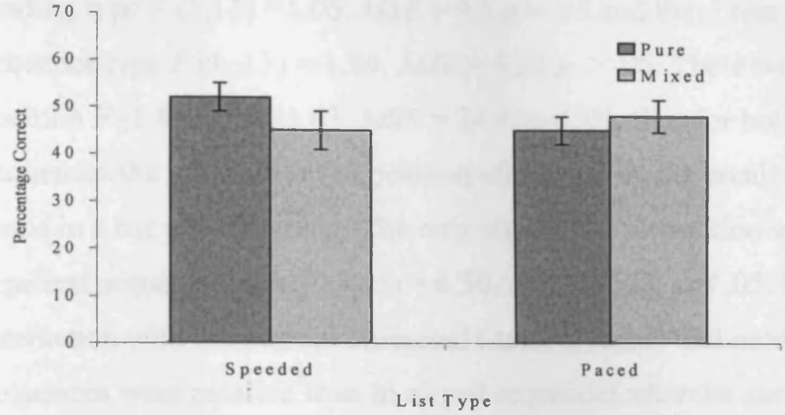


*Figure 6a* Overall percentages of correctly recalled items in pure and mixed trials after speeded and paced reading conditions. Error bars show Standard error.

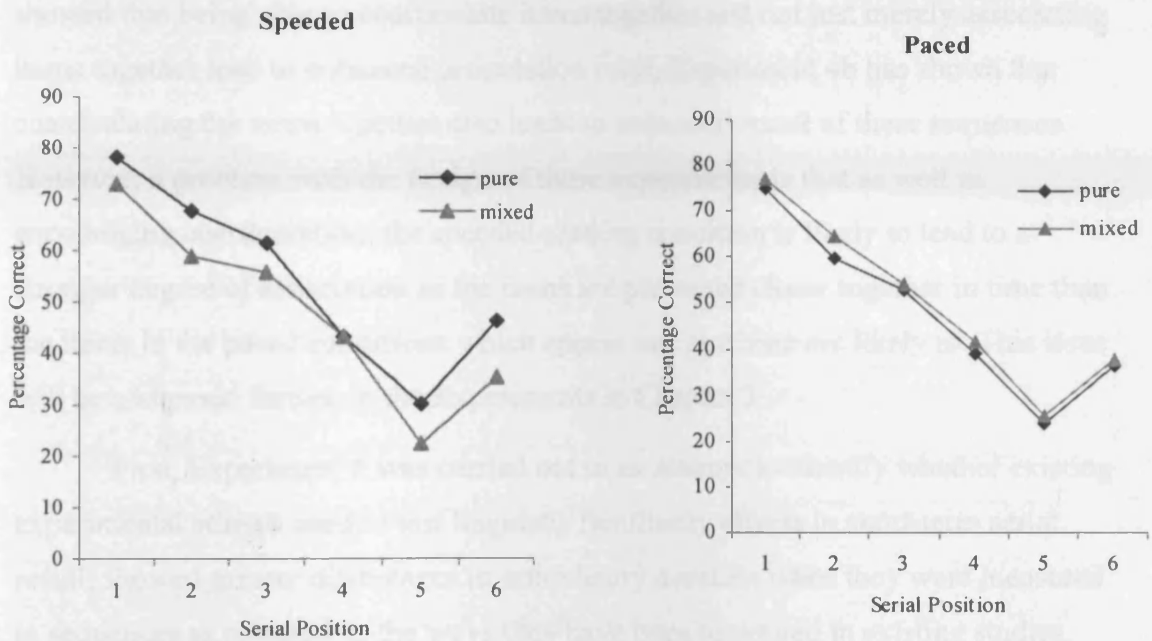


*Figure 6b* Percentage of correctly recalled items at each serial position for pure and mixed trials for speeded and paced reading conditions.

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A repeated measures ANOVA with factors reading type (paced or speeded), list type (pure or mixed) and serial position was carried out on these data. Mauchley's test indicated that the assumption of sphericity had been violated for the main effect of serial position. Therefore degrees of freedom were corrected using Greenhouse Geisser estimates of sphericity for this factor (ε = .372).There was no main effect of reading type $F(1,11) = 1.06$, $MSE = 9.5$ $p > .05$.and there was no main effect of sequence type $F(1, 11) = 1.89$, $MSE = 4.22$ $p$ .> .05. There was a main effect of serial position $F(1.8, 20) = 31.63$, $MSE = 34.4$, $p < .01$, thus for both pure and mixed sequences the standard serial position effect with better recall of initial items and last items in a list was observed. The only significant interaction was between reading type and sequence type $F(1,11) = 6.50$, $MSE = 1.37$, $p < .05$. Exploration of the interaction with Bonferroni corrected t-tests revealed that more items in pure sequences were recalled than in mixed sequences after the speeded reading condition $t(11) = 2.66$ $p < .02$, but in the paced reading condition the mean difference of .361 between pure and mixed sequences was not significant, $t(11) = 1.06$. $p = .312$.

In The results of this experiment reflect the result from Experiment 4a which showed that being able to coarticulate items together and not just merely associating items together lead to enhanced articulation rates. Experiment 4b has shown that coarticulating the items together also leads to enhanced recall of these sequences. However, a problem with the design of these experiments is that as well as encouraging coarticulation, the speeded reading condition is likely to lead to a stronger degree of association as the items are presented closer together in time than the items in the paced conditions which appear one at a time are likely to. This issue will be addressed further in the Experiments in Chapter 3.

First, Experiment 5 was carried out in an attempt to identify whether existing experimental stimuli used to test linguistic familiarity effects in short-term serial recall, showed greater differences in articulatory duration when they were measured in sequences as opposed to the ways they have been measured in existing studies.

## 2.8 Experiments 5: Word Frequency Effects

The preceding experiments have shown that when familiarity of nonwords is manipulated within the experimental setting, experience of coarticulations benefits recall performance and sequence production. Yet it is still unclear from these experiments, whether such coarticulatory differences are present in the familiar and unfamiliar word stimuli used by others in serial recall experiments. Evidence for a purely redintegration hypothesis for linguistic familiarity effects is based on studies which have shown differences in memory span between familiar and unfamiliar items which is not matched by differences in their articulatory duration (e.g. Thorn & Gathercole, 2001; Hulme et al., 1991; Brown & Hulme, 1993; Hulme et al., 1997; 2003). Consequently, speech rate has been dismissed for being an inadequate explanation of immediate serial recall performance. However such studies have not measured articulatory duration of sequences, but individual or pairs of item.

Experiment 1 has already shown that when measured in isolation words and nonwords (taken from Gathercole et al., 2000) do not differ in articulatory duration, but when measured in sequence, articulatory duration is significantly longer for nonwords than the words. Furthermore Experiment 3 showed that there were coarticulatory differences between familiar and unfamiliar stimuli, which did not show up when the duration of pairs of items was measured. Hitherto, the effects of word frequency on language production have not been assessed. Thus, Experiment 5 is going to examine whether there are differences between high and low frequency stimuli when a different method of measurement is used.

An examination of the five experiments in the Hulme et al., (1997) paper on word frequency effects, shows up an inconsistency in the way articulatory duration was measured. In their study, Hulme et al, (1999) measured speech rate in two different ways throughout their experiments. In Experiment 1, speech rate was measured by instructing participants to rapidly repeat pairs of the items ten times, four pairs of high frequency words and four pairs of low frequency words were presented to get a speech rate measurement for both high and low frequency items. However in the remaining experiments of the same paper (Experiments 2-5), speech rate was measured by getting participants to rapidly repeat each item individually ten times (with this measure no different was found in the speech rate of high and low frequency items (Experiment 2). However, as indicated by the preceding experiments in the present thesis, both these methods could underestimate the contribution of coarticulatory fluency. Experiment 5 will use the stimuli from word frequency studies carried out by Hulme et al., (1997; 2002), and measure the time taken to articulate items in isolation rapidly ten times, in pairs rapidly ten times and in sequence as rapidly as possible. The differences between the high and low frequency stimuli will be calculated.

The procedure will follow that of Hulme et al., (1997) with two exceptions. First, all types of measurement (individual, pair and sequence) will be taken as speech rate measures. Second, instead of memory span, serial recall performance of seven item lists will be assessed.

### 2.8.1 Method

*2.8.1.1 Participants*

Eighteen undergraduate psychology students from Cardiff University took part in this study in return for course credit. They were all aged between 18 and 23 years. All participants had normal or corrected-to-normal vision and hearing and had English as their first language.

*2.8.1.2 Design & Materials*

The eight short high frequency and eight short low frequency word sets used by Hulme et al., (1997) were the stimuli used in this study. The high frequency set comprised words with a frequency of 103 words per million or more according to the norms of Kučera and Francis (1967), they were; *hour, colour, game, fear, view, art, unit, order*. The low frequency set comprised words with a frequency of 5 words per million or less, they were; *foal, vow, truce, vet, crock, elf, dolt, lisp*. Hulme et al., (1997) indicated that these words were matched on articulatory duration and concreteness ratings.

*2.8.1.3 Procedure*

Participants were seated in a soundproof laboratory in front of a microphone. Initially they were presented with each of the high frequency and low frequency items in a random order, which they were required to read aloud, this enabled the experimenter to check their pronunciation before the serial recall task and to familiarise the participant with the items that they would be presented with throughout the rest of the experiment. After this they were given instructions for the serial recall task. They were presented with twenty types of each sequence (words and nonwords). Each sequence was six items long and each item was presented at a rate of one item per second, when the whole sequence had been presented participants were required to recall the sequence aloud in its order of presentation. Participants were instructed that the order was very important and if they were unsure of any item, they were to respond 'blank'. No item was repeated in any one trial and no more than two types of the same type appeared successively. All responses were recorded into *SoundForge*, so they could be marked.

Once the serial recall part of the experiment had finished participants were required to do the speech rate part of the experiment. The order of the three types of speech measurement was counterbalanced across participants.

For the individual item speech rate measurement, each item was presented individually at the centre of the computer screen and participants were instructed to repeat each word 10 times as quickly as possible, they were monitored by the experimenter, and when they had uttered 10 repetitions the word disappeared, before the next item was presented.

For the pair duration participants were presented with four randomly constructed pairs of high frequency and four low frequency pairs one at a time. Again, participants were instructed to rapidly repeat each pair as quickly as possible. They were monitored by the experimenter and when they had completed ten repetitions of the pair, the pair disappeared from the screen and the next pair was presented. The order of high and low frequency pairs was alternated. Two practice pairs were presented at the beginning, consisting of novel words.

Finally, for the sequence duration participants were presented with four high frequency and four low frequency, six-word sequences which were presented alternately. Participants were required to articulate each sequence as quickly as possible, once a sequence had been read the next sequence was presented. Again all responses were recorded onto *SoundForge* so they could be later analysed, and the mean times of the separate measurements could be converted into speech rate for the high and low frequency conditions. The experiment was conducted in a single session, which lasted about 45 minutes.

### 2.8.2 Results

*2.8.2.1 Serial Recall*

Serial recall responses were transcribed for each participant and marked according to a strict recall criterion; only items that had been correctly recalled in the correct serial position were marked as correct. Figure 7 shows the mean percentage correct of items at each serial position for the high frequency and low frequency sequences. High frequency word recall was significantly better than low frequency word recall over all serial positions. 65% of high frequency words were recalled correctly compared to 48% low frequency word sequences.

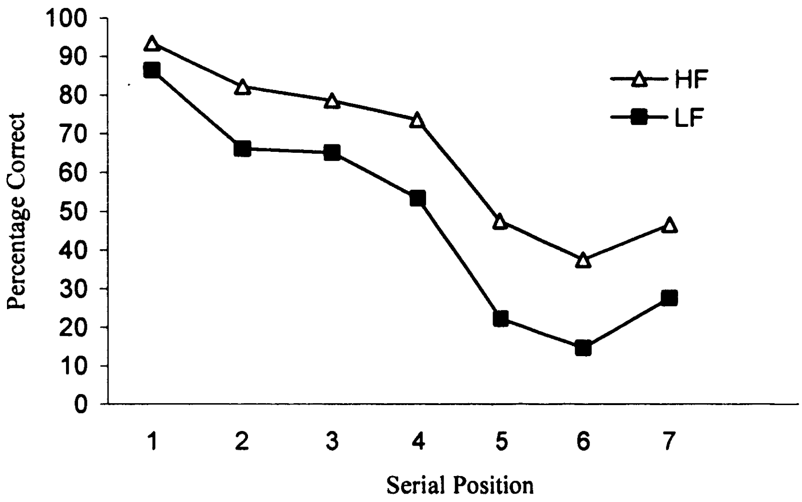


*Figure 7* Mean percentage of items recalled correctly in each serial position for high frequency (HF) and low frequency (LF) word lists.

A repeated measures ANOVA with factors word type (high and low frequency) and serial recall was carried out on the data. Mauchley's test indicated that the assumption of sphericity had been violated for the main effects of serial position. Therefore degrees of freedom were corrected using Greenhouse Geisser estimates of sphericity for this factor ($\varepsilon = .584$). There was a main effect of word type $F(1,17) = 29.5$, $MSE = 24.1$, $p < .01$ indicating that high frequency items were recalled better than low frequency items. There was also a main effect of serial position $F(3.5,59.5) = 99.7$, $MSE = 14.0$, $p < .01$, thus for both high and low frequency words the standard serial position effect with better recall of initial items was observed. There was also a significant type by serial position interaction $F(6, 102) = 2.78$, $MSE = 5.27$, $p < .05$. Hulme et al., (1997, 2003) reported a similar result with the same sets of items that high frequency words are recalled significantly better than low frequency words.

*2.8.5.2 Articulatory Duration/Speech rate*

The participants' voice was recorded during each of the speech rate tasks and the time taken to articulate the individual items or pairs 10 times or the sequences in the high and low frequency conditions were measured from the visual waveform in *SoundForge 5.0*. The mean of these times was converted into articulatory duration for each condition and for each type of speech rate measurement; this data is shown in Figure 8.

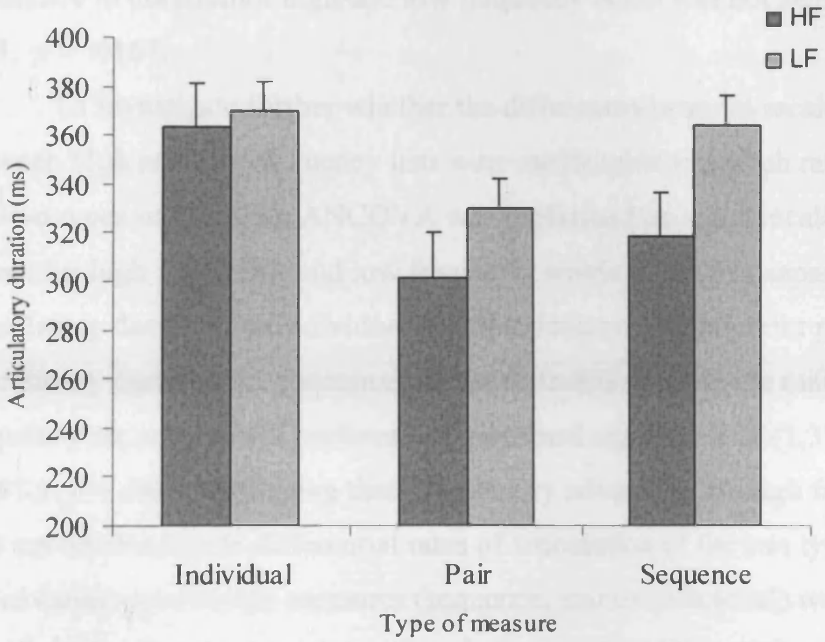


*Figure 8.* Mean articulatory duration in milliseconds of the high frequency (HF) and low frequency (LF) words when repeated rapidly individually, in pairs, or when articulated rapidly in sequence. Error bars represent standard error.

In all speech rate conditions the high frequency items were articulated faster than the low frequency items, although the difference between the two types of words is more pronounced in the pair and sequence measures than the individual measures. A Repeated measures ANOVA, with the factors type of measure (individual/pair/sequence) and type of word (high/low frequency) was carried out. This showed a significant main effect of word type, $F(1, 17) = 62.61$, $MSE = 341.56$, $p < .001$. High frequency words were spoken faster than the low frequency words. There was not a significant main effect of type of measure $F(2, 34) = .1.97$, $MSE = 6177$, $p > .05$, but there was a significant interaction between measure and type, $F(2, 34) = 13.55$, $MSE = 297$, $p < .001$. This reflects the fact that there was much less of a difference between high and low frequency items in the individual articulation condition than there was in either the pair or the sequence condition. Post hoc t-tests with Bonferroni correction (α was set at.0167 - two tailed) were used to analyse the difference in speech rate for high frequency and low frequency words for the three different articulation measures. The analyses revealed that the difference between high and low frequency words was significant for the pairs $t\,(17) = 5.54, p < .0167$ and for the sequences $t\,(17) = 5.11,\ p < .0167$, but for the items in isolation thee difference in duration of high and low frequency items was not significant, $t\,(17) = 2.53,\ p > .0167$.

To investigate further whether the differences in serial recall performance between high and low frequency lists were attributable to speech rate differences for the two types of items, an ANCOVA was performed on serial recall performance scores for high frequency and low frequency words with three separate covariates: the articulatory duration for individual items, articulatory duration for pairs of items and articulatory duration for sequences of items. In this analysis the main effect of frequency on serial recall performance remained significant [$F\,(1,31) = 11.847$, $MSE = 187.1, p < .005$] suggesting that the memory advantage for high frequency words was not attributable to differential rates of articulation of the two types of list. None of the covariate speech rate measures (sequence, pair or individual) were found to be significantly related to serial recall performance, $F\,(1,31) = .719, p > .05$, $F\,(1,31) = .45, p > .05$ and $F\,(1,31) = .000, p > .05$ respectively. Therefore there was still a main effect of frequency on serial recall performance even when differences in speech rate were controlled for. This indicates that there are effects of frequency in serial recall performance, which remain even when articulatory duration differences between the two types of item are controlled for, suggesting that frequency effects in serial recall are not attributable to articulatory duration differences.

Hulme et al., (1997) found in their first experiment, when short, medium and long items were taken into account and articulatory duration was measured in pairs there was a significant difference between high and low frequency duration, although the differences in recall were not believed to be attributable to speech rate differences when an ANCOVA was carried out with speech rate as the covariate. This result has been replicated in the present experiment just using the short duration items. Thus, from this experiment it is impossible to conclude that differences in high and low frequency items are purely down to differences in articulatory fluency. It could be that articulatory fluency is a more influential factor in determining serial recall performance when items are nonwords (as in experiments 1-4 of the present series) rather than real words that is when more emphasis may be placed on rehearsal. Therefore, the results from this experiment cannot rule out the suggestion that other processes are more important in determining the recall of word items, possibly the existing associations made between items in long-term memory (e.g. Stuart & Hulme, 2000).

Although the results from the ANCOVA has indicated that the differences in serial recall performance between high and low frequency words is not solely due to differences in speech rate, it has still managed to highlight the fact that different measures of articulation rate produce very different results. The duration results of the present experiment indicate that there are much bigger differences between high and low frequency items when pair and sequence duration is examined than when individual repetition is considered in isolation. This further suggests that there are coarticulatory differences involved in articulating high and low frequency words especially when they are articulated in sequence. This may have implications for how articulatory duration should be measured in immediate serial recall experiments. In addition, articulatory duration is typically measured after the serial recall task, whereby they would have had practice of assembling the items into sequences for rapid recall. It has already been found in the preceding studies, practice on a serial recall task which involves the rapid assembly of items into a sequence leads to enhanced level of production of nonword sequences not matched by word sequences. Thus, it may not be a true measure of articulation rate, as at the beginning of any study the difference in articulatory rate may possibly be larger than it seems at the end where participants have had practice assembling and recalling the items in sequence.

## 2.9 General Discussion of Experiments 1 – 5

These five experiments have investigated whether linguistic familiarity effects observed in serial recall experiments – commonly attributed to the item-based process of redintegration – may be explained by the fluency with which a sequence can be articulated. The first three experiments showed that as serial recall performance improved with familiarisation, the articulatory duration of sequence production decreased, whereas the duration of singles or pairs of items did not show this facilitation. These findings suggest that as coarticulations became more practiced – increasing the articulatory fluency of the sequence – serial recall performance improved. Furthermore, the results of Experiments 4a and 4b suggested it was the inter-item coarticulation rather than the formation and strengthening of associative links between items that led to the observed decrease in articulatory duration and enhanced recall performance of pure sequences.

The final experiment showed that although there were greater differences between the high frequency and low frequency items, used by other researchers, when sequence and pair duration was measured than when individual item repetition was measured, a further ANCOVA established that the difference in serial recall performance of high and low frequency words was not attributable to speech rate differences. Thus, the results from this experiment are therefore unable to rule out that processes other than fluency of rehearsal, such as the use of long-term knowledge or associations are aiding the recall of high frequency items (e.g. Stuart & Hulme, 2000). Nevertheless, the experiments identified that there are greater articulatory differences and constraints when sequence duration is taken into account rather than just measuring rapid repetition of individual items or pairs. Crucially then, studies where articulatory differences have been ruled out as a significant determinant of the differential recall performance of familiar and unfamiliar stimuli may be based on inaccurate measures of articulatory duration. A brief summary of the main findings of Experiments 1 - 5 will follow presently, with particular emphasis on how the results contribute to the growing body of evidence that suggests it may not be necessary to implicate specialist mnemonic constructs or processes to explain immediate serial recall performance. Rather it is argued that immediate serial recall performance can be more parsimoniously described with recourse to the processes which primarily exist for the production and perception of language (e.g. speech) and which are co-opted to aid the retention of verbal material in the short-term.

Typically, serial short-term serial recall research has focussed on the properties of individual items making up a sequence rather than the articulatory demands involved in producing items in sequence. These foregoing experiments however have shown that articulatory fluency, and in particular the coarticulations involved in the assembly of a whole sequence, affects the articulatory duration and recall performance of items. Traditionally models of short-term memory concentrate on the importance of rehearsal for serial recall performance (e.g. Baddeley, 1986; 2001) but the rehearsal of items at the sequence level and related articulatory factors involved in articulating sequences of items – such as coarticulation - are not usually specified. Due to the apparent absence of articulatory differences between stimuli sets the role of familiarity (e.g. lexicality, word frequency effects) on short-term memory has also been attributed to the item-based process of redintegration (Hulme et al., 1991; Hulme et al., 1995; Thorn & Gathercole, 2001). The results of the present experiments have shown that sequences where items had been articulated together were recalled better and articulated faster than exactly the same items placed in unpractised sequence formation. Despite all the items being equally familiar to the participant and therefore having an equal degree of redintegrative support – only the items in sequences where coarticulations were familiar had better recall performance. This raises the possibility that articulatory fluency rather than redintegration accounts for some of the linguistic familiarity effects observed in short-term serial memory.

Current theories of immediate serial recall also concentrate primarily on the selection and recall of each item separately (e.g. Burgess & Hitch, 1999; Page & Norris, 1998; Brown et al., 2000), in these models, items exist in relative isolation of one another in memory. Consequently the coarticulations involved in assembling and rehearsing items into a sequence are overlooked. The present experiments indicate that it is perhaps more accurate to see memory for serial order involving the production and planning of the to-be-remembered items as a whole sequence, rather than by iterative retrieval of individual items.

The finding that familiarity with the coarticulations involved in saying items in sequence together affects the articulatory duration and recall of items enables us to question the ways articulatory rate and duration should be measured in serial recall experiments. Currently there are inconsistencies in the methods used to measure articulatory duration and rate both across experiments and within experiments, common methods include measuring articulation rate of items in isolation or rapidly articulated pairs (Baddeley et al., 1975; Lovatt et al., 2000; Hulme et al., 1997). These methods however, do not take into account all possible coarticulations needed to articulate sequences as long as those typically presented for serial recall (i.e. 6 to 9 items). In experiments 1-3 it was found that only sequence duration was affected by familiarisation, while one-item and two-item utterances did not show any decrease in duration after familiarisation. Noticeably, the time taken to say an item in a sequence was much faster than when articulated in isolation, and only sequence duration was affected by familiarisation. This shows that measuring items in isolation or pairs minimises coarticulatory effects on to-be-remembered items which has been previously shown to influence serial recall (Murray & Jones, 2002).

Studies that have dismissed articulatory differences when interpreting the effects of familiarity may have overlooked actual coarticulatory differences, especially if stimuli were matched on item or pair duration. In accordance with this Experiment 5 was carried out using stimuli taken from other experiments which have examined familiarity effects, in an attempt to distinguish whether there are larger differences between the two types of stimuli used when a different type of speech rate measure is employed which is closer to the requirements of the serial recall task. The frequency data showed that there was a much larger difference between low and high frequency words when pair or sequence duration was measured than when individual word repetition was measured. The largest difference between high and low frequency words was observed when sequence duration was measured suggesting that there are coarticulatory differences in the two types of list. However it was concluded that differences in speech rate did not explain the differences in serial recall performance. Thus, it is possible that coarticulatory fluency may be more influential in determining serial recall performance when the items to-be-recalled are nonwords. Thus, with nonwords there is an absence of other mnemonics (e.g. word associations) when recall involves nonwords of differing familiarity so participants may focus on the articulatory properties of sequences to a greater extent. In the recall of word stimuli other skills may be relied on.

Taken together these findings indicate that when matching experimental stimuli, the time taken to assemble and articulate the items into whole sequences should be taken into account. Previous studies which have dismissed articulatory differences as an inadequate explanation of serial recall differences possibly use insensitive measures of articulatory duration, leading to an under-estimation of the role played by articulatory fluency on immediate serial recall performance. Furthermore, as Experiments 1 & 2 showed, participation in a serial recall task leads to the familiarisation of the coarticulations involved between items; therefore speech rate is significantly quicker after the serial recall task than before it. Studies where articulation rate measurements are taken at the end of the experiment may also result in an underestimation of the initial differences in articulation rate; Experiment 1 showed that the difference between unfamiliar and familiar items is greater before rather than after serial recall. A similar method involving the measurement of recalled sequences has also been proposed as a more accurate measure of articulatory duration, especially with respect to the of examination word-length effects (Mueller, Seymour, Kieras & Meyer 2003), this method also takes into account all coarticulations, but a recalled sequence rather than a read one is measured. Experiment 5 showed that there were bigger differences in articulatory duration between high and low frequency words when pairs or sequences were measured than when individual items were measured.

The present findings of Experiments 1-4 support the view that serial recall performance and the retention of items in working memory is parasitic on general perceptual and motor planning processes (Jones, Macken & Nicholls, 2004). In the case of verbal materiel the processes involved in serial recall tap into the same operations that primarily exist to process speech. So, the closer the to-be-remembered material matches a person's language skills or speech habits the more efficient the recall performance achieved (Macken & Jones, 2003). The proposal that the underlying articulatory control processes at work in language and serial memory are the same in both cases has been highlighted by the finding that errors in natural speech are very similar to errors made in serial recall experiments (Ellis, 1980; Treiman & Danis, 1988).

A comprehensive study of speech errors Ellis (1980) examined all the errors made by participants when they were required to recall five nonsense syllables. The syllables used in the study all contained different combinations of consonants and vowels, to enable the classification of the different types of errors that were made. Firstly, instead of the errors occurring completely randomly it was instead found that the types of errors were highly constrained. Moreover, the identified classes of errors all had a corresponding error observed in natural speech. The similarity in errors of errors of speech and serial recall was explored by Ellis (1980) who proposed what he termed an 'response buffer, whose purpose is to hold pre-planned stretches of speech before it is required for speech production' (Ellis, 1980, p624). Although the primary function of the response buffer was stipulated to be the production of speech, it was suggested that it could also be used in serial recall tasks where it is necessary to briefly hold a sequence of events that are required to be reproduced at recall. He explained that both short-term memory errors and speech errors are influenced by the same variables in the same way (Ellis, 1980). More recently it has been suggested that it is perhaps not necessary to implicate such a store in explaining errors from speech, rather it could occur due to cyclic rehearsal whereby a output sequence is planned and rehearsed, this process then is not linked to any buffer or store (e.g. Jones, Macken & Nicholls, 2004; Jones, Hughes & Macken, 2006; Macken & Jones, 2003).

Coarticulation is one specific feature of fluent speech that in previous verbal serial recall experiments has been largely overlooked. The complexity of the articulatory gestures needed to make the transition from the end of one item into the beginning of another item in sequence affects recall performance (Murray & Jones, 2002). The present experiments have shown that increasing the familiarity of coarticulations increases the readiness with which a sequence of to-be-remembered items can be assembled into a speech plan for rehearsal and recall. Practising articulating items together increases the familiarity of the coarticulations between items, making them more fluent to articulate and reproduce in sequence. This in turn could explain the enhanced recall performance for this type of list.

To date few other studies have taken into account the complexity of articulatory gestures needed to coarticulate separate items together. However, one comprehensive study into speech errors and serial recall involved presented adults with a serial recall task consisting of spoken nonsense syllables (Treiman & Danis, 1988). The authors examined the recombination errors and found that vowel liquid rhymes (items ending with /l/r/w/y/h) were more likely to be retained than vowel obstruent rimes (items ending with /p/b/t/d/k/). This could be because the articulatory gestures are more complex for vowel obstruent rimes than vowel liquid rimes which are easier to coarticulate. Manipulations of the wordlikeness of nonwords have found recall for word-like nonwords to be superior to the recall of less word-like nonwords (Vitevitch et al., 1997; Gathercole, Frankish, Pickering & Peaker, 1999). This is usually attributed to better redintegrative support for word-like nonwords. However it is possible that items with common sound sequences are repeated more quickly than those with less common sound sequences due to the articulatory gestures involved being more familiar, making the items easier to repeat and consequently better recalled. Therefore, the word-likeness effect in serial recall may not have its effect solely in redintegration but in articulatory differences between word-like and less word-like nonwords.

These experiments have highlighted the role that the articulatory fluency of to-be-remembered items plays in serial recall performance. The familiarity of coarticulations has an effect on the memorability and duration of items in sequences; however, we have yet to establish the full extent to which coarticulatory factors have an effect on language production and serial recall performance. It is unclear whether coarticulation has to be actually carried out to affect later duration and recall or perhaps merely hearing coarticulated sequences affects later production and memorability of sequences. Studies with children have found that at just nine months old infants are sensitive to coarticulation information which enhances their ability to recognise syllable sequences (Curtin, Mintz & Byrd, 2001; Mattys & Jusczyk, 2001).

In conclusion, the results of these experiments suggest that articulatory and linguistic factors, involved in articulating a sequence, contribute to verbal serial recall performance. Increasing the familiarity with the articulatory fluency of sequences led to enhanced recall for sequences involving these particular sequences. Furthermore, it the contribution of speech gestures and coarticulation has been largely overlooked in previous accounts of serial recall phenomena such as phonological similarity and lexicality effects. Therefore, studies that show item based redintegration effects due to an absence of any difference in articulation rates have possibly overlooked the contribution of articulatory constraints involved in coarticulating whole sequences of items. Stimuli for serial recall experiments need to be matched for articulatory difficulty both within and across word boundaries in order for sequences to be of the same articulatory duration. We have yet to establish whether this speech-based process of coarticulation could contribute to other short-term memory phenomena (e.g. phonological similarity and word length/complexity effects). These experiments also lend support to the theories that short-term memory performance is underpinned by language production processes. Rapid repetition of items in a sequence, which in itself involves coarticulation, is a way of co-opting speech habits in order to impose transitional probabilities on to lists of items that otherwise have very little in the way of cues to aid recall.

Chapter 3 will further examine the evidence that speech habits have a determining role in immediate serial recall performance and examine in more detail how coarticulation may determine and influence language production and immediate serial recall performance. Studies which have indicated that both adults and children become sensitive to phonotactic constraints by merely listening to novel stimuli will also be addressed, before introducing Empirical series 2. These next experiments will attempt to identify whether with practice articulating items in sequence, coarticulations can be learned and generalised to the production and recall of different items but which share the familiar coarticulations. As well as seeing whether coarticulations can be generalised across words, these experiments will also attempt to further disentangle more accurately the effects of association and coarticulation, an issue which was initially addressed in Experiments 4 of the current series.

# CHAPTER 3:
# Coarticulation Generalisation: Further Evidence for a Motor/Gestural Basis to Verbal Short-term Memory Performance

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## 3.1. Abstract

Three experiments examined the proposal that familiarizing participants with coarticulated sequences would enhance articulatory fluency and serial recall of a separate set of items, which shared these coarticulations. Experiment 6 showed that the rapid repetition of sequences resulted in enhanced fluency of sequences containing different items but practiced coarticulations. Experiments 7 and 8 examined whether increased articulatory fluency is reflected in increased memory performance. In Experiment 7, there was no significant increase in recall performance after familiarisation. In Experiment 8, both presentation rate and retention interval were increased to encourage the use of rehearsal. Both sequences containing the same items and sequences containing different items but the same coarticulations to the familiarized sequences were recalled significantly better after familiarisation. Thus, the (co)articulatory fluency with the articulatory gestures needed to negotiate the boundaries between words in a sequence rather than just associative factors is an important determinant of serial recall performance. Furthermore, merely producing items in sequence enables the generalisation of articulatory fluency to different words where the coarticulatory gestures needed at the transitions between words were matched.

## 3.2 Introduction

Series 1 demonstrated that when unfamiliar items were practiced together, the articulation rate increased and this was reflected in enhanced memory performance of lists of items that had been practiced together compared with lists of items that had been practiced but not together in a sequence. Thus, familiarising participants with the coarticulations involved in saying items together in sequence proved beneficial for later sequence production and immediate serial recall performance of items in sequences where the coarticulations had been practiced. The results from these experiments suggested that familiarity and experience of articulatory planning and production of items in sequences rather than just items in isolation is an important, albeit largely overlooked, determinant of immediate serial recall performance for verbal material. These experiments provide further support for the idea that immediate serial recall performance can be regarded as being parasitic on language perception and production processes. Instead of explaining verbal short-term memory in terms of specialised mnemonic processes such as the action of a short-term phonological store, it has been suggested that immediate serial recall performance can be more simply understood by the action of production and perception processes, which are primarily used in language but can be co-opted to support the order of material in the short-term (e.g. Jones et al., 2004). Thus, in order to retain the order of rapidly presented verbal stimuli, participants use what skills (particularly language) they have available to them.

The aim of the current chapter is to further investigate whether the articulatory fluency of sequence production is an important determinant of serial recall performance. Since the focus of this chapter is on how language production processes can affect serial recall performance, the main components involved in the production of spoken language will be briefly outlined. Moreover, how features of connected speech, such as coarticulation may also influence rehearsal and serial recall performance will be discussed. This chapter will then proceed to discuss a number of studies that have examined how features of language can be rapidly acquired by both speech production and perception processes from brief exposure of sounds together. Such studies have shown that recent listening or production experience can affect both the production and perception processes involved in connected speech. Studies which have involved the introduction of novel or nonsense phonotactic regularities and grammar, have found that individuals are able to assimilate this and implicitly learn this grammar, which is reflected in both the errors made and in speed of production.

The three experiments in this chapter examine further whether familiarity with the articulatory and co-articulatory fluency of items in sequence can affect both later productions of items in sequence and subsequent recall performance of items in sequences with which participants have been familiarised. Hence, the experiments in the present thesis will remain with the issue of how familiarising participants with certain coarticulations can affect serial recall performance through enhancing the planning and production of a sequence for rehearsal and output. In addition, the experiments examine whether practising the coarticulations involved in the production of a sequence of items can be generalised to the production and recall of a different set of words, which contain the same pattern of practiced coarticulations. Moreover, the three experiments described will endeavour to further disentangle the effects of association and coarticulation, which were first addressed in Experiment 4 of Chapter 2. The experiments aim to identify whether familiarising participants with the production of certain sequences can affect and improve the production and fluency of a different sequence of items, but one that crucially involve the same coarticulations. These experiments attempt to further demonstrate how familiarity with assembling items into sequences can influence speech production and serial recall performance.

## 3.2 Language Production and Perception Basis to Immediate Serial Recall Performance: An Overview

The previous two chapters of the present thesis introduced the idea that short-term memory performance, rather than being a product of a dedicated store and specialised phonological loop, is instead a reflection of processes that primarily exist for the perception and production of language (Macken & Jones; 1995; Macken, Jones & Nicholls; 2004; Hughes, Jones & Macken, 2005). Such a proposal focuses on how many cognitive abilities are underpinned by perceptual and production mechanisms which primarily exist to support other abilities such as speech production processes and auditory perception. These mechanisms are then co-opted to aid performance on serial recall tasks. This is a different approach to the issue of serial recall performance from the working memory model and questions the involvement of a phonological store. Instead memory performance is seen as being reliant upon a combination of acoustic perceptual and articulatory/speech factors. It involves two elements; a perceptual process and an articulatory or motor/gestural process (Jones, Macken & Nicholls; 2004; Hughes, Jones & Macken, 2005), the latter process being the specific focus of the present thesis.

### 3.2.2. Motor/Gestural Basis to ISR

Whereas the working memory model and other similar models have a rehearsal mechanism at their core, this process is usually construed as being quite separate from normal language processes. Typically, rehearsal is seen as a revivification process, whereby the phonological codes of to-be-remembered items are refreshed through subvocal rehearsal of the separate items. However, another way to interpret the rehearsal process is in the form of the planning of a gestural sequence that can be reproduced to maintain order and output when recall is required. Hence, it is likely that articulatory constraints and or determinants of language production also serve to constrain/determine immediate serial recall performance. Evidence that immediate serial recall performance reflects normal language planning and production processes has come from a number of sources including; speech error research, observations of speech timing and neuropsychological studies. Most notably, it has been found that both the pattern of errors and the timing of output in serial recall tasks can be replicated by the simple act of just reading out a list of items, where there is little or no burden on memory.

#### *3.2.2.1 Evidence for link between memory and language: Speech error research*

Compelling evidence that serial recall responses are the result of normal language planning and production processes has come from speech error research. It has been consistently found that errors of phonological serial recall are in fact errors of production (Ellis, 1980; Mackay, 1970; Treiman & Danis, 1988). These studies have documented the striking similarity between the type of errors made on verbal serial recall tasks and those made in normal speech production, when no memory load is required.

From his extensive examination of speech errors, Ellis (1980) identified that the types of errors made on serial recall task had a corresponding error type in natural speech production and furthermore, the pattern of errors could be replicated when phonologically similar items were just read aloud, without any memory constraint. Ellis (1980) examined the errors made when participants were required to recall five different nonsense syllables (all of which were made up of different combinations of vowels and consonants), instead of finding a random pattern of errors, the errors identified showed a number of regularities in the types of errors made. The majority of errors made were then found to be characteristic of natural speech errors such as spoonerisms (e.g. Mackay, 1970; Nooteboom, 1969; Shattuck-Hufnagel, 1992).

From these results, Ellis (1980) proposed what he termed a ‘response buffer’ the purpose of which it was claimed is to hold pre-planned stretches of speech before they are required for production. Although the primary function of the response buffer was stipulated to be the production of fluent speech, Ellis (1980) suggested that it is also highly likely to be utilised during serial recall tasks, where it is also necessary to briefly hold a planned sequence of events that are required for reproduction at recall. This suggestion that both short-term memory errors and speech errors are influenced by the same variables in the same way (Ellis, 1980), is compelling evidence that verbal serial recall performance is heavily dependent on language planning and production processes. Further evidence for the relation for language production processes and memory has come from studies which have shown that when participants make substitution errors in serial recall, they typically share the manner of articulation of the phonemes they replace (e.g. Bisiacchi, Cipolotti & Denes, 1989; Caramazza, Miceli & Villa, 1986), similarly consonant intrusion errors in serial recall tasks have been found to be acoustically similar to the items they replace (Conrad, 1964). Thus, all the errors observed in typical serial recall responses could be explained as occurring by the same means as those in natural speech.

Thus far, the experiments in the current thesis have predominantly focussed on the production and serial recall of nonword items. Ellis (1980) and subsequent researchers of serial recall (e.g. Treiman, 1983, 1995; Treiman & Danis, 1988) have also observed that the errors made in nonword serial recall are qualitatively different to those made in word serial recall tasks. Whereas serial recall errors made on word lists are characterised by misordering errors of whole words, for nonword serial recall the predominant error involves transpositions of parts of words from one item to the other. The high probability of recombination errors in nonword recall was taken advantage of in one study, which illustrated how the linguistic structure of items (e.g. the onset and the rime structure of syllables), which is crucial to normal speech production and perception processes are also critical units when it comes to immediate serial recall performance (Treiman & Danis, 1988; Treiman, 1995).

Using nonword syllables Treiman & Danis (1988) identified that the linguistic structure of syllables (e.g. onset and rime) that govern language production are also apparent in serial recall errors. The authors identified that with regard to serial recall errors the way syllables break apart and recombine is not a random process; instead some groups of phonemes are more likely to be preserved than others. Specifically, it was found that with CVC syllables, the break is typically at the C/VC boundary, where the onset consonant of one syllable recombines with the rime of another item. As noted in Chapter 2, Treiman & Danis also identified that some VC rimes were more cohesive than others, affecting the likelihood of them remaining together. Moreover, syllables with uncommon VC rimes are harder to remember and to pronounce than syllables with more common rimes (Treiman, 1983). Thus it is likely that in the case of unfamiliar items the articulatory fluency of an item is crucial to how likely it is to be recalled.

Both the natural speech error research and linguistic evidence discussed as well as data from other sources such as the examination of errors made in word games (e.g. Treiman, 1983, 1995) and serial recall all demonstrate a striking resemblance to the pattern of errors found in serial recall errors. Further evidence that errors in serial recall errors are errors of production comes from a study by Shattuck-Hufnagel (1992) who monitored participants reading aloud tongue twisters as well as reciting tongue-twisters from memory. The pattern of errors for both conditions was found to be identical, suggesting that serial recall and speech errors arise during production planning, which is the processing stage that is common to both conditions, rather than from memory. Thus, taken together, such studies seem to indicate that speech planning and production processes primarily used for language, also underpin performance on serial recall tasks. The standard phonological loop model fails to predict in detail the pattern of errors that occur in short-term memory tasks. Instead, the locus of phonological similarity effect is not thought to be in the phonological loop or rehearsal process but due to similar item representations in the phonological store becoming confused (e.g. Baddeley, 1986, 1990). However, the evidence from speech errors suggests errors of phonological similarity arise from speech planning processes in rehearsal (e.g. Ellis 1980; Treiman, 1983; Treiman & Danis, 1984) rather than from confusions occurring in an abstract phonological store construct.

#### *3.2.2.2. Summary of speech error evidence*

Speech error research has illustrated the dependence of immediate serial recall performance on language processes. Thus if rehearsal is understood to involve the planning of a gestural sequence that can be reproduced to maintain order and output when recall is required, then the constraints of language production should also constrain memory performance for sequences. Thus, it is necessary to discuss what is involved in producing a sequence of connected speech. The next section will briefly outline the processes considered necessary for language production. Much of the research on speech production is focussed on the production of individual items rather than the production of whole utterances. However, there are a few theories which do discuss features of connected speech such as coarticulation. These will all be discussed presently.

## 3.3 Language Production

The experiments in Chapter 2, illustrated that faster production times and enhanced serial recall performance for practiced sequences was the result of increased articulatory fluency. It was further suggested that through familiarising participants with sequences, the participants become familiarised and more practiced at the coarticulations involved in assembling the items into a sequence, leading to more efficient rehearsal and performance. Hitherto, the features involved in coarticulating items together have not been discussed; hence the current section is going to outline some of the phenomena involved in connected speech production. If, as it is argued in the present thesis, speech processes guide serial recall performance, then the phenomena involved in connected speech are also likely to occur when planning and producing a serial recall rehearsal sequence and response.

Within the area of language research, it is broadly agreed that that are three main components to speech production namely, conceptualisation, formulation and articulation (e.g. Butterworth, 1980; Dell, 1986, 1988; Levelt, 1989). Uttering words begins with the activation of concepts or reading words and results in overt articulation, whereby a plan for what has to be said is assembled and stored, before the brain sends muscle commands to the vocal tract (Caplan, Rochon & Waters, 1992; Dell, 1986; Levelt, 1989). Of particular interest to this thesis is articulation, which involves the precise articulatory planning of the linguistic form and its subsequent execution. Levelt (1989) describes how a stored word form needs to be translated into a phonetic plan, which is understood to be a detailed prescription of the articulatory gestures needed for successive syllables that is assembled and then articulated. This assembly of a motor plan is known as 'phonetic encoding', phonetic encoding and articulation follow different time scales so it has been suggested that phonetic plans of sound sequences are stored temporarily in a buffer before they are finally downloaded to the articulators (Levelt, 1989). Such a buffering device allows fluent delivery of the articulatory movements. Then each part of the phonetic plan is retrieved and the single motor commands unpacked, then during the stage of motor execution the unpacked motor commands are delivered to the articulators and executed by the different speech muscles.

Although there is an abundance of research into the production of single words, connected speech has received much less attention. It is unlikely that in the production of connected speech speakers concatenate citation forms of words, it is argued instead, that rhythmic, pronounceable structures (namely phonological words) that largely ignore lexical word boundaries are created (Levelt & Wheeldon, 1994; Nespor & Vogel, 1986; Wheeldon & Lahiri, 2002). Although language research primarily focuses on individual spoken units there are a number of differing views on what constitutes a spoken unit (e.g. one word, a phrase or short sequences of syllables). Specifically, it is argued that the minimal unit of phonological encoding is the phonological word (e.g. Levelt, 1989; 1992; Levelt & Wheeldon, 1994). The phonological word is constructed from the individual word segments which are first retrieved separately and then reconstructed to form a phonological word which has only one main stress. Moreover, it has been suggested that during the assembly of the speech motor plan gestural scores or articulatory motor programmes for whole syllables (especially frequent ones) are read out from a repository (syllabary) of ready-made syllable sized motor programs (Crompton, 1982; Levelt 1989; Levelt & Wheeldon, 1994; Roeleofs & Meyer, 1999).

It has been proposed that instead of frequent syllables being reconstructed afresh each time they are needed, overlearned articulatory gestures, are instead accessible from a store of ready made articulatory-phonetic syllable programs/gestures (Crompton, 1982; Levelt 1989). Crompton (1982) was the first to suggest the existence of a syllabary to account for the frequent occurrence particular speech errors. Since then, effects of word frequency on language production have also been attributed to the effects of a syllabary rather than word frequency (Levelt & Wheeldon, 1994). In their study Levelt & Wheeldon (1994), found Dutch words ending in a high frequency syllable were produced faster than those ending in a low frequency syllable, independent of word frequency and articulatory difficulty (Levelt & Wheeldon, 1994).

### 3.3.1 Connected Speech Production

Serial recall performance involves not only the rehearsal of individual items but also assembling them into a motor-gestural sequence. Speaking is a highly complex motor act; not only are muscles of the vocal tract controlled and inter-coordinated, but the muscles of the respiratory system are also involved (e.g. Ladefoged, 1968). Phonological segments (phonemes) are rarely uttered in isolation. Moreover, phonological segments are not identical in all contexts instead phonological segments are known to vary to become more similar in voice, place and manner to adjacent syllables; this is known as assimilation or coarticulation. This process is even more apparent in rapid speech (and arguably rehearsal), as it allows for smooth and fluent speech production with the minimal amount of articulatory effort.

It is impossible for the vocal tract to move instantly form one target formation for a sound to the next. Thus, instead of each phoneme having an invariant articulation form, which then would involve a much more complex transition to the next item, the vocal tract varies the articulation of phonemes in order to "...steer a graceful and rapid course through the sequence" – this is the result of coarticulation

(Kuhnert & Nolan, 1997, p62). It seems likely that the more familiar a coarticulatory transition is the quicker and more efficiently coarticulated sounds will be produced.

*3.3.1.1 Coarticulation and Assimilation*

There are two types of coarticulation/assimilation, these are preservatory, where a sound takes on the characteristics of a sound that precedes it and anticipatory whereby a sound is influenced by a following sound, this type of assimilation is common in English than preservatory. Assimilation can be further classified into three types depending on what features of the adjacent sound become familiar, voice, place or manner. Assimilation of manner where one sound changes its manner of articulation to be become more similar to an adjacent sound, e.g. a stronger consonant (obstruent) becoming a weaker one. Assimilation of manner is typical in rapid speech, whereby the utterance needs to be less demanding to articulate.

Coarticulatory processes both between words and within words are possibly going to be more marked or prevalent in rapid speech, such as list reading and sequence production during serial recall. Although it is likely that words used in a serial recall task are not commonly articulated together, so are more complex to articulate. Furthermore the properties or familiarity of a word may also affect pronunciation and coarticulation. It has been found that that unstressed vowels are more likely to be reduced in high frequency than low frequency words (Fidelholtz, 1975). Also consonant reduction or the deletion of final /t/ and /d/ is more likely in high than low frequency items. Less overlap in assimilation or articulation has been observed in low frequency compounds 'lard core' compared to matched high frequency compounds 'hard core' (Stephenson, 2003). This is likely to be due to the fact that this is an uncommon pairing and therefore uncommon transition, which may be more effortful.

*3.3.1.2 Coarticulation between syllables*

Coarticulation is the "overlapping of adjacent articulations" (Ladefoged, 2001, p.272). Thus during connected or fluent speech most sound segments transmit information not only about themselves but also about neighbouring sound segments. The degree of coarticulation between adjacent segments has been found to depend upon the segments location with respect to word boundaries (Fujimura, 1990). In particular, articulatory segments at the edges of prosodic domains or words are strengthened (Fourgeron & Keating, 1997), so they carry more pronounced articulation and consequently exhibit less overlap or coarticulation with adjacent segments (Byrd, 1996; Byrd & Saltzman, 1998). Thus less coarticulation is likely to signal a word boundary and more coarticulation signals more lexical cohesiveness.

The experiments in this chapter will look at how familiarisation with the coarticulations involved between syllables can affect sequence production and recall performance. Relative to single word production and coarticulatory processes within syllables, less research has been carried out on the spoken production of items in longer sequences and the between item coarticulations involved from finishing the pronunciation of one item and initiating the pronunciation of the next item. In the case of rapid speech the more smooth and less effortful the transition is then the more fluent the production of the items. As mentioned previously one study which manipulated the complexity of transitions between words, was able to show that words placed in sequences containing more complex transitions were recalled less well than words placed in sequences where the transitions between items were less complex and involved a much lesser degree of adjustment to start saying the next word (Murray & Jones, 2000).

The experiments in this chapter will also examine whether reading aloud sequences of items can improve articulatory fluency and consequently improve serial recall performance. Participants will be repeatedly presented with sequences of items which will be required to be read aloud in a familiarisation stage. It is predicted that simply producing these items will affect later productions of these sequences and of sequences which contain different items but the same coarticulations. There is a growing body of evidence which shows that merely listening or producing sound sequences for a short period of time can result in the adaptation of language production and perception processes, if this is the case then practice saying nonword sequences should benefit serial recall performance too, as the motor gestural plans for production will be assembled more efficiently. Before describing the experiments the research examining how language production and perception processes can adapt to recent experience will be discussed.

### 3.4 Learning/Acquiring Language from Experience

The experiments in the current chapter will examine whether familiarising participants with the production of certain sequences is able to improve the articulatory fluency and recall of separate sequences, which share the same coarticulations. Not only do these studies aim to further disentangle effects of coarticulation and association, but they will also examine whether coarticulatory fluency can be generalised across different words. A number of studies have already been able to demonstrate that relatively short listening to or production of sound sequences results in the adaptation of language production and perception processes.

Speech processing is known to be guided by phonotactic regularities which determine what sound sequences are possible in a speaker's language. For example, in English one such rule is that in English the sound ng [ŋ] as in the word ring only ever occurs at the end of a word, never occurring as a word onset. Such phonotactic constraints are believed to be encoded by speech production processes, and are known to influence speech production (e.g. Dell, Reed, Adams & Meyer, 2000; Taylor & Houghton, 2005). Indeed, spontaneous errors of speech rarely result in the production of sequences that violate phonotactic constraints, so, speech errors typically follow the phonotactics of the language being spoken (e.g. Mackay, 1972; Treiman & Danis, 1988).

The role of certain language processes such as phonotactic regularities in short-term memory has already been pointed to by experiments that have manipulated the phonotactic frequency of nonwords (Gathercole, 1995; Vitevitch et al., 1997). Words that are rated as more 'word-like' than others are recalled more accurately than nonwords rated as less wordlike (Gathercole, 1995). Phonotactic influences are also seen in the perception and production of nonwords - nonwords with common sound sequences can be repeated more quickly than those with less common sound sequences (Vitevitch., 1997). It has also been well documented that ones perceptual and production capacities can be reorganised given experience with the phonotactic regularities of a novel language.

In addition to research that has shown that phonotactic regularities are an important influence on speech processes, a number of other studies have examined how easily phonotactic regularities are assimilated. Techniques which have involved exposing participants to a sequence of CVCs that are subject to certain novel rules have shown that knowledge of phonotactic regularities can be acquired rapidly and this is manifest in the errors which speakers subsequently make, which typically respect the rules from the exposed sequences. In one such study, Dell, Reed, Adams & Meyer, (2000) investigated the learning mechanism that is responsible for the language production systems sensitivity to the positions of speech sounds. The authors wanted to examine whether participants could implicitly learn the phonotactic constraints from the repetition of lists, for this study, participants were required to recite sequences of four consonant-vowel-consonant (CVC) nonsense syllables (e.g. *hes feng neg kem*). Within the sequences there was always one [ŋ] segment, which in English only occurs as the coda part of the word, and always one [h] segment which can only be an onset in English. Thus, any errors made with these sounds were expected to respect these phonotactic constraints.

Moreover, within the experiment other phonotactic constraints were created. In one experiment half the participants experienced the segment [f] always as a syllable onset and [s] always as a syllable coda, whereas the other half of participants experienced the opposite pattern. Each participant completed four sessions, speaking more than 6,000 syllables in total. An examination of the errors demonstrated that participants were sensitive to such constraints, as the errors made respected the phonotactic constraints of the experiment. It was suggested that this sensitivity to the occurring sound distributions was acquired implicitly by participants while they were simply producing the syllables as accurately as they could. This is presented as evidence that the language production system is able to adapt to recent language experience.

Other studies have shown that phonotactic regularities can also be acquired by merely listening to sound sequences for a brief period of time (Botvinick & Byslma, 2004; Marjerus, Van der Linden, Mulder, Meulemans & Peters, 2004; Onishi, Chambers & Fisher, 2002). Adults have been shown to acquire novel phonotactic regularities not present in English by merely being exposed to them in a stream of nonsense speech sounds, this acquisition of phonotactic regularities was manifest in the errors made in a speeded repetition task (Onishi et al., 2002). Sensitivity to languages regularities is believed to occur early in life. For example, infants exhibit babbling patterns consistent with the prosodic pattern of their native language as young as 10 months old (Levitt & Wang, 1991; Levitt & Utman, 1992) and they exhibit sensitivity to rhythmic characteristics as well as to phonotactic regularities of their native language (Mehler, Jusczyk, Lambertz, Halsted, Bertoncini & Amiel-Tison, 1998). Sensitivity to phonotactic constraints is also apparent from an early age, infants listen longer to sequences containing their languages phonotactics than sequences that do not follow such phonotactics (Jusczyk, Friederici, Wessels & Svenkerud & Jusczyk, 1993).

When nine-month-old infants are exposed to a continuous sequence of CV syllables governed by an artificial grammar, for as little as two minutes, they later displayed differential listening times to either 'legal' or 'illegal' words according to the new phonotactic grammar (e.g. Saffran, Aslin & Newport, 1996, Jusczyk et al., 1993; Jusczyk, Luce, & Charles-Luce, 1994). These studies are a further indication that ones phonotactic structure of phonological knowledge can be changed rapidly. In addition, infants have also been shown to use phonotactic regularities to segment speech (Mattys & Jusczyk., 2001) they are also sensitive to the way in which phonotactic sequences align with word boundaries (Mattys, Jusczyk, Luce & Morgan, 1999). Thus merely listening to novel phonotactic grammar can alter the phonotactic expectations that guide speech processing (e.g. Onishi et al, 2002; Marjerus et al, 2004).

Coarticulatory information has also been found to affect perception of sequences; at nine months, infants are sensitive to coarticulation information, which enhances their ability to recognise syllable sequences (e.g. Curtin, Mintz & Byrd, 2001; Mattys & Jusczyk, 2001*)*. Within a language the transitional probability from one sound to the next is highest when two sounds follow within a word but those spanning a word boundary will be relatively low. For example in the utterance *pretty#baby*, transitional probability for ty-ba is lower than pre-ty. Adults and children use these statistical probabilities to discover word boundaries in artificial speech (Saffran, Aslin & Newport, 1996; Saffran, Johnson, Newport & Aslin, 1999; Johnson & Jusczyk 2001). Infants rely on articulatory cues to segment sound patterns from fluent speech and associate a lack of coarticulation with the occurrence of word. It has been found that infants are sensitive to both acoustic and allophonic cues to word boundaries (Mattys & Jusczyk, 2001).

The experiments in the current chapter will investigate whether the production and coarticulation of sequences can affect later articulatory fluency and serial recall.

The effect on memory, of exposing participants to certain phonotactic regularities has been examined by Marjerus, Van der Linden, Mulder, Meulemans and Peters, (2004). In their study, Marjerus et al., (2004), exposed both adult and 8 year old participants to an artificial phonotactic grammar, before giving then a nonword repetition task (short-term memory measure). The nonwords in the repetition task were either 'legal' or 'illegal' with regard to the previously experienced phonotactic grammar. The results showed that recall performance of the legal nonwords was significantly better than serial recall performance of the illegal nonwords. These results were taken as an indication that short-term memory is directly influenced by sublexical phonological knowledge, which can be rapidly changed. These studies have illustrated how from relatively brief listening or production experience knowledge of sound sequences can be learned and becomes apparent in both perceptual and production processes

### 3.5 Introduction to Experiments 6 – 8

The studies discussed above have shown that when language knowledge is manipulated in the laboratory, participants are sensitive to the phonotactic regularities of later spoken and heard sound sequences. The purpose of the three experiments in the present series is to examine whether coarticulatory information can also be learnt through practicing the articulatory production of sequences and then generalised to another set of words which share the coarticulations. The familiarity of coarticulations will be manipulated. If articulatory fluency of the coarticulations involved in articulating the items together is enhanced by familiarisation, then this should be reflected in both the production and memory performance of the sequences of the same items and sequences which contain practiced coarticulations.

In addition, these experiments will attempt to further disentangle the effects of association and coarticulation, which were first addressed in Chapter 2. Although the experiments of Chapter 2 went some way to establishing whether the benefits from reading items together rapidly was the result of coarticulatory fluency rather than association. The results of Experiment 4, which distinguished between paced and speeded reading are questionable; although the items were the same, items in the speeded condition were presented closer together in time than items in the paced condition, it is well established that timing between pairings is very important for forming associations. Stimuli need to be perceived as belonging together before associations can be formed. Thus, in the speeded condition whereby the items were presented at the same time as each other, associations were probably much more likely to be formed than in the paced conditions were items were presented one after the other. This issue will be addressed in the remaining experiments of this thesis.

The final three experiments examine whether practice with coarticulating items in sequences can be generalised across lists which share the same coarticulations but contain different items. Examining whether this affects speech production times and serial recall performance will enable the identification of whether practicing coarticulations can generalise to novel words. As in the previous experiments there will be three separate stages, a baseline reading or memory stage, a familiarisation stage involving the speeded repetition of lists, and a final reading or memory stage.

Each participant will only be exposed to one, two or three sets of items. There will be two groups of two sets of nonwords, and the words in each set of one group will share the same onset and offset portion but will differ in the vowel portion (e.g. set A, *pem, darp,* set B, *pim, derp)* thus, sets A and B will share the same coarticulations as will sets C and D. This manipulation allows approximate control of coarticulations. It is hypothesised that if a participant is required to rapidly repeat sequences of pure A items in the familiarisation stage, then in Stage 3 not only the production speed of A sequences should be enhanced from the baseline but also the production of B sequences, which share the practiced coarticulations. In contrast, the production and serial recall performance of C sequences (which do not contain either the same items or the same coarticulations to those practiced) should be unaffected. If this were the case it would suggest that coarticulations are being learnt between words which are making the production of these coarticulations more fluent, which can then benefit the production of other words which share the same coarticulations.

### 3.5.1. Experiment 6: Coarticulation Generalisation in Sequence Production

#### *3.5.1.1. Participants*

Twenty-five undergraduate psychology students at Cardiff University participated in this study in return for course credits. They were aged between 18 and 24 years of age, there were 9 males and 16 females. All participants reported normal or corrected- to-normal vision and hearing and had English as their first language. None of the participants had taken part in any of the previous studies in this thesis.

*3.5.1.2 Apparatus & Materials*

As with the previous experiments all the stimuli were nonwords. Twenty-four nonwords were taken from the Gathercole et al. (2001) study, although this time items were selected on the basis that that for each item there was a corresponding item in the Gathercole set which shared its initial and offset consonants. Both of the matching items were then selected (e.g. *pem* and *pim*) and assigned to different sets. Thus, in total four sets of six nonwords were used, however, during testing each participant was only exposed to three out of the four sets. The four nonword sets were labelled A, B, C & D, sets A and B contained items within which the onset and offset syllables were matched, but the vowel portion of the items were different (e.g. set A; *pem, darp, nerg, tudge, lub, bick;* and set B; *pim, derp, norg, tidge, lib, bock*). The same rule applied to sets C and D (e.g. set C; *mon, gub, chad, darch, jit, mup;* and set D; *mun, gab, chud, derch, jat, mip*). It was a within-participants design and before testing started each participant was allocated the three sets of items, which they would be exposed to during the experiment, two similar sets and a different set (e.g. AB & C or AB & D or CD & A or CD & B).

For the Stages 1 and 3 (the articulation stages) four six-item sequences were constructed from each of the sets a participant had been allocated (e.g. four pure A sequences, four pure B sequences and four pure C sequences). All items in a sequence were simultaneously presented visually on a computer screen, with one sequence at a time being presented. The final serial recall task consisted of 45 trials in total (fifteen sequences from each allocated set). All the sequences were six items in length with no item being repeated in any one trial.

*3.5.1.3. Procedure*

Participants were tested individually in a soundproof room, where they were seated in front of a microphone. Before the experiment, each participant was allocated three sets of items to which they would be exposed. Allocation of item sets was counterbalanced across participants, with 6 participants seeing each combination. Initially participants were presented with every item from all the sets they had been allocated, each item appeared individually at the centre of the computer screen and participants were required to clearly read aloud each word. This part of the experiment aimed to familiarise participants with the pronunciation of the items as well as ensuring that similar items were pronounced differently. Once all the items had been presented and accurately spoken the experiment proper began Stage 1 involved the baseline measurement for reading the different types of sequences. Items to be spoken in sequence were presented simultaneously and participants were required to read each sequence aloud as quickly and accurately as possible from left to right, once the sequence had be read, the next sequence appeared. Each participant read twelve sequences in total; four from each of the sets they had been allocated. All sequences were recorded using *SoundForge 5.0* software.

In Stage 2, the familiarisation stage, participants were presented with six item sequences, which appeared in the centre of the computer screen. This time the familiarisation stage involved production of sequences from only one of the sets of items. Participants were required to read aloud each sequence as quickly and accurately as possible, then the next sequence appeared. Each of the 40 different sequences were presented three times. Following the familiarisation stage was the second articulation duration measurement stage (Stage 3), where participants were required to read sequences aloud as quickly as possible. As in Stage 1, each participant read 12 sequences; four from each of the sets they had been allocated.

Finally, participants were given instructions for the serial recall task (Stage 4), the to-be-remembered items six-item sequences were randomly presented with a presentation rate of one item per second. Once the last item had been presented, a cue was given for the participant to recall the sequence in its original order, substituting 'blank' for any serial position where they could not recall the item. Recall responses were spoken and recorded in SoundForge. The serial recall consisted of 45 sequences; 15 sequences from each of the three sets a participant had been allocated. The sequences were presented in a random order, but there were no more than two successive trials of the same type of sequence and no sequences were repeated. The whole procedure took just under an hour to complete.

### 3.5.2. Results & Discussion

*3.5.2.1 Articulatory duration (pre and post-familiarisation)*

The sequence recordings from Stage 1 and Stage 3 were labelled and saved for each participant then the duration of each utterance was measured in milliseconds from the beginning to the end using *SoundForge 5.0* software. Mean sequence duration was calculated for each sequence type, and then this number was divided by six to produce a calculation of mean duration per item for each sequence type. Thus, each participant provided a duration measurement for each of the three sequence conditions before and after the familiarisation stage, the three conditions being as follows; *same item sequences*, which were sequences containing the same items as those familiarised in Stage 2, *different item-same coarticulation* sequences, which were the sequences which contained different items but identical coarticulations to the ones practiced in the familiarisation stage and finally *different item-different coarticulation* sequences which contained both different items and different coarticulations between items to those encountered during familiarisation. As mentioned previously, which set of items was which sort of sequence for each participant, was counterbalanced across participants.

Figure 9 shows the articulatory duration of the items spoken in sequence before and after the reading/familiarisation stage. There was no appreciable difference in the articulatory duration of the different conditions prior to familiarisation, and no difference was expected at this stage as all sequence types were equally novel and therefore undifferentiated to the participant. However, after the familiarisation part of the experiment (Stage 3) all sequence types showed a reduction; the greatest reduction in articulatory duration was observed for the *same item* sequences, followed by the *different item-same coarticulation* sequences and finally, the *different item-different coarticulation* sequences showed the smallest reduction in articulatory duration after practice on sequence reading.

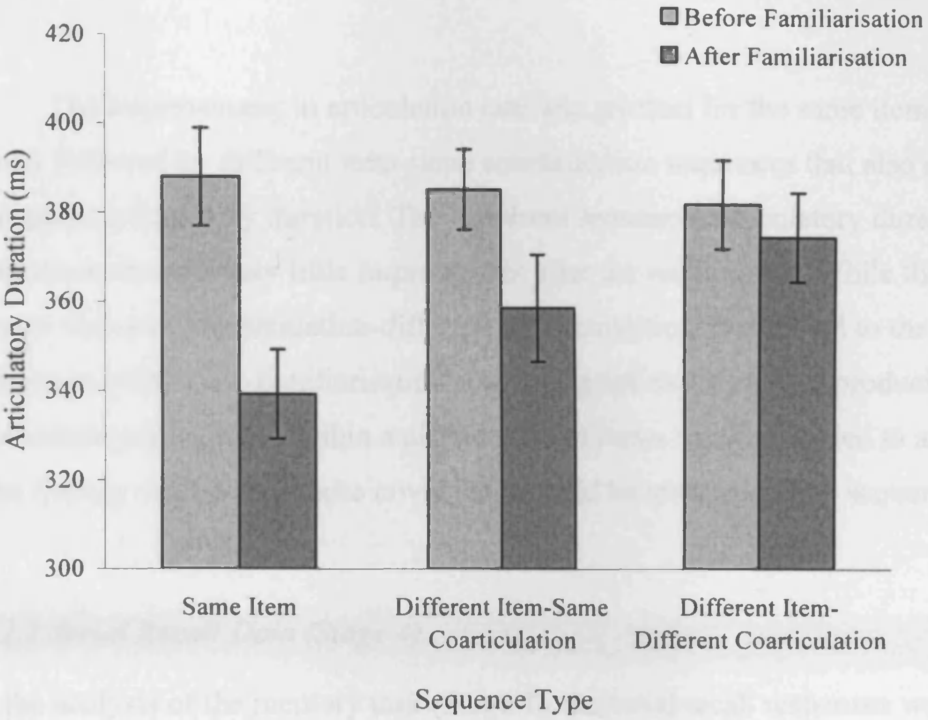



*Figure 9* Articulatory duration of items in milliseconds before and after practice of reading sequences. Error bars show Standard Error.

A repeated measures ANOVA revealed a significant main effect of Stage, $F$ $(1, 24) = 11.74$, $MSE = 2426$, $p < .05$, indicating that articulatory duration decreased after reading practice .There was also a main effect of sequence type, $F$ $(2, 48) = 4.60$, $MSE = 588$, $p < .01$. Contrasts revealed that there was a significant difference in articulatory duration between *same item and different item-different coarticulation* sequences $F$ $(1,24) = 11.49$, MSE $=937$, $p < .05$ but there was no difference in articulatory duration between *same item* and *different item-same coarticulation* sequences $F$ $(1,24) = 3.02$, $MSE = 1150$, $p > .05$ or between *different item-same coarticulation* and *different* sequences $F$ $(1,24) = 1.38$, $MSE = 1443$, $p > .05$ There was also a significant type by stage interaction $F$ $(2, 48) = 12.64$, $MSE = 423$, $p < .001$. Post-hoc paired Bonferroni corrected t-tests were used to analyse the performance differences between stages across time for the three conditions, for the *same item* condition, the mean difference of 48.7 between stages 1 and 2 was significant, $t(24) = 5.25$, $p < .01$ and for the *different item/same coarticulation* the mean difference of 26.7 was significant $t(24) = 2.84$, $p < .01$ but there was no such enhancement for different item sequences from Stage 1 to Stage 3, $t(24) = 0.79$, $p = .44$.

The improvement in articulation rate was greatest for the same item sequences (50ms) followed by different item-same coarticulation sequences that also showed a decrease in articulatory duration. The 'different sequence' articulatory duration in comparison showed very little improvement after the reading task While the actual items in the same coarticulation-different items condition were novel to the participant, at the post-familiarisation stage, the prior experience of producing the coarticulatory transitions within a different set of items nonetheless led to an increase in the fluency with which those novel items could be assembled into sequences.

*3.5.2.2 Serial Recall Data (Stage 4)*

For the analysis of the memory task (Stage 4), the serial recall responses were listened back to and only items that had been correctly recalled in the correct serial position were marked as correct. Each participant's trial responses were then divided into whether they contained the same item, same coarticulations or different sequences to the ones that they had been familiarised with in Stage 2. It was hypothesised that the serial recall data would reflect the data from the serial recall task, however this was not the case and the data was less straightforward. Figure 10 shows the serial position curves for the three conditions. Overall the pattern of the data followed the articulatory duration data; correct recall performance was greatest for the *same item* sequences (48%of items were recalled correctly), the next most accurate performance was for the *same coarticulation-different item* sequences (44% correct), and the least accurate performance was achieved on the *different item* lists (only 42% correct). Thus, overall performance on the serial recall task was very poor; participants struggled with trying to recall six nonword items in order.

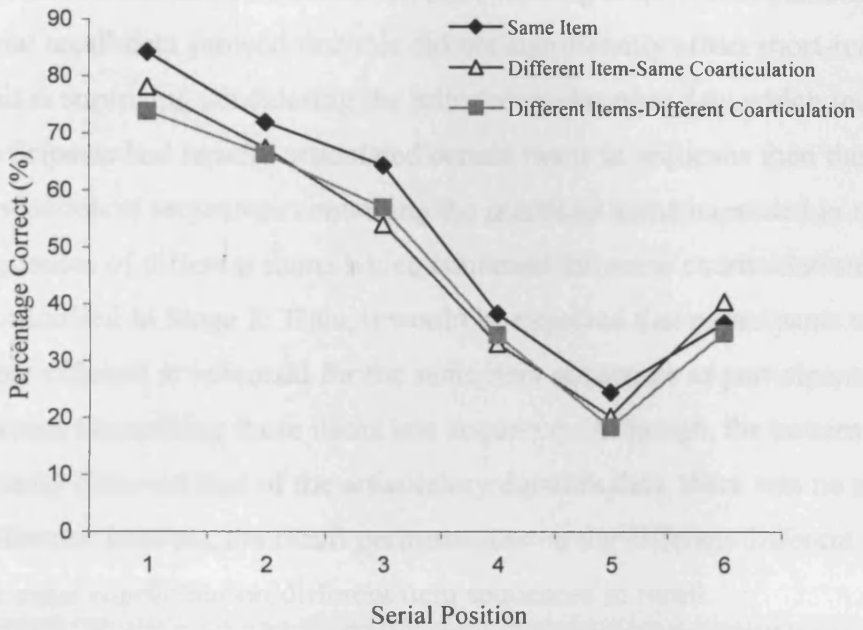



*Figure 10* Serial position curves for percentage of items correctly recalled in each serial position for same item, same coarticulation and different item sequences to those practiced in Stage 2.

A repeated measures ANOVA with factors, type of sequence (*same-same, different-same, different-different*) and serial position was used to analyse the data. Mauchley's test indicated that the assumption of sphericity had been violated for the main effects of serial position. Therefore degrees of freedom were corrected using Greenhouse Geisser estimates of sphericity for this factor ($\varepsilon = .410$). There was a main effect of type $F\,(2, 48) = 3.28$, $MSE = 58.10$, $p < .05$. Planned contrasts showed that only the *same item* lists were recalled significantly better than *different item* lists $F\,(1,24) = 5.17$, $MSE = 95.45$, $p < .05$, there were no differences between *same item* and *different item –same* coarticulation lists or between *different item-same coarticulation* and *different item/different coarticulation* lists (all $p > .05$).There was also a main effect of serial position, $F\,(5,120) = 55.60$, $MSE = 15.2$, $p < .05$, however, there was no type by serial position interaction, $F\,(10,240) = 1.37$. $MSE = 2.79$, $p > .05$.

Thus in summary, the articulatory duration data supported the hypothesis that practising both items and coarticulations increase the rate of articulation. This suggests that when articulating items together, the gestures needed for the coarticulations between unfamiliar words become easier and the learning can be transferred to a different set of words containing these coarticulations. However, the serial recall data showed that this did not significantly affect short-term memory. This is surprising considering the articulatory duration data which indicated that after participants had rapidly articulated certain items in sequence then their later production of sequences containing the practiced items increased in rate, as did sequences of different items which contained the same coarticulations to those familiarised in Stage 2. Thus, it would be expected that participants would have been more efficient at rehearsal for the same item sequences as participants would have had practice assembling these items into sequence. Although, the pattern of the results broadly followed that of the articulatory duration data, there was no significant difference between the recall performances on the different/different sequences and the same coarticulation/different item sequences in recall.

Thus this result suggests that participants are either not relying on rehearsal processes as much so the coarticulatory fluency improvement is not being reflected in serial recall scores or coarticulatory fluency is not an important determinant of serial recall performance. Or, it is possible that no significant difference was observed as overall participants were particularly poor at the serial recall of the nonword items – with just over 50% being recalled correctly in the same item condition. Furthermore, only 15 trials of each sequence type were used and there was only one of each sequence type practice trial. The similarities between the same coarticulation and same item list may also have led to more confusions in responses, as sequence types were presented in a random order rather than blocks. In addition it is possible that the serial recall of the different set of words may have been better than predicted due to the distinctiveness of these lists compared to the similar sequence types. It is well documented that the more distinctive items in a list are the better the recall (e.g. Saint-Aubin & Poirier, 1999). It is possible that measuring serial recall performance both before and after a familiarisation stage, and calculating the improvement made would be a more sensitive measure of whether practiced coarticulations can be generalised to other items in a serial recall task.

Experiment 7 was carried out to further examine whether coarticulations which are generalised in production performance can be also generalised to other words in serial recall performance. This time a between subjects experiment was used to try and minimise confusions occurring between sequence types in the serial recall. In addition serial recall improvement was measured by recording serial recall performance both before and after familiarisation of one sequence type. In this experiment, each participant carried out three separate stages; Stage 1 was a baseline serial recall task consisting of 15 trials of only one type of sequence (either A, B, C or D), Stage 2 was a familiarisation task involving the rapid articulation of one sequence type (either A, B, C or D), finally, Stage 3 was another serial recall task consisting of the same types as sequence as those experienced in Stage 1. Thus, each participant only saw one or two different sequence types depending on which condition they were in. In the same item condition, the sequences in all three stages were the same. In the same coarticulation condition, the serial recall sequences were different to the familiarisation sequences but they shared the coarticulations. In the different condition, the familiarisation stage (Stage 2) involved familiarisation with a completely novel set of words.

### 3.5.3. Experiment 7: Coarticulation Generalisation in Serial Recall

#### *3.5.3.1. Participants*

Sixty undergraduate psychology students at Cardiff University took part in the study as part of their course requirement. They were aged between 18 and 24. All participants reported English as their first language and had normal or corrected-to-normal vision and hearing. None of the students had taken part in any of the previous studies.

#### *3.5.3.2 Design and Materials*

For this study a between-participants design was adopted to try and improve recall performance for nonword items. Each participant was randomly allocated to one of three conditions; these were; the same item, different item-same coarticulation or different item condition. There were 20 participants in each condition. The same sets of items (A, B, C & D) as those used in Experiment 5b were used; this time whichever condition the participant was allocated, they were only exposed to two of the possible four sets of words. This time instead of articulation measures before and after familiarisation participants were required to perform a serial recall task. The serial recall sequences consisted of six items presented one after the other at a rate of one item per second. Presentation mode was visual. There were two separate serial recall tasks, one at the beginning of the experiment the other at the end; both tasks contained 12 trials each. There were four practice trials.

*3.5.3.3 Procedure*

Participants were seated in a soundproof booth, in front of a microphone. Initially, each item from one of the sets a participant had been allocated was presented individually for them to articulate. This allowed participants to become familiarised with the pronunciations of all the words that they would be required to remember in the serial recall task. Once all the items had been presented and read aloud, participants were given instructions for the serial recall task. Participants were presented with six-item sequences; items in a sequence appeared one at a time at a rate of one item per second. Once the final item of a sequence had been presented, participants were immediately given a cue to recall the sequence of words in its original order. Recall responses were made vocally and participants were instructed to say 'blank' on any of the serial positions, where they were unsure of the item. In total, there were 12 sequences and two practice trials all made up of items from the one set the participant had been allocated. Next, participants were presented with a reading (familiarisation) task. As in the previous experiment, a sequence of six items appeared simultaneously in the centre of the computer screen, and participants were required to read the sequence aloud as quickly and fluently as possible. Each time the screen flashed the participant was required to read out the sequence again. In total forty different sequences were presented and each one required articulating three times. Once all the sequences had been read, participants were presented with another serial recall task made up of 12 six-item sequences. All the items were from the same set as the first serial recall task but were put in different orders in the sequences. The serial recall responses were recorded so that any improvement in recall accuracy from the first serial recall task could be calculated.

### 3.5.4. Results & Discussion

The serial recall responses were listened back to and marked according to a strict serial criterion. Only items that had been correctly recalled in the correct serial position were marked as correct. For each participant two serial recall measures were calculated, one from the baseline memory task (Stage 1) and one after the reading task (Stage 3). The data were divided into one of three conditions; whether participants had been familiarised with the same item set as the set they had been required to recall (*same item* condition) or whether the participant had been familiarised with different items but involving the same coarticulations as the memory set (*different item-same coarticulation* condition) or finally whether participants had been familiarised with a completely different set of items to the set they had to recall (*different item condition*). Performance increase was measured for each condition. It was predicted that due to practice all serial recall scores would improve from the baseline serial recall task to the the second serial recall task. Figure 11A shows average overall recall performance for each condition before and after the familiarisation task and Figure 11B details the percentage of item recalled correctly in each serial position, before and after reading for each of the three conditions

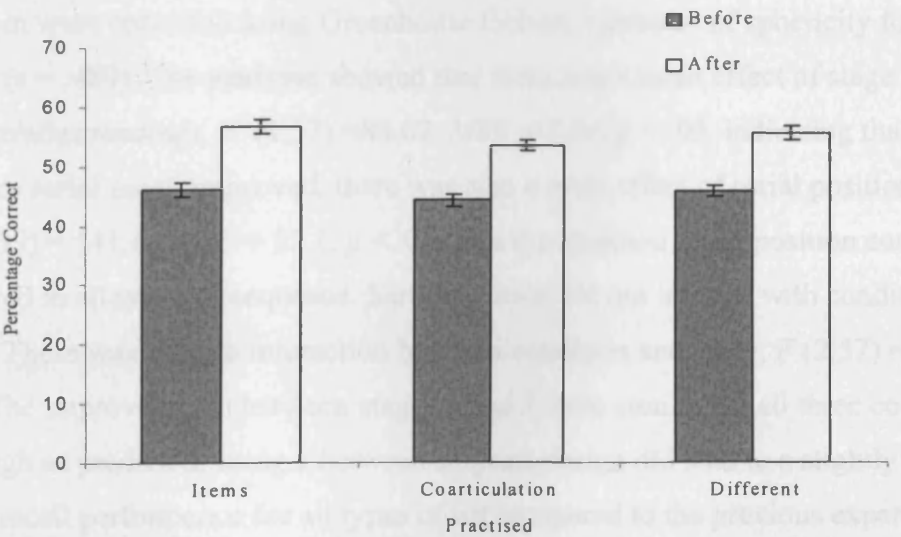



*Figure 11A* Average percentage of items correct in serial recall tasks before (Stage 1) and after (Stage 3) familiarisation for the three conditions. Error bars show Standard Error.

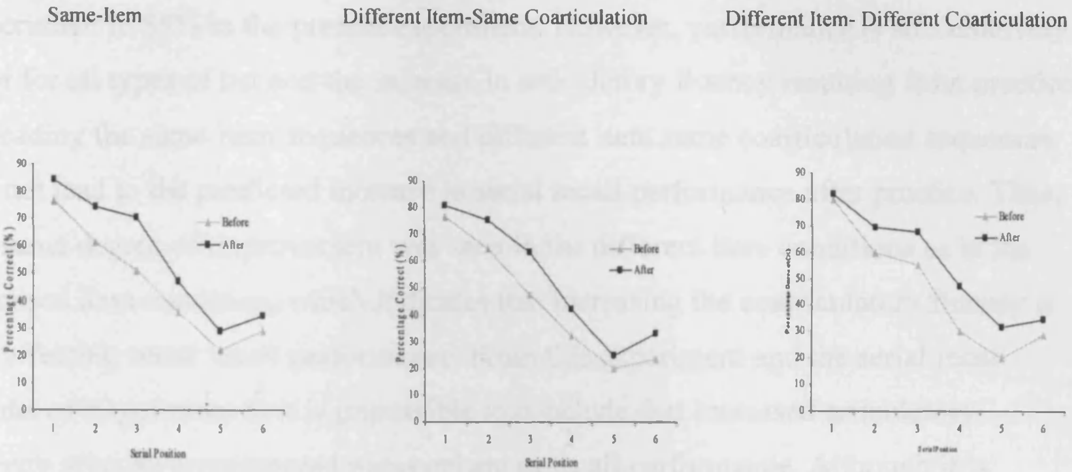



*Figure 11B* Average percentage of items recalled correctly for each serial position before and after each reading condition.

It was predicted that increase in memory performance would be very similar for same item and same coarticulation conditions, but a lesser or no increase was predicted in the different condition. However, performance increase between serial recall tasks of Stages 1 & 3 was equivalent for all three conditions; a mixed ANOVA with the within factors stage and serial position and between factor condition practiced was carried out. Mauchley's test indicated that the assumption of sphericity had been violated for the main effects of serial position. Therefore, degrees of freedom were corrected using Greenhouse Geisser estimates of sphericity for this factor ($\varepsilon = .489$). The analyses showed that there was a main effect of stage (before/after reading), $F\ (1,57) = 84.67$, $MSE = 3.04$, $p < .05$, indicating that after practice serial recall improved, there was also a main effect of serial position, $F\ (2.5,139) = 141.6$, $MSE = 12.1$, $p < .05$, thus the standard serial position curve occurred in all types of sequence. Serial position did not interact with condition or stage. There was also no interaction between condition and stage, $F\ (2,57) = .139$, $p > .05$. The improvements between stages 1 and 3 were similar for all three conditions, although as predicted, using a between subjects design did lead to a slightly enhanced serial recall performance for all types of list compared to the previous experiment (Experiment 6) where participants had to recall all types of sequence (same coarticulation, same item and different item) within the same test. Overall percentage correct rose slightly from an average of 45% items across all lists in the previous experiment to 55% in the present experiment. However, performance is still relatively poor for all types of list and the increase in articulatory fluency resulting from practice of reading the same item sequences and different item same coarticulation sequences did not lead to the predicted increase in serial recall performance after practice. Thus, the same degree of improvement was seen in the different item conditions as in the practised item condition, which indicates that increasing the coarticulatory fluency is not affecting serial recall performance. From this experiment and the serial recall results of Experiment 6, it is impossible to conclude that increased articulatory fluency of to-be-remembered items enhances recall performance. Although it is possible that participants are not engaging in rehearsal, in order to retain the words which could mean that increased coarticulatory fluency would not be influencing the recall performance to the same degree.

A possibility to be tested in the next experiment is that by slightly increasing the presentation rate and adding a short retention interval between presentation of the last item in a sequence and recall, the role of rehearsal processes will be more prominent. Consequently, it is predicted that increased articulatory fluency should enhance rehearsal and recall performance for the familiarised sequences and possibly the sequences containing the familiarised coarticulations but not in the condition where participants have been familiarised with different items and different coarticulations to the sequences they are recalling.

### 3.5.5 Experiment 8
### Coarticulation Generalisation and Serial Recall

Experiment 8 was carried out to identify whether faster presentation rate and retention interval would enhance the effect of coarticulation generalisation on serial recall performance. In a serial recall task setting when items are rapidly presented the most efficient way to retain the order is to repeat them, in addition when a retention interval is added, it is necessary for a participant to keep rehearsing the sequence. Another between-participants design was used and participants had to complete two short serial recall phases but this time instead of immediate recall, they were required to wait for ten seconds before they gave their serial recall responses. It was predicted that this would give them more opportunity to rehearse the items in the sequence so make more use of the coarticulations involved and possibly emphasise the influence of articulatory fluency in the task In addition, items were presented at a faster rate, which is also more likely to encourage rehearsal.

*3.5.5.1 Participants*

Thirty-six undergraduate psychology students from Cardiff University took part in the study as part of their course requirement. They were aged between 18 and 24. All participants reported English as their first language and had normal or corrected-to-normal vision and hearing. None of the students had taken part in any of the previous studies.

*3.5.5.2 Design & Materials*

This study utilised a between-participants design, each participant was randomly allocated which of the three conditions they would be in. There were twelve participants in each condition. The conditions and stimuli were identical to those used in the previous experiment except for the timing and presentation rate of the serial recall task. This time both presentation rate of the to-be-remembered items was increased, and a retention interval between presentation and the cue for recall was added; participants were required to wait for ten seconds before giving their responses.

*3.5.5.3 Procedure*

The procedure was the identical to the previous experiment except for the presentation of the serial recall tasks. Item presentation rate was slightly faster (one item every 750ms) than before and after the last item of a sequence had been presented, they had to wait ten seconds until the screen flashed before they gave their responses. As before recall was vocal and any position where they were unsure of the item they responded 'blank'. Thus, the experiment consisted of a brief familiarisation of each of the individual words, followed by a twelve trial serial task made up of items from a participants allocated set, next, was the reading (familiarisation stage) which was identical to the previous experiment. The experiment ended with a final serial recall task, again the presentation rate and retention interval were the same as in the baseline stage.

### 3.5.6 Results & Discussion

As before all serial recall responses were transcribed from the recordings and only items that were recalled in the correct serial position were marked as correct. As predicted, overall recall performance had increased from an overall average of 50% of all items correct in the previous experiment to 57% in the present experiment. This suggests that by increasing the presentation time and longer retention interval which aimed to encourage the use of more rehearsal and articulatory processes. Figure 12A shows the average serial recall performance for each condition before and after the familiarisation stage and Figure 12B shows the percentage of items correctly recalled in each serial position, before and after practice for all three conditions. As before, serial recall performance improved across all conditions.

A

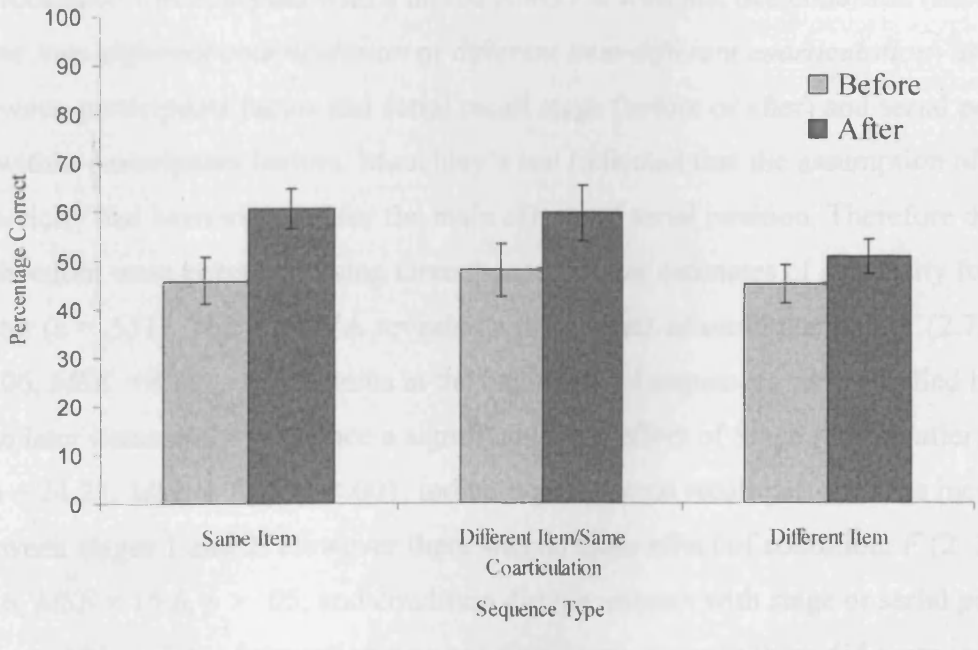
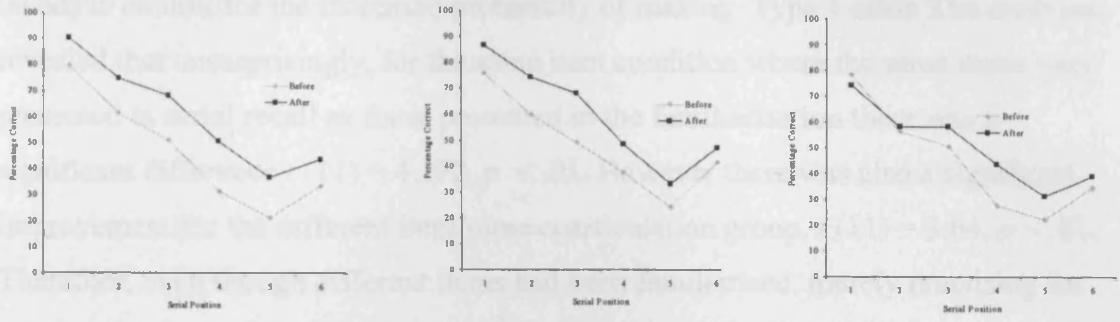



*Figure 12A.* Percentage of items recalled correctly before and after familiarisation with the different sequence types. Error bars show Standard Error.




Same Item | Different Item-Same Coarticulation | Different Item

*Figure 12B.* Percentage of items correctly recalled in each serial position before and after familiarisation for the different sequence conditions.

This time, the longer retention interval, which was added to encourage the use of rehearsal, seems to have affected the results. From Figure 12A and 12B the greatest improvement in serial recall accuracy seems to be in the same item condition with the next greatest improvement in the same coarticulation-different item group and finally the least greatest improvement appears to be in the different item group. Serial recall performance was analysed with a mixed ANOVA with practice condition (*same item, same item-different coarticulation* or *different item-different coarticulation*) as a between-participants factor and serial recall stage (before or after) and serial position as within-participants factors. Mauchley's test indicated that the assumption of sphericity had been violated for the main effects of serial position. Therefore degrees of freedom were corrected using Greenhouse Geisser estimates of sphericity for this factor ($\varepsilon = .551$). The ANOVA revealed a main effect of serial position, $F(2.7,90.8) = 77.06$, $MSE = 8.89$, $p < .05$, items at the beginning of sequences were recalled better than later items in the sequence a significant main effect of Stage (before/after), $F(1, 33) = 24.21$, $MSE = 7.49$, $p < .001$, indicating that serial recall performance increased between stages 1 and 2. However there was no main effect of condition, $F(2, 33) = .716$, $MSE = 15.6$, $p > .05$, and condition did not interact with stage or serial position.

Although the interaction was not significant, because there did seem to be quite large differences between the stages for the three conditions, Bonferroni corrected post hoc paired samples t-tests were used to examine whether the difference in overall serial recall performance from the first serial recall task to the second serial recall task was significant for each of the three conditions. $\alpha$ was set at .01 (two-tailed) to control for the increased probability of making Type 1 error. The analyses revealed that unsurprisingly, for the same item condition where the same items were presented in serial recall as those presented in the familiarisation there was a significant difference $t\ (11) = 4.172, p < .01$. However there was also a significant improvement for the different item/same coarticulation group, $t\ (11) = 3.64, p < .01$. Therefore, even though different items had been familiarised, merely practising the coarticulations lead to enhanced recall performance of the different items. Moreover in the different item, different coarticulation condition there was an improvement from the first to the second serial recall task, but this was not significant at $\alpha$ 0.01, $t$ $(11) = 1.285, p > .01$

The results of this experiment partially reflect the results of experiment 6, which measured the increase in the rate of production of utterances after familiarisation with different types of items. In Experiment 6 the greatest increase in speech rate was observed in the same item sequences followed by the same coarticulation sequences and finally the different item/coarticulation sequences resulted in the least speech rate improvement, as seen in the serial recall results of the present experiment. Thus the preceding experiments have shown that although practice with a novel lists of items but ones that share the same coarticulations at the word boundaries, leads to enhanced fluency (Exp.6) it does not necessarily lead to increased serial recall performance (Exp 6 & 7), it is likely though that when more emphasis is placed on rehearsal (e.g. with the addition of a retention interval) then the influence of coarticulatory fluency may be more pronounced (Experiment 8).

### 3.6 General Discussion of Experiments 6 – 8

The three experiments described in the current chapter have investigated whether or not the enhanced articulatory fluency that results from rapidly repeating certain sequences of items (as shown in the experiments of Chapter 2) can be generalised to both the production fluency and serial recall performance of different sequences of items, but ones which contain highly similar coarticulations at the word boundaries. The experiments attempted to address further whether familiarity with the articulatory gestures needed to utter sequences affects later production fluency and enhances serial recall performance. Experiment 6 showed that the articulatory fluency of a sequence was enhanced when participants had been familiarised with either the items or the coarticulations in the repetition stage (Stage 2) of the experiment. Sequences containing both different items and different coarticulations to the ones practiced did not show any facilitation in articulatory fluency. Experiment 8 then showed that after practicing reading either the same items as those recalled or different items with the same coarticulation or completely different items the enhanced articulatory fluency from the familiarisation stage affected the serial recall performance of the same item sequences and the different item/same coarticulation sequences. In comparison, the improvement in the different item/different coarticulation sequences between Stages 1 and 3 was much smaller. There were two main goals to these experiments; firstly they attempted to distinguish further between coarticulatory factors and associative factors when explaining the effects of linguistic familiarity on to-be-remembered sequences, which was explored in Chapter 2 and secondly, the experiments examined whether merely reading sequences of items allows for the coarticulations to be generalised and therefore benefit the pronunciation and enhance the recall of different sequences of words.

### 3.6.1 Association and Coarticulation

Experiments 1, 2 and 3 in Chapter 2 found that increasing the familiarity with sequences rather than items resulted in enhanced recall and articulatory fluency for those items which had been practiced and then later presented in the same sequences. For items which had been practiced but in different sequences there was no such advantage, even though the items should have increased in familiarity as all items had been experienced the same number of times. This was attributed to the increased articulatory fluency of items in practiced sequences. However, it was noted that the formation and strengthening of associative links between items in practiced items could explain the findings rather than familiarisation with coarticulations. Hence, an attempt to disentangle coarticulation effects and associative links was carried out and the results of this experiment (Experiment 4) suggested that it was the inter-item coarticulation rather than the strengthening of associative links between items that led to the observed decrease in articulatory duration and enhanced serial recall of practiced sequences.

Thus, Experiments 6, 7 and 8 in the current chapter were designed to more accurately separate the effects of association and coarticulation. In Experiment 6, it was found that the production fluency of sequences increased after practice for both sequences containing items that had been practiced together (and therefore associated together) and also sequences of different items (not associated) containing coarticulations that had been practiced together. Thus, even though the separate items were not associated together the fact that the coarticulations had been practiced lead to enhanced serial recall performance, suggesting that there is a role for coarticulation not just association in production fluency. These results were then partially reflected in the serial recall results of Experiment 8, where serial recall performance was enhanced for sequences where the items had been practiced and sequences where just the coarticulations had been practiced.

The greatest enhancement in production fluency (Experiment 6) after the familiarisation stage was seen in the same item condition. A lesser but still significant different was observed for the different item same coarticulation condition. It should be noted that while the label, different item-same coarticulation condition suggests the coarticulations were matched completely it is nearly impossible to match the coarticulations involved completely. It is well documented that coarticulation often spreads over more than one sound; typically the vowel in a syllable typically determines the target. Thus it is likely that the coarticulation between target position of the articulatory apparatus. For example in the initiation of the /b/ in the sounds /bu/ and /be/ the position of the lips is quite different; at the start of the /bu/ sound the lips are rounded whereas at the start of the /be/ sound the lips are shut together flat. Similarly in the current experiments the coarticulatory gestures at the p#n transitions between *darp#nerg* will be slightly different to those between *derp#norg* with the latter coarticulation involving more lip rounding than the former one due to the following rounded vowel. Of course it was not possible for coarticulations to be matched completely as coarticulation is affected by all surrounding sounds including the nuclei or vowel of the CVC structure.

Although degree of coarticulation is known to be lowest when spanning a word boundary, it has been found to be more pronounced during the production of rapid speech which was required in both the reading and serial recall experiments of the present series. One study examined the articulation of consonants spanning a word boundary found that speaking faster decreased the articulatory duration of the separate consonants but also increased the coproduction or coarticulation between the successive articulations (Byrd & Tan, 1996).

### 3.6.2 Coarticulation Generalisation.

It was noted in the introduction that a number of studies have been carried out which show how language processes can be adapted from relatively brief listening or production experience of novel grammar. In adults this has been manifest in the sort of errors made in repetition and in serial recall tasks (Dell et al., 2000; Marjerus et al., 2004; Botvinick & Byslma, 2004). Studies which have manipulated the phonotactics of an artificial grammar in the laboratory have also been able to show that by exposing participants to sequences affects there later production and recall performance (e.g. Dell et al, 2001; Onishi et al., 2001; Marjerus et al, 2000; Botvinick & Byslma, 2004).

Similarly the results of the present experiments showed that getting participants to merely repeat sequences of items as quickly as possible, the articulatory gestures involved in coarticulating the items together became more practiced and consequently easier to assemble into motor sequences. As noted in the beginning of this chapter, it is believed that motor programs for common syllable sequences can be retrieved directly from a syllabary rather than having to assemble each segment separately. It is possible that the familiarisation task may have led to more efficient assembly of the motor routines required, especially between items for the practiced item sequences and the practiced coarticulation sequences, which originally would have been unfamiliar and more complicated to assemble into sequence.

The finding that the improvement in articulatory fluency gained from articulating a certain sequence of items together could be generalised to a different set of items, which only shared the coarticulations is a new finding. Most studies examining serial recall performance have not investigated whether the similarity in a sequence structure can affect serial recall performance. However there have been a number of studies on language production which have examined whether training on some sound sequences can be generalised to different albeit similar sound sequences.

Some studies have focussed on the treatment of participants who suffer from disorders of language such as apraxia of speech, – a disorder characterised by the impairment of planning and sequencing sounds – such patients have been found to have a very poor memory span suggesting that such processes contribute significantly to rehearsal and recall performance. Training patients with apraxia of speech on the repetitive articulation of sounds such as simple consonant singles (e.g. *tip*) and complex consonant clusters (e.g. *trip* or *strip*), resulted in patients being able to apply this learning to the articulation of different consonant singles and to a lesser degree to different consonant clusters (e.g. Maas, Barlow, Robin & Shapiro, 2002).

In another study Japanese speakers were trained on the non-native contrasts between the /r/ and /l/ sound, which occur in English. Training on separate /r/ and /l/ words resulted in this learning being transferred to the production of new words, this was manifest in the generalisation task. In another study it was shown that the later production of utterances can be changed just from listening to someone else producing sounds such as /p/ or /k/ with extended voice onset-times, this phonetic imitation can be generalised to other stimuli with the same sounds but which had not been heard (Nielsen, 2005). Thus, the experiments in the present chapter have also shown that practice producing items in sequence and in particular the gestures required to coarticulate items can affect later production and recall of these items an also generalise to a separate set of words but ones that share similar coarticulations.

### 3.6.3. Conclusions

Taken together the results of the current experiments have shown that practice with items and the coarticulations involved in assembling the items in the sequence influences not only production but this may also be reflected in serial recall performance, although the serial recall results of the preceding experiments suggests that the influence of coarticulatory fluency in serial recall performance is more prominent when more emphasis is placed on rehearsal by adding retention intervals.. This is further evidence that sequence production and serial recall performance is parasitic on language production processes, and particularly emphasises the motor-gestural basis to verbal short-term memory. As immediate serial recall performance involves the assembly of items into a articulatory plan to be used in rehearsal and at output, then the language processes such as coarticulation which are critical to sequence (or connected speech) production are likely to be important albeit largely overlooked determinants of serial performance. The more familiar or practiced someone is at assembling items into sequence then the more efficient the involved processes will be.

Despite the assembly of items into a sequence playing an obvious role in memory for serial order, relatively few studies into serial recall performance have focused on the role of sequential structure in memory for serial order, instead common findings (e.g. lexicality and frequency) are usually attributed to item-based factors. Early studies have shown that the immediate serial recall of words was positively related to how well those lists approximated the word-to-word transition probabilities of English, an effect that has been repeated with letters whereby strings of letters which followed the bigram frequency structure of English are recalled more accurately than those that do not (Baddeley, 1965; Mayzner & Schoenberg, 1965).

More recently evidence has been presented suggesting that knowledge concerning the transition probabilities among sequentially-organised items affects recall performance. In their study Botvinick & Byslma (2001) showed that when participants were exposed to sequences where different probabilities governed the likelihood of which syllables followed which syllables, there later errors on a serial recall task typically followed the most probable pattern of syllables. This is presented as strong evidence for long-term knowledge being use to reconstruct the degraded memory traces for sequences, However the results of the current experiments suggest articulatory processes involved in assembling items into sequences may also be an important determinant of immediate serial short-term memory for verbal items.

# CHAPTER 4:
# General Overview and Theoretical Implications

## 4.1 Aims of Thesis

This thesis has been concerned with the articulatory factors involved in the assembly and production of sequences, and how these characteristics of language production can affect immediate verbal serial recall performance. A huge body of short-term memory research is focussed on the ability to recall a list of items in order, and serial recall tasks have uncovered some canonical effects of short-term memory performance. However, in explaining these serial recall phenomena the conceptual and empirical focus has been predominantly on the characteristics of the individual items making up the sequence rather than properties involved in the planning and production of a sequence. The current thesis endeavoured to redress this neglect, demonstrating that the articulatory fluency in sequence production may also be an important determinant of serial short-term memory. In particular, increased familiarity of articulatory programming of the boundaries between items (coarticulation) was shown to improve serial recall performance. In this final chapter, the main themes and findings of the thesis will be reviewed before discussing the implications of the studies and directions for future research.

The experiments in this thesis addressed the issue of how much the constraints of speech production shape sequence production and memory performance. Specifically, the studies investigated whether the ability to say items in sequence as opposed to in isolation is a key determinant of serial recall performance. Initially, the experiments sought to establish the existence of differences between articulatory duration of items differing in linguistic familiarity, even when there are no apparent differences between the individual item articulatory duration, demonstrating the need to use sequence rather than item duration to accurately measure articulatory duration. Second, the experiments aimed to establish that articulatory fluency of sequences (particularly coarticulatory fluency) is an important but largely overlooked determinant of serial short-term memory and whether familiarity with the articulatory character of sequences particularly the coarticulation of items determines the improvement with experience. More generally it is hoped that the current work provides further support for the growing body of evidence which suggests that verbal serial short-term memory rather than being the product of a specialised phonological store and mnemonic processes, is instead parasitic on language production and perception processes.

### 4.2. Summary of the Key Findings

The empirical work presented in the present thesis sought to assess the contribution made by increased coarticulatory fluency of sequences to improvement in serial recall – independent of item familiarity or redintegration – when participants become more familiar with the to-be-remembered sequences. The first experiments in Chapter 2 (Experiments 1, 2 & 3) found that as serial recall performance improved with familiarisation of the stimuli, the articulatory duration of sequence production decreased, whereas the duration of singles (Experiments 1 & 2) or pairs (Experiment 3) did not show this facilitation.

In Experiment 1 the contribution of increased co-articulatory fluency to immediate serial recall performance was assessed for words and nonword items. Initial measures of articulatory duration found that when individual item duration was measured there was no difference between word and nonword items. Yet, when sequence duration was measured participants were considerably slower at articulating the nonword than the word sequences, this indicates that there are differences between familiar and unfamiliar items, which only show up when the whole sequence is taken into account. A serial recall task then identified a lexicality effect – better recall performance for words than nonwords – yet, with practice, performance improved more for the nonword than the word sequences. A subsequent measure of articulatory duration showed that while individual articulatory duration was unaffected by serial recall practice, both word and nonword sequences were spoken significantly faster than before the serial recall task, moreover the greatest improvement was observed for the nonword sequences, mirroring the serial recall data.

Although the results of Experiment 1, suggested that linguistic familiarity was increasing at the articulatory sequence level, what exactly was improving with familiarity, the *item* or the *sequence*, was still unclear. From a redintegration standpoint it could be argued that the reason nonword recall improved more was due to long-term phonological knowledge of the nonword items being built up with familiarity. Thus, Experiment 2 was designed to pit phonological redintegration against coarticulation. The remaining experiments in the thesis adopted a methodology distinct from the usual studies examining linguistic familiarity effects in serial recall (e.g. Gathercole et al., 2001; Roodenrys et al., 1993), instead of using items which differed in their level of pre-experimental familiarity (e.g. words/nonwords, high/low frequency items), the familiarity was manipulated directly within the experimental setting. Thus, only nonwords were used in all but one (Experiment 5 consisted of high and low frequency word items) of the remaining experiments in the thesis.

In Experiments 2 and 3, item familiarity with the articulatory character of sequences was manipulated and it was found that despite all items being equally familiar to participants, the items recalled in practiced sequences compared to unpractised formation were recalled better. Moreover these experiments demonstrated that there were articulatory duration differences between items of varying familiarity which only showed up when sequence duration rather than item duration (Experiments 1, 2, 3 & 5) or pair duration (Experiments 3 & 5) were taken into account. Using existing linguistic familiarity stimuli, Experiment 5 indicated that the largest differences occur when items are measured in sequences. Experiments 4a and 4b of empirical series 1 were undertaken to try and establish whether the results from the previous experiments were (as argued) the result of increased coarticulatory fluency rather than increased associative support for the items that had been familiarised together. Although the results of Experiments 4a and 4b supported a coarticulatory fluency contribution to performance, the issue of association versus coarticulation was also taken up in the experiments of Chapter 3. In an additional experiment (Experiment 5) stimuli used to assess word frequency effects in short-term memory, were used to examine whether there were differences between the high and low frequency words which was less apparent when individual repetition of items was measured. Although, differences in articulatory duration was seen across measures, speech rate differences were not found to account for the frequency effect in serial recall, suggesting that maybe the articulatory fluency of a sequence may be less critical when the stimuli are real words, when other processes (possibly existing word associations) can be used as an aid to reproduce the information at recall.

Chapter 3 presented three experiments that assessed whether coarticulatory fluency can be gained and generalised to a different set of stimuli that share the same coarticulations. Familiarisation with coarticulatory gestures resulted in enhanced production fluency (Experiment 6) and to a much lesser degree enhanced serial recall performance (Experiment 8) for sequences of items that had been practised and sequences of items where the coarticulations but not the individual items had been practised. As well as demonstrating that coarticulatory fluency can be generalised, these experiments provided further support that the results of the experiments in Chapter 2 were due to the contribution of increased coarticulatory fluency rather than just the strengthening of associative links between items in practised sequences. The serial recall results of experiments 6 and 7 were less clear cut and indicated that the familiarity of sequences was not as influential in determining serial recall performance. By increasing the demand on articulatory rehearsal, the results of Experiment 8 demonstrated that familiarity with coarticulatory gestures was reflected in serial recall performance of both same item and same coarticulation sequences.

Taken together the results of these experiments suggest that the articulatory character of a to-be-remembered sequence is a crucial determinant of serial short-term memory performance. Moreover, these findings provide further evidence to support the view for explaining verbal short-term memory performance in terms of auditory perceptual organisation and motor/gestural skills that are primarily used in the service of speech. Thus, articulatory fluency involved in assembling the to-be-remembered items into an output sequence may have an influential yet largely overlooked role in serial recall performance, especially when serial recall involves nonwords.

## 4.3. Theoretical implications of the studies for short-term memory research

### 4.3.1 Role of the Sequence

Traditionally, short-term serial recall research has primarily focussed on the properties of individual items making up a sequence rather than the articulatory demands involved in producing items in sequence. The experiments in the present thesis have shown that articulatory fluency and in particular the coarticulation involved in the assembly of a whole sequence, affects the articulatory duration and recall performance of items. These findings have both theoretical and methodological implications for short-term memory research.

*4.3.1.1 Models of Short-term Memory*

Traditionally models of short-term memory concentrate on the importance of rehearsal for serial recall performance (e.g. Baddeley, 1986; 2001) but the rehearsal of items at the sequence level and related articulatory factors involved in articulating sequences – such as coarticulation – are not usually specified. Sequence level factors particularly regarding the articulatory character of the sequence are largely overlooked in traditional models of verbal short-term memory. Computational models of memory for serial order (e.g. Burgess & Hitch, 1999; Henson, 1998; Page & Norris, 1998) generally agree that properties of an individual item affects the memorial strength of an item independent of other items in a to-be-remembered sequence. Such models typically view rehearsal as a vehicle for refreshing individual representations of to-be-remembered items while a separate competitive queuing process then determines the sequence in which the items will be outputted. However, the experiments in the present thesis have demonstrated that there are articulatory-based sequence-level factors, which may also constrain short-term memory performance. The present experiments present a challenge for recent computational models of serial recall (e.g., Brown, Preece & Hulme, 2000; Burgess & Hitch, 1999; Henson, 1998; Page & Norris, 1998), that refer to mechanisms that are largely insensitive to sequence structure.

*4.3.1.2 Redintegration Accounts of Linguistic Familiarity Effects*

Explanations of linguistic familiarity effects (e.g. lexicality, language familiarity and word frequency) observed in serial recall were the predominant focus of this thesis. Such effects are traditionally characterised as operating through the item-based construct of redintegration. Models incorporating a redintegration process, propose that partial, temporary phonological representations in the short-term store are used as a retrieval cue to locate the closest match in long-term memory, with such a representation providing the basis for output (Burgess & Hitch, 1998; Henson, 1997; Neath, 2000; Page & Norris, 1998). The more available and accessible the long-term knowledge (e.g. word items, high frequency items) the better the redintegrative support is thought to be.

However, the experiments in the current thesis demonstrated that the fluency with which sequences may be assembled into sequences of articulatory gestures might also partially account for those effects previously ascribed to redintegration. The studies indicated that with practice, familiarity with the sequence affected recall more so than practice with individual items. Specifically, it was found that coarticulatory fluency of the boundaries between list items – necessarily a sequence-level factor – affected verbal short-term serial recall performance. The apparent absence of articulatory differences between stimuli with different degrees of familiarity has been used to further argue the existence of item-based processes of redintegration (Hulme et al., 1991; Hulme et al., 1995; Thorn & Gathercole, 2001). Consequently, articulatory explanations for linguistic familiarity effects are usually disregarded in favour of redintegration explanations (e.g. Thorn & Gathercole 2001). However, the current experiments showed that the articulatory fluency of the stimuli was also affected by familiarity.

Item-based redintegration accounts of short-term memory phenomena, by definition ignore the superordinate properties of the sequence such as those arising from combining items of a particular type into a to-be-remembered sequence are ignored. However, there is existing evidence that the articulatory complexity of certain item combinations does affect short-term memory performance when all other factors are controlled for (e.g. Murray & Jones, 2000). The current experiments also showed that even though all test items were equally familiar to the participant, and should have had the same level of item-based redintegrative support, serial recall performance and production was only observed for items in sequences where the coarticulations between items had been practiced.

Despite early research demonstrating better recall performance for word or consonant strings that contain high frequency rather than low frequency letter or word transitions (Baddeley, Conrad & Hull, 1965; Miller & Selfridge, 1951) the effects of sequential structure to serial recall are largely overlooked when explaining short-term memory phenomena. The results of the present experiments suggest that there should be more emphasis on measurable sequence level factors such as articulatory fluency (see below for methodological issues) rather than abstract factors (such as trace reconstruction) when explaining short-term memory phenomena.

More recently, evidence has been presented which disputes item-based redintegration accounts by emphasising instead the importance of inter-item associations (Hulme, Stuart, Brown & Morin, 2003; Stuart & Hulme, 2000) and/or background sequence knowledge (e.g. Botvinick & Bylsma, 2004; Botvinick & Plaut, 2003). For example, it has been shown that when high and low frequency items are presented in list together the word frequency effect is abolished. It is argued that high frequency words co-occur more often, which makes them easier to recall together and that it is easier to make inter-item associations, which aids redintegration (Stuart & Hulme, 2000; Stuart Brown & Morin, 2003; Ward, Woodward, Stevens & Stinson, 2002).

Alternatively, it is also possible that due to the fact that high frequency words do co-occur more often than low frequency words this affects their production, as it is likely that coarticulations between high frequency words are more practiced than those between low frequency words. Perhaps, high frequency words are inherently easier to say and are more suited for connected coarticulated speech than low frequency items. However, the stimuli used in Experiment 5 of the present series did not show that speech rate determined performance. A comprehensive examination of high and low frequency words found that differences existed between the two types of items separate from their frequency rating (Landauer and Streeter 1973) including differences in their phoneme and letter distributions, mean word length, and similarity neighbourhoods. Thus, the articulatory programming between items may also partially explain these sequence-level effects rather than associative factors.

#### *4.3.1.3 Methodological Issue: Measurement of Articulatory Duration*

The theoretical pre-occupation with the item within short-term memory research is reflected in the methods used to measure articulatory duration and rate. In Chapter 1, the massive inconsistencies that exist when measuring articulatory duration and articulation rate were highlighted (see also; Mueller et al., 2003). Primarily, duration of pairs or individuals is measured rather than that of longer sequences of words (which are arguably what are required for rehearsal). Researchers, which dismiss articulatory differences in favour of redintegration-based effects commonly,

only take the articulatory duration of one or two items into account. Thus, it is possible that if stimuli used for serial recall tasks were measured differently there may be more of a difference in duration between familiar and unfamiliar items. Moreover, it has been proposed that different articulatory measures tap different things. For example, Saito & Baddeley (2004) compared a simple reading task with tongue twister articulation and concluded that simple articulation rate relates to speech execution and the control of the articulators, in contrast, tongue twisters reflect speech programming and planning.

Thus, sequence measurement provides a more accurate measure of articulatory duration by uncovering not only the duration of items but also capturing the time taken to plan/execute the articulatory gestures necessary to negotiate the boundaries between words (the between item coarticulation). It is also likely that due to the demands of a serial recall that coarticulation (necessary for rapid and fluent speech) is an especially significant process in the rehearsal process where quick shortened fluent sequences are required. As serial recall tasks involve the assembly of a motor output plan for whole sequences, then the whole sequence (which reflects the articulatory demands of the task) rather than concatenated items should be measured to accurately determine the articulatory duration of items. The studies have indicated that sequences of familiar items are likely to involve more familiar coarticulations between words than unfamiliar items are but with practice the coarticulatory fluency and serial recall performance improves. However, it is important to note that differences in familiarity are unlikely to change the overall phonetic structure of words or the way articulators interact, so regardless of how familiar items are, some familiar items "unique New York" will always be less fluently articulated than less familiar items.

### 4.3.2 Nature of Rehearsal

Whereas traditionally, trace decay and rehearsal models have a rehearsal mechanism at their core, it is usually construed as being quite separate from normal language processes. Typically, rehearsal is seen as a revivification process, whereby the phonological codes of to-be-remembered items are refreshed through subvocal rehearsal of the separate items. However, another way to interpret the rehearsal process is in the form of the planning of a gestural sequence that can be reproduced to maintain order and output when recall is required. The studies in this thesis supports the view of rehearsal involving the planning of a whole gestural sequence, thus, to-be-remembered items are unlikely to be independent from all other items in a list, instead knowledge of the articulatory sequence structure is also likely to aid recall performance, this emphasises the articulatory contribution to short-term memory. Sequences of items, which are more familiar, are more likely to contain coarticulations that are more familiar and easier to assemble into an output plan than a sequence of unfamiliar items.

Further support for rehearsal in immediate serial recall involving the planning and sequencing of a gestural sequence can be taken from neuropsychological studies that have examined the short-term memory performance of individuals with different language disorders. Such studies have identified that it is not necessary for rehearsal to be enacted; instead only the motor planning component of rehearsal is necessary for rehearsal to occur. Dysarthric patients typically exhibit severe speech disturbances due to impaired motor control of the vocal tract; but they show normal memory span performance, indicating that they are still performing rehearsal and are able to plan the sequence, even though muscle control of speech production is impaired (Baddeley & Wilson, 1985; Bishop & Robson, 1989; Vallar & Cappa, 1987). In contrast, patients with apraxia of speech, a condition where there is impairment of speech-motor planning are unable to plan and sequence speech sounds (Ballard, Granier, & Robin, 2000; Kent & Rosenbek, 1983) and consequently they have impaired memory span due to the lack of ability to plan articulatory sequences.

### 4.3.3 Primitive or Parasite?

A principal aim of this thesis was to provide further evidence for a perceptual organisation and motor/gestural account of serial short-term memory performance. Such a view rather than concentrating on the particular characteristics of the to-be-remembered items (the level at which the previously discussed models operate) focuses more on the processes which underpin the relationships within and between items in a to-be-remembered sequence. Thus, serial recall performance rather than reflecting the operation of bespoke stores and mnemonic processes, is proposed to be parasitic on general perceptual and motor planning processes, (Jones et al., 2004; Jones, Hughes & Macken, 2006; Macken & Jones, 2003). There has been an accumulation of evidence suggesting that many effects traditionally classed as short-term memory phenomena can be more simply and accurately understood by recourse to processes of auditory perceptual organisation and gestural skills that are co-opted opportunistically to meet the demands of the short-term memory task (e.g. Jones, Macken & Nicholls, 2004; Jones, Hughes & Macken, 2006; Jones, Macken & Harries, 1997; Nicholls & Jones, 2002; Macken & Jones, 2003; Hughes & Jones, 2005).

Thus, in the case of verbal material, when rehearsal is permitted the processes involved in serial recall are likely to tap into the same operations that exist to process speech. The serial recall task demands the reproduction of a previously rapidly presented unfamiliar sequence of items. It is suggested that the easiest way to do this is to reproduce it for rehearsal and reproduction. Thus, the closer the to-be-remembered material matches ones language skills the more efficient recall performance is achieved (Macken & Jones, 2003). It was shown in the present thesis that familiarity with the between item articulatory transitions lead to faster production and better recall of sequences containing practiced coarticulations, indicating that articulatory familiarity at the level of the sequence affects short-term memory performance.

The suggestion that the underlying control processes at work in language production and serial recall are the same in both cases, has been highlighted by the finding that errors in natural speech are very similar to errors made in serial recall experiments (Ellis, 1980; Treiman & Danis, 1988). In addition the fact that the nature of errors and pattern of timing of output can be reproduced by the mere act of reading a list, when there is no significant burden on short-term memory is particularly suggestive of memory performance being parasitic on language production processes (Sternberg et al., 1978; 1980).

Despite the evidence that the underlying articulatory processes used for language (speech) and verbal serial recall are the same, most models do not detail how linguistic structure affects short-term memory. Instead many models of memory for serial order propose that item recall is governed by general principles, and as a result any specific constraints related to the linguistic nature of the stimuli are ignored (Brown et al., 2000; Burgess & Hitch, 1992; 1999; Nairne, 1988; 1990). However there is an accumulation of evidence showing that serial recall performance is influenced by sublexical language knowledge. In particular, previous research, which has dealt with nonword recall, has shown that the linguistic structure of an item is an important determinant of whether an item is recalled correctly (Gathercole, 1995; Vitevitch et al., 1997). For example, the observation of sublexical effects such as the word-likeness, word neighbourhood and phonotactic frequency effects have pointed to the role of language in short-term serial recall (Gathercole, 1995; Roodenreys & Hinton, 2002), whereby knowledge of the language aids the reconstruction of familiar items. Moreover, examination of nonword serial recall has uncovered sensitivity to language and syllable structure in the types of errors made. Thus, it has been argued that in order to account for such effects models of short-term memory should incorporate some linguistic principles (Nimmo & Roodenreys, 2006).

There are some short-term memory models – psycholinguistic models – which specifically acknowledge that verbal material places unique demands on memory (Hartley & Houghton, 1996; Gupta & MacWhinney, 1997). Some attempts have even been made to model verbal serial recall solely in terms of speech based processes (Martin, Lesch & Bartha, 1999). Psycholinguistic models attempt to explain short-term serial recall phenomena (especially those observed from nonword stimuli) in terms of linguistic principles. These models of short-term memory have been proposed which incorporate models of language production with models of memory for serial order (e.g. Hartley & Houghton, 1996; Gupta & MacWhinney, 1997). Such models suggest that language-processing mechanisms underlie and constrain verbal serial recall performance and argue the need to integrate linguistic research with memory models. It has been suggested that by incorporating linguistic constraints into models of short-term memory a fuller account of verbal short-term memory can be achieved (Nimmo & Roodenreys, 2006). Consistent with this the experiments in this thesis have shown that coarticulation, which is a feature of fluent speech, is an important determinant of short-term memory performance. Thus, it is argued that the constraints of speech production are also the constraints of serial recall performance where the principle goal is to reproduce an ordered sequence of items.

Psycholinguistic models of short-term memory (Hartley & Houghton, 1996; Gupta & MacWhinney, 1997) highlight how certain linguistic principles (e.g. sonority and syllable structure), are likely to affect whether items are recalled correctly or not. The Hartley & Houghton (1996) model offers the most developed account of how language affects short-term memory, sequence level factors and how such features affect the accuracy of language production are less clearly detailed and more research is required. Thus, despite the substantial input from language processes to verbal serial recall performance, few models are able to accommodate fully how aspects of language planning and production processes affect serial recall. Within descriptions of both short-term memory phenomena and language production there needs to be a more principled understanding of errors, which occur in sequence production and connected speech. Immediate serial recall performance is likely to draw heavily on speech-based processes and there is extensive evidence pointing to the role of language processes in short-term memory performance, but there is the tendency for it to be overlooked in favour of implicating the actions of specialised mnemonic processes and phonological stores.

## 4.4 Further Directions and Considerations

### 4.4.1. Relative Contribution of Coarticulation and Redintegration

One of the main aims of this thesis was to examine an alternative effect of linguistic familiarity in short-term memory to that represented by the item-based phonological-level redintegrative account. Although, the experiments suggest that the fluency with which sequences can be assembled into sequences of articulatory gestures can partially account for those effects previously ascribed to the long-term memory process of item redintegration, the relative contribution or interplay between the two different processes to immediate serial recall performance still needs to be determined. Practice with coarticulations was shown to be important in increasing articulatory fluency, and subsequent serial recall performance. However, articulatory fluency is likely to be a long-term skill itself. However, in the one experiment where the relationship between speech rate and serial recall was examined, speech rate serial recall differences between high and low frequency words were not thought to be attributable to speech rate differences. In addition it is possible that articulatory fluency is more influential when the items are nonwords and also when more importance is laid on rehearsal processes (such as in Experiment 8, when a retention interval was added to encourage rehearsal).

Thus, it is still unclear the relative contribution of long-term memory and articulatory fluency to explaining linguistic familiarity effects. The language familiarity effect – more accurate recall performance for lists of items in a bilinguals first rather than second language – is an example of a linguistic familiarity effect which has been attributed to more efficient redintegration processes for the first rather than second language items. Moreover the absence of first language superiority when a serial recognition task rather than a serial recall task is used has been further used to demonstrate that redintegration is the key determinant of the linguistic familiarity effect, as redintegration is not necessary in recognition as all items presented (Thorn et al., 2001). However such a finding could just as easily been attributed to the perceptual component (as opposed to the speech based one of serial recall performance) whereby auditory perceptual processes hold the ability to discriminate between two different orders is the key perceptual rather than speech based. Thus, serial recognition tests a different skill (auditory perceptual organisation) to that of serial recall (where articulatory processes are involved). So whereas coarticulatory fluency should affect serial recall performance, no such affect should be seen in auditory serial recognition, of course if items for serial recognition are visually presented then there will have to be some sort of recoding (articulatory rehearsal), so then recognition should be affected by articulatory factors. Thus, sequences containing complex articulatory transitions in serial recognition should only affect the recall of visually presented items.

Further studies could compare short unfamiliar items compared to long familiar items, which share coarticulatory gestures to see whether, the frequency and lexicality effects in serial recall would disappear. In addition, it is possible that a distinction needs to be drawn between long-term memory processes that occur at encoding (articulatory fluency of sequence) and those that supposedly occur at retrieval (phonological code reconstruction or pattern completion process, e.g. Schweickert, 1993). Another possible way to try and distinguish effect of redintegration and coarticulation would be to expose participants to coarticulated speech. Whether or not listening to coarticulated to-be-remembered speech under suppression would lead to improved recall and production remains to be seen. In addition, the effects of coarticulation on serial recall that were observed should not be present if, during serial recall task articulatory suppression is undertaken. It is likely that the importance of (co) articulatory fluency is arguably going to be much more apparent when the to-be-remembered are unfamiliar, and every possible skill is needed to retain the order of to-be-remembered items.

### 4.4.2 Coarticulation

The foregoing experiments in this thesis demonstrated that with practice although the duration of sequences of familiar items decreases, the improvement is much more pronounced in sequences of unfamiliar items. It has been argued that highly familiar strings of words are likely to be assembled much quicker than less familiar strings of words. It still unclear how much practice would be needed in order for word and nonword sequences to be articulated at the same speed. There is a need to establish further, how items are organised into whole sequences in connected speech. The results of these experiments could have implications for understanding how language is acquired. For example, when learning a new language, rather than just learning individual words, need to learn how to say them in sequence in quick succession too.

It has been suggested that familiar syllables or over learned sound sequences can be retrieved directly from a syllabary containing the articulatory plans for high frequency syllables. Evidence suggests that over learned sound sequences can be retrieved directly from a syllabary containing familiar syllables (Levelt & Wheeldon, 1994), such syllables are available for the high but not the low frequency items. It is proposed that speakers retrieve pre-stored commands for syllable articulation from a mental library (or syllabary) of such commands, especially in the case of frequent syllables (e.g. Crompton, 1982, Levelt and Wheeldon, 1994; Levelt, Roelofs & Meyer, 1999).

Coarticulated and highly over learned verbal utterances require less extensive neural activation than single nonspeech orofacial gestures (Riecker, Ackermann, Wildgruber, Meyer, Dogil, Haider & Grodd, 2000). Extensive practice of coarticulating items together is likely to result in more coarticulation, when participants are more familiar with what they are saying then they are also going to be more likely to shorten syllables in an overlearned sequence. Frequent syllables claimed to be stored in a mental syllabary tend to exhibit more coarticulation than rare syllables, which are assumed to be assembled on-line from smaller units (Levelt &

Wheeldon, 1994; Whiteside & Varley, 1998; Croot & Rastle, 2004). It is also possible that practiced coarticulated syllable strings (e.g. well known syllables, phrases) may be organised as structural (whole) units rather than individual commands to various muscles, requiring less effort to plan or output.

Evidence for a syllable frequency effect in speech has come from Schweitzer and Möbius (2003), who claimed that if speakers store auditory representations of perceived speech tokens for use as perceptual targets in speech production (i.e. how sounds should sound), then speakers will possess many different exemplars for high frequency syllables that are heard more often than low frequency syllables. Thus, low frequency syllable targets have to be computed from the concatenation of the target regions available for the subcomponents of the syllable (segments, onsets, rimes). It was subsequently found that when the articulatory duration of individual segments and whole syllables were measured, it was found that the durations of segments comprising each syllable and the duration of the whole syllables were closer for the low than the high frequency syllables (less coarticulation in low frequency items). It is possible that speakers are able to store articulatory plans larger than syllables (e.g. multisyllabic words or common phrases), which would influence the articulatory fluency of sequences too.

Another interesting finding and one that could be extended to studies of sequence production including coarticulation of speech gestures is that individuals who are skilled at something, such as musicians use less effort to someone who is less skilled. For example, Mortifee, Stewart, Schulzer & Eisen (1994) found evidence of smaller cortical representation areas of hand muscles in a highly trained violinist compared to subjects missing comparable motor skills. Thus, this finding suggests, that when someone becomes highly trained at something, then their motor plans for output become require less effort, as could be the case for frequently used sequences of sounds.

### 4.4.3. Link between perception and production/motor skills

A principal aim of the experiments in the current thesis was to provide further support for the accumulation of evidence suggesting that immediate serial recall, rather than being a product of the interaction between a specialised phonological store and phonological loop component, is instead parasitic on articulatory (motor/gestural) processes and auditory perception processes which are used to impose order on to-be-remembered material.. However, the primary focus of the experiments has been on the gestural component or the motor output planning processes affecting serial recall rather than the pre-encoding perceptual processes. Thus investigations are needed to further examine the influence of auditory perceptual organisation on memory for serial order.

The working memory model has been criticised for ignoring pre-encoding perceptual processes, which may govern how information is organised (Jones, Hughes & Macken, 2006). Auditory perceptual processes have been shown to play an important role in encoding order. It is unclear from the present studies whether the encoding of sequence order is affected by coarticulation or whether the articulatory fluency of a sequence governs how a listener perceives auditory material before an output plan is constructed. The ability to assemble items into a coarticulated plan was shown to affect serial recall performance; however is it possible that coarticulated speech is initially perceived and organised differently to concatenated speech? Perhaps listening rather than producing coarticulated speech is sufficient enough to benefit production and serial recall performance?

There is a growing body of evidence highlighting the strong links between perceptual and motor processes. Studies of monkeys have led to the identification of a specific type of pre motor neuron known as a 'mirror neuron' which has highlighted the immediate connection between perception and action. These 'mirror neurons' have been shown to become activated both when a monkey makes a particular action and when it observes another individual (monkey or human) making a similar action (Rizzolatti & Craighero, 2004).

Moreover, there is evidence that the perception of sounds leads to the activation of corresponding speech-motor areas in humans, a connection has been made between language production and language perception processes. The motor theory of speech perception proposes that the perception of speech involves mapping speech onto the speech production system such as articulatory gestures (e.g. Liberman & Whalen, 2000). Such a proposal suggests that speech perception and speech production processes use a common range of motor primitives that during speech production are at the basis of articulatory gesture generation whilst during perception they are activated in the listener as a result of an acoustically evoked motor resonance. Thus, the articulatory motor system may intervene in perception.

It was demonstrated by Watkins, Stafella & Paus, (2003) that both auditory and visual speech perception facilitates the excitability of motor system involved in speech production. More specifically another study has shown that when participants were made to listen to words, listening to the words produced a phoneme specific activation of speech motor centres in them. Moreover perceiving phonemes that require when produced a strong activation of tongue muscles (e.g. words and nonwords containing the rr sound), automatically produces when heard an activation of the motor centres controlling the tongue muscles (Fadiga, Craighero, Buccino & Rizzolatti, 2002). Studies such as this have been used to support the idea that the perception of sounds only occurs when corresponding articulatory gestures are activated.

Studies examining imitation effect also indicate a connection between the perception and production of language. One study demonstrated that when participants were required to read out words prior to, and after being exposed to the same words being read by someone, their post-exposure utterances were then judged as a closer imitation to the heard version (even though not asked to imitate) than the earlier version (Goldinger & Azuma, 2004). Thus, these results showed that people tend to imitate the heard version of words (especially in relation to duration and prosody). Moreover, this imitation is increased both by the number of times the word was heard in the training phase (more presentations, more imitation) and by the pre-experimental frequency of the word (lower frequency, more imitation). Similarly, Nielsen (2005) demonstrated a close tie between language perception and production by recording how participants' voice onset times for words beginning with /p/ were affected by exposure to target speech. If there are perceptual-motor links in speech then passive listening to coarticulated as opposed to concatenated speech may also benefit later production fluency and serial recall performance.

### 4.4.4 Articulatory fluency and manual fluency

The increase in articulatory fluency resulting from practice assembling items into a sequence increases the efficiency of motor-output planning resulting in better serial recall and production performance. Traditionally memory for verbal and nonverbal material has been regarded as separate. However, this has been disputed by the finding that serial order memory for both verbal items and spatial locations is disrupted by both auditory verbal and nonverbal (tones) sequences (Jones & Macken, 1995), Findings such as this point to the idea that processes involved in short-term memory are not specific to language but a general sequencing process which governs sequential behaviour.

There is a wealth of research that has focussed on the assembly and production of motor sequences. Most influentially, Sternberg and colleagues (Sternberg, Monsell, Knoll & Wright; Sternberg, 1978; Wright, Knoll & Monsell, 1980) investigated the processes involved in assembling plans for short action sequences of both speech and typing. What they found was that there is an outstanding level of order and regularity involved in the production of sequences. The ordering and sequencing of serial-order information is apparent in many tasks, not just those requiring language production, therefore the ability to plan and sequence articulatory gestures may be a reflection of a more general process for planning motor sequences.

A connection has been found between reading ability and manual fluency (Carello, Marciarille LeVasseur & Schmidt, 2002). It was suggested that both a sequential tapping task (manual fluency) and a reading task (articulatory fluency) share the requirement of coordinating muscles over space and time. Thus, coarticulated sequencing skill underlies both reading and sequential finger movements. In addition, reading disabled children such as dyslexics have been found to have accompanying deficits in motor coordination such as slower and more error prone in manual coordination and balance tasks (e.g. Wolff, Michel, Ovrut & Drake, 1990). Thus, serial recall performance (where planning and processing of sequences is essential) may reflect a general ability to sequence events and movements.

### 4.4.5 Short-term memory as an emulator system

One possible interesting development is to conceive of short-term memory as part of an emulator system (Grush, 2004). This is an extension of the use of feed-forward models for the control of movement. Briefly, this consists of an emulator – embodying both synthesised perception and motor commands – that can act in the production of gesture but importantly can be used 'offline' to enact an output plan without motor acts. Whether rehearsal can be regarded as a type of emulation process has yet to be explored fully but is consistent with the interpretation of short-term memory as being parasitic on the motor and perceptual system.

### 4.5 Summary and Conclusions

The present thesis has demonstrated that familiarity with the articulatory character of a to-be-remembered sequence as opposed to an individual item, influences serial recall performance. Coarticulation, which is characteristic of fluent speech, was the specific focus of the experiments. The experiments demonstrated that having the opportunity to practice assembling nonword items into a sequence, required for rapid production resulted in an increase in the articulatory fluency with which sequences of such items may be produced. Importantly, such practice did not lead to a greater fluency in the production of individual items or the production of sequences where the items were familiar but the transitions between them were not. The specificity of this effect of familiarity on articulatory duration was precisely mirrored in the effect of familiarity on serial recall performance, implicating the factor of coarticulatory fluency in the effect of linguistic familiarity on serial recall.

The findings of these experiments indicate the importance of considering lists of to-be-remembered items as a connected spoken stream, as well as in terms of individual item characteristics. In addition to demonstrating the importance of sequence level articulatory planning factors when explaining linguistic familiarity effects and other serial recall phenomena, these studies have further highlighted that the processes involved in serial recall tap into the same operations that exist to process speech. More generally, the findings of this thesis lend further weight to the view that serial recall performance may be parasitic on general perceptual and motor planning processes.

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