

**CROSS-MODAL PERCEPTUAL INTEGRATION:
STUDIES IN AUTISM, THE BROADER AUTISM PHENOTYPE
AND TYPICAL DEVELOPMENT.**

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Thesis submitted for the degree of Doctor of Philosophy,

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Summary of Thesis

Integration of sound and vision is important for humans to interact efficiently with their environment. Co-occurrence of sensory inputs in space and time orients attention (Spence & McDonald, 2004), highlights causal relationships between events (Blakemore et al. (2001), and enhances representational formation from infancy (Jordan et al., 2006).

Dysfunction within the neural mechanisms supporting multisensory processing hypothetically has widespread consequences, particularly in terms of social interaction as social stimuli are feature-rich and cross-modal. People with autism spectrum disorders are diagnosed on the basis of atypical behaviours relating to social interaction. Iarocci and McDonald (2006) consider that subjective perceptual incoherence in individuals with ASD reflect dysfunctional multisensory processing which may be causal to development of autism.

Evidence of superior vision processing in ASD supports the idea that enhanced perceptual functioning (EPF) is an important part of the autism phenotype (Mottron et al., 2006). Bertone and Faubert (2006) propose that perceptual integration within single modalities is compromised, resulting in elevated simple stimulus feature processing. Their Signal Integration Theory (SIT) accommodates superiorities in autistic task performance that are theoretically related to a cognitive preference for detail-processing (Weak Central Coherence theory; Happé & Frith, 2006).

In this thesis, a cross-modal phenomenon was selected assessing multisensory processing in typical children, adults with autistic traits and children with ASD. Processing cross-modal perceptual stimuli (Sekuler et al., 1997) relates to perceptual system functioning (Bushara et al., 2003) and is theoretically relevant to the development of intuitive physics (Michotte, 1963), a cognitive process spared in ASD (Baron-Cohen, Wheelwright, Scahill, Lawson & Spong, 2001).

Visual disembedding and intuitive physics tasks show gender differences (Halpern et al., 2007). Sex differentiation in cognition has led to the Extreme Male Brain theory of Autism (Baron-Cohen, 2002), in which autistic 'traits' are expressed in everyone to some extent; ASD is described as representing extreme male brain functioning at one end of a continuum, the other end representing the 'extreme female brain'.

Research using adapted cross-modal perceptual stimuli is presented. This evaluates whether cross-modal integration is compromised in relation to autism. Gender, autistic trait expression and perception/cognition relationships between cross-modal causality and intuitive figures/visual disembedding are also researched to determine whether ASD might, in future, be remodelled in terms of extreme male perceptual development.

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Abbreviations

ADHD Attention Deficit (Hyperactivity) Disorder

AS Asperger Syndrome

ASD Autism Spectrum Disorder

BAP Broader Autism Phenotype

BDT Block Design Test

CEFT Children's Embedded Figures Task

CoMG Crash or Miss Game

dB Decibels

DZ Dizygotic

EF Executive Function

EFT Embedded Figures Task

EPF Enhanced Perceptual Functioning

ERP Event-Related Potential

fMRI functional Magnetic Resonance Imaging

HFA High-Functioning Autism

MS Milliseconds

MZ Monozygotic

NEO-PR-I Revised NEO personality inventory

NVIQ Non-Verbal Intelligence Quotient

PDD-NOS Pervasive Development Disorder, Not Otherwise Specified

PIQ Performance/Peformal Intelligence Quotient

PPMC Pearson's Product Moment Correlation

RG Reduced Generalisation

SIT Signal Integration Theory

SOA	Stimulus Onset Asynchrony
SC	Superior Colliculus
TD	Typically Developing
ToM	Theory of Mind
VIQ	Verbal Intelligence Quotient
WCC	Weak Central Coherence
WCST	Wisconsin Card Sorting Task
WHN?T	What Happens Next? Task

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Chapter 1: Cognition, Perception and Perceptual Integration in Autism Spectrum Disorder

1.1 Overview

Autism is a pervasive developmental disorder primarily related to atypical social and communication behaviours. Since its original description by Kanner (1943), the diagnostic definition of autism has been widened to reflect a triad of behaviours (Wing, 1981): Disruption of social relationships; difficulties with communication, and a restricted range of behaviours (either in terms of personal interests, or demonstrable lack of imagination, or in relation to repetitive stereotypical movements). This triad has been incorporated into diagnostic criteria to describe a wide range of related conditions, and the umbrella term Autistic Spectrum Disorder is now used to represent individuals who show considerable heterogeneity in abilities, intellectual range and behaviours. Further, a 'special case' has been made of a related syndrome Asperger Syndrome (or AS), a high-functioning form of autism in which individuals have normal or above normal intelligence with no speech development delay. Debate continues as to whether defining AS as an autism spectrum disorder is valid, however.

Sensory and perceptual abnormalities are manifest in many individuals with ASD (O'Neill & Jones, 1997), but are described as peripheral symptoms, rather than core indicators of the conditions (DSM-IV; APA, 1994)¹. The marginalisation of highly prevalent sensory issues reflects the fact that, at the psychological level, autism has been regarded as the product of a 'core cognitive deficit' (Frith, 1996). Three such unitary accounts proposed to explain the behavioural autistic

¹ Although they were included in core diagnostic criteria in DSM-III (1980)

phenotype are Theory of Mind (Baron-Cohen, Leslie & Frith, 1985), Weak Central Coherence (Frith & Happé, 1994) and Executive Dysfunction (Ozonoff, Pennington & Rogers, 1991) theories. Empirical evidence in support of each of these theories has mainly been interpreted in terms of cognitive rather than perceptual functioning. However, in neuroconstructivist terms, it is thought that early compromises in perceptual processing may generate atypical brain maturation (Karmiloff-Smith, 1998), and so both sensory and perceptual differences may contribute to emergence of autistic cognition that each unitary theory describes.

The idea that perceptual development may have causal significance in ASD is supported by many recent advances in understanding the nature of perceptual processing in autism (Mottron, Dawson, Soulières, Hubert & Burack, 2006). The majority of studies reporting significant effects on perceptual tasks between ASD and control groups have been unimodal, predominantly investigating visual task performance and thresholds (for a review, see Dakin & Frith, 2006). A growing body of evidence of atypical audition has also been reported (e.g., Järvinen-Pasley & Heaton, 2007; Bonnel et al., 2003). However, little research has been published in relation to cross-modal integration failure, or to multisensory processing in general.

Given that the typical *developmental* characteristics of autism include difficulties in speech and emotional comprehension acquisition, this area must be considered of research interest (Iarocci & McDonald, 2006). Both of these socio-cognitive functions involve a high degree of audio-visual integration, and putatively require active interaction with the social environment from birth in order to emerge successfully in the developing mind. Therefore, ASD may ultimately be redefined to

acknowledge perceptual development as being fundamental to both diagnostic models and individual outcomes.

The argument investigated in this thesis is, therefore, that the ASD phenotype is associated with weaknesses in perceptual (audio-visual) integration. A series of studies is presented here exploring one particular aspect of perceptual integration, cross-modal perceptual causality (Guski & Troje, 2003; Sekuler, Sekuler & Lau, 1997). This is a phenomenon in which presentation of an auditory signal influences interpretation of a dynamic visual event, such that one disk passing over a second disk onscreen is perceived as one disk launching the second. The visual information provided is ambiguous, and the event is generally interpreted as non-causal in the absence of the auditory signal. Hence, integration of the auditory and visual information serves to generate the impression of cause-and-effect. Recent evaluation of the neural systems involved in producing cross-modal perceptual causality suggests that the phenomenon is predominantly the result of perceptual, rather than attentional or cognitive, processing (Bushara, Hanakawa, Immisch, Toma, Kansaku & Hallett, 2003).

Cross-modal perceptual causality therefore provides a means of investigating audio-visual integration at the perceptual level. This thesis presents a series of studies in which novel adaptations of the original audio-visual causality paradigm (Sekuler, Sekuler & Lau, 1997) are used to measure sensitivity to cross-modal causal perception phenomena in typical children, adults with several autistic traits and children with ASD. The primary aims of the thesis are to establish whether or not evidence exists for compromised perceptual integration in ASD, and

whether any such compromise may have relevance to the emergence of two aspects of cognition that have previously been associated with autism, namely intuitive physics and central coherence.

The key study in Chapter 2 (Experiment 3) with typically developing children demonstrates that the novel cross-modal perceptual causality task is sensitive to factors such as age and gender. This chapter also introduces a new intuitive physics task that is shown to measure intuitive physics abilities across a wide age range. The chapter concludes with an examination of the inter-relationships between age, perception and cognition using these two new tasks.

Autism is highly heritable (Beaudet, 2007), and many relatives of probands exhibit autistic-like behaviours but with reduced severity (Bailey, Palfeman, Heavey & Le Couter, 1998). The contemporary idea of autism is not as a category of 'otherness', but as representing the extreme end of a continuum along an autistic dimension that is normally distributed across the general population (Baron-Cohen, 2008a). If cross-modal perceptual integration is compromised in ASD, evidence of this should be apparent in individuals with a relatively high number of 'autistic traits'. In Chapter 3, aspects of cross-modal perceptual causality in young adults self-reporting several such traits is examined (Experiments 4 and 5).

Baron-Cohen (2002) has reconceptualised ASD as representing 'extreme male brain' function, based on converging evidence of inter-relationships between science ability, the male cognitive phenotype and autism. Baron-Cohen et al. (2006) states that autistic processing over-relies on 'systemising' (a masculine style of

thinking) at the extent of 'empathising' (a predominant factor in feminine cognition). Systemising is purportedly the basis for physics ability; Chapter 3 therefore includes an experiment in which associations between the broader phenotype, cross-modal integration and intuitive physics advantage is tested (Experiment 4).

Systemising is related in some respects to contemporary weak coherence theory (Happé & Booth, 2008), which characterises autistic cognition as a bias towards processing local detail over global form. In Experiment 5, superiority on a task in which piecemeal processing is an advantage, the Embedded Figures Task (EFT), is hypothesised to be associated with relatively high expression of autistic traits. Given evidence that visual search is associated with EFT performance in children with autism (Jarrod, Gilchrist & Bender, 2005), relationships between perceptual integration, EFT measures and autistic trait expression are also assessed in this study.

Gender influences both intuitive physics and EFT performance, in that males generally outperform females on these tasks. Correlations between perception and cognition are therefore also reported by gender subgroup in both experiments in Chapter 3, and findings discussed in the context of Extreme Male Brain theory (Baron-Cohen, 2002).

The hypothesised relationship between disrupted cross-modal integration and ASD is the basis of Chapter 4. In Experiment 6, cross-modal perceptual causality sensitivity is evaluated in children with ASD. As evidence of perceptual

differences between autism and Asperger Syndrome has been reported with respect to emotional stimuli (Mazefsky & Oswald, 2006), it is important to assess whether findings reported in Experiment 6 are influenced by conflation of the two stimuli. The final analysis provided therefore contrasts data from diagnostic subgroups derived from Experiment 6a.

1.2 History of diagnosis of ASD, and its impact on empirical research.

The seminal account of autism was provided by Kanner (1943), in which he stated that the eleven boys he observed showed an “inability to *relate themselves* in the ordinary way to people and situations from the *beginning of life*.” This sentence describes autism as fundamentally a social behaviour disorder that is present from birth. Independently of Kanner, Asperger (1944) also emphasised social disruption in his patients, listing a lack of empathy, little ability to form friendships, and one-sided conversation as characteristics of ‘autistic psychopathy’. The social dysfunction he described therefore strongly suggests that his syndrome is associated with Kanner’s ‘early infantile autism’ (Wing, 1981).

Originally the definition of autism was unclear. Describing the regressive, withdrawn state associated with childhood schizophrenia as autistic (Bleuler, 1951) masked the different developmental paths of these disorders (Tidmarsh & Volkmar, 2003). Also, psychiatric interpretation of autism as the result of disrupted mother-child relationships (Bettelheim, 1967) denied its genetic nature. Autism was therefore not clearly recognised as a distinct disorder until Wing and Gould (1979) produced a classification system that clearly delineated the condition from mental

retardation with social dysfunction. They proposed that diagnostic confusion over the core features of autism could be reduced by focusing on a triad of social impairments: An abnormality of reciprocal social interaction; closely associated with impairment of communication, and constrained imagination, with the latter resulting in a narrow, repetitive pattern of activities.

In a meta-analysis of prevalence studies undertaken in diverse countries, Wing (1993) later found that the triad clearly described every case included in each report, irrespective of multiple classification systems and sub-types devised by research groups. She also concluded that inclusion or exclusion of general intellectual functioning as an autism criterion influenced rates found in the reviewed studies. Wing (1993) therefore extended the triadic definition of autism to include a wider range of children that was independent of intellectual ability, and the term 'autism spectrum' was introduced.

The spectrum now comprises Autistic Disorder plus a subset of related Pervasive Developmental Disorders (Asperger Disorder/Asperger Syndrome, Rett's Disorder and Childhood Disintegrative Disorder, and Pervasive Developmental Disorder-Not Otherwise Specified, or PDD-NOS), all of which have separate classification criteria under DSM-IV-R. Autistic Disorder is characterised by impairments in all three domains apparent before three years of age. Asperger Syndrome (AS) is qualitatively characterized by more subtle atypicalities in social reciprocity and restricted repetitive and stereotyped behaviour relating to a narrow range of interests and activities, despite apparently normal language and cognitive development prior to three years. The generic term PDD-NOS describes people who

meet autism (but not AS) criteria outside of the normal age range, or who show severe challenges in some but not all domains with/without cognitive or language delay (Freitag, 2007). The term autistic spectrum disorder (ASD) is now synonymous with any or all of these conditions.

The description of ASD at the behavioural level in terms of the triad generated a bias within empirical research towards examination of its cognitive origins, as social functioning relies on complex representational processing. Although fruitful in many respects, this emphasis on cognition as the foundation of the autistic phenotype has led to the marginalisation of other factors, such as perception and attention, that may also be important to 'understanding the enigma' (as Uta Frith described autism to be; Frith, 1996). Furthermore, the search for a single cognitive process to account for the every autistic behaviour has reduced emphasis on developmental aspects of the condition; the implication within some theories being that the systems supporting candidate cognitive processes are absent from birth, rather than fail to emerge as a consequence of developmental constraints.

As there is evidence of perceptual, sensory and multisensory dysfunction in ASD (section 1.3 below), compromised perceptual integration may have a fundamental role to play in explaining ASD within a developmental context. However, as not much is currently understood about multisensory processing in autism, first it is important to determine whether any evidence exists that integration is abnormal at the perceptual level in autism and related conditions. The purpose of

this thesis is therefore to explore cross-modal perceptual integration, which, it is argued, is potentially important for multiple aspects of cognitive development.

1.3 Cognitive accounts of ASD: the search for a unitary cause

The search for a single cognitive account of autism has produced some highly cogent theories, the most influential being: Weak central coherence (WCC; Frith & Happé, 1994), atypical development of Theory of Mind (and 'mindblindness'; Baron-Cohen, Leslie & Frith, 1985), and executive dysfunction (Ozonoff, Pennington & Rogers, 1991). It is important to note that none of these single cognitive explanations has provided a true unitary account of autism, as no one theory describes all diagnosed individuals' cognitive abilities or social behaviours, or can account for all components of the autistic behavioural triad (Happé, Ronald & Plomin, 2006).

Consideration of the impact of atypical perception on cognitive processing is putatively more relevant to weak central coherence theory. For instance, an important test of weak central coherence (the Embedded Figures Task) has been shown, using fMRI techniques, to be dependent on enhanced right primary visual cortex functioning in individuals with AS, whereas controls were shown to have high activation in left parietal regions (Manjaly et al., 2007). Therefore, although all three cognitive theories of autism are described below, most attention is directed towards weak central coherence in this section.

1.3.1 Weak Central Coherence Theory

Kanner (1943) originally noted that his autistic children were obsessed with preservation of sameness due to, he thought, inability to experience global form independent of attention to constituent parts. Frith (2003) states that “In the normal cognitive system there is a built-in propensity to form coherence over as wide a range of stimuli as possible, and to generalize over as wide a range of contexts as possible” (page 159). In the weak central coherence (WCC) theory of autism, individuals with ASD are said to have a core deficit in such centralised information processing, with subsequent failure to comprehend the global meaning or form of a stimulus (Frith & Happé, 1994). This deficit is associated with preferential processing of the local meaning/form/detail within the stimulus.

Kanner (1943) related detail-processing to restricted interests and insistence on repetition and patterns. Frith and Happé (1994) argued that weak central coherence also provides an explanation of the superiorities as well as deficits exhibited by many individuals with ASD. For instance, the Block Design Test (see Figure 1.1) has been found to be performed faster by children with ASD than by their peers (Shah & Frith, 1993). The cognitive explanation for this effect is that these participants could match the blocks to details in the pattern without the impediment of perceiving its overall form. This interpretation was corroborated by their finding that pre-segmentation of the block pattern significantly aided task speed in their control children.



Figure 1.1: Block design task element and target pattern (from Shah & Frith, 1993)

Conversely, context-dependent task performance is compromised in ASD. In the homograph test, a word with two pronunciations and meanings but one orthographic form can only be read out loud correctly if the overall sentence context is comprehended. Children with autism reading a sentence using the word ‘tear’ were found not to know whether it referred to a rip or to crying, although the semantic context provided should have resolved this ambiguity (Frith & Snowling, 1998).

Happé (1997) considered whether error rates in autism on homograph tests were reduced by supplying context information early in the ambiguous sentences. She found that her autistic group failed to benefit from the disambiguating effect of providing the context clause first for infrequently used homograph trials. As the control children did benefit from this ‘homograph-after’ sentence structure, she concluded that the target children could not use preceding context to alter homophone choice, therefore they displayed a preference for processing words over sentences. Similarly children with autism will use ‘local’ semantic associations to complete a sentence in a way that fails to make sense, rather than use a word that

satisfies its global requirement for meaning (for instance, completion of “the sea is full of salt and” with “pepper”, not fish; Happé & Frith , 2006).

Weak central coherence is described as being cognitive in nature because context-based tasks suggest that detail-processing bias in autism does not simply apply to visual stimuli tasks. Rather, WCC is considered to be domain-general, hence superior performance of the block design test has been interpreted to reflect cognitive processing.

A major concern regarding Weak Central Coherence theory

Weak central theory is challenged by findings that global processing is *not* invariably absent in ASD. Several studies (Mottron, Burack, Stauder & Robaey, 1999; Mottron, Burack, Iarocci, Belleville & Enns, 2003) demonstrate that individuals with autism have access to global representations, and can respond to stimuli at a global level if directed to do so explicitly. Mottron et al. (2003) contrasted responses of adolescents with high-functioning autism (HFA) with those of matched controls across a series of tasks using hierarchical stimuli comprising local and global letter forms. Their study showed that the target and control groups produced similar response times on configural grouping tasks (in which intact and visually-degraded letters had to be identified) and in hierarchical tasks. However, the adolescents with HFA showed no time cost in identifying letters embedded in a global word form in a disembedding task, whereas the control participants found this condition more challenging than when the target letters were presented in

isolation. Therefore the ASD group here displayed piecemeal processing superiority *alongside* intact global representation capacities.

The findings reported by Mottron et al. (2003) suggest possible limitations to the WCC theory, as global and local processing were framed originally as being oppositional. It would appear that global representations do not impede rapid processing of local-level information. Evidence of intact global processing has resulted in weak central coherence being redefined as a cognitive *style*, in which detail processing is substituted for global representational cognition as the default system (Happé & Frith, 2006). This suggestion implies that performance on tests of weak coherence may reflect recruitment of different strategies, and alternative dominant brain pathways, in autism.

Is weak central coherence actually weak perceptual coherence?

Another established test of WCC theory is the Embedded Figures Task (Witkin, Ottman, Raskin & Karp, 1971). Shah and Frith (1983) demonstrated that children with autism were better able than controls to recognise a simple shape camouflaged (or 'embedded') within a more complex illustration (Figure 1.2). Superior 'visual disembedding', i.e. better accuracy and reduced response times, has been repeatedly found in relation to ASD (Jolliffe & Baron-Cohen, 1997; Morgan, Mayberry & Durkin, 2003; Shah & Frith, 1993; Van Lang, Bouma, Sytema, Kraijer & Minderaa, 2005).



Figure 1.2: Example stimulus from Embedded Figures Task (from Witkins et al., 1971).

However, the EFT can be solved using different strategies. Each of the distinct information types provided by a complex form (such as colour, or edge) is processed both independently and within integrative signalling in the visual system. The EFT puzzles therefore can be solved using a *single visual dimension*. Strong perceptual integration of the multiple features of the complex form would impede recognition of the target. Cognitive coherence weakened by poor feature integration at the perceptual level would, conversely, produce EFT superiority. Combined with concomitant enhanced feature processing, the edge outline of the target would therefore be relatively more salient than the product of visual integration in individuals with weak perceptual coherence.

Perceptual factors in EFT performance have been explored by Jarrold, Gilchrist and Bender (2005), who compared responses of children with and without autism on two versions of a search task, and correlated results to performance of the children's embedded figures task (CEFT; Witkin, Oltman, Raskin & Karp, 1971). The first, a feature search task, directed participants to identify an element within an array according to a unique perceptual feature. This task is thought to involve generating a map of the single dimension's distribution across the scene. In the

second conjunction search task, two visual features (colour and shape) defined a single element amongst an array of items that shared either colour or shape with this target. Searching involves the application of visual attention to each element in turn to detect the unique feature combination. Feature search can be fast and efficient, unaffected by number of display elements, but conjunction search is affected by the number of elements present.

The study by Jarrold et al. (2005) showed that the autism group outperformed the ability-matched controls across all tasks. It also produced evidence of a double dissociation apparent between groups when response times for each search task were correlated with CEFT response speed. Data from children with autism produced a positive correlation between feature search efficiency and CEFT rapidity; control children showed a positive relationship between CEFT and conjunction search speeds. The conclusion drawn by Jarrold et al. (2005) was that the resources recruited in response to CEFT stimuli differ between the two groups. Autistic individuals faster at single feature search were also faster at identifying the target in the EFT trials. For the control group, however, ability at the individual level to cohere non-target distractors together to identify the target was related to EFT speed, suggesting that EFT performance involved formation of higher-order integrated representations for these children.

This perception/cognition relationship study (Jarrold et al., 2005) requires replication with older participants; the age disparity between IQ-matched groups created by including low-functioning children with autism being unacceptably large. Also, no mention is made as to whether the target and control children were gender-

matched (as the two sexes differ on EFT performance; Witkin, 1950). However, this research successfully raises the challenge that rapid embedded figure detection recruits different processes in ASD and typically developing (TD) children, a conclusion supported by evidence from fMRI studies in which individuals with ASD have been shown to have atypical brain activation patterns in response to EFT stimuli. Lee et al. (2007) found generally reduced cortical activation in children with autism, and concluded that EFT resolution was achieved parsimoniously by the autistic brain. Ring et al. (1999) detected the involvement of regions associated with lower-level perceptual processing in response to EFT stimuli in an ASD group, but not in the controls, and Manjalay et al. (2007) have reported that adolescents with AS/HFA show high right V1 activation in response to EFT stimuli.

Findings of perceptual system involvement on EFT task performance argues against disrupted cognitive coherence as the process underpinning autistic abilities and behaviours across multiple domains. Furthermore, enhanced visual feature processing may develop in ASD at the cost of perceptual integration, in which case it should be possible to find an inverse relationship between sensitivity to cross-modal phenomena and EFT performance. This idea is explored by relating EFT measures to cross-modal perceptual causality scores in students with high expression of autistic traits (Experiment 5).

1.3.2 Theory of Mind and 'Mindblindness' Theory

An alternative cognitive account of ASD is that the autistic child fails to develop a 'Theory of Mind', or the ability to process information regarding another

person's thoughts, feelings and knowledge (Baron-Cohen, Leslie & Frith, 1985). Individuals with ASD are thought not to "impute mental states to themselves and others" (Premack & Woodroof, 1978, p. 515), and consequently are not aware that the contents of another mind are different from their own. Being unable to understand the ways in which another person's thinking differs from your own makes social behaviour unpredictable; many people with ASD find others incomprehensible as a result of such 'mindblindness' (Baron-Cohen, 1995). This difficulty relates purely to the social world, and is therefore domain-specific, allowing for evidence that cognitive processing in other domains (physical cognition, for instance) is intact or, indeed, superior in relation to ASD.

Robust evidence that individuals with autism lack a 'theory of mind' exists. For instance, in the Sally-Anne 'false-belief' task (Baron-Cohen et al., 1985) a doll (Anne) is shown to hide something belonging to another doll (Sally) in her absence, so that the object is not where Sally put it before leaving. When asked to predict where Sally will search for the item on her return, children of four years have shown that they know Sally will look in the area where she left it (Wimmer & Perner, 1983). The ability to distinguish between the doll's belief and reality suggests these children could process knowledge at a metarepresentational level (i.e., I think she believes....). Children with autism, however, do not appear able to make this judgement, and instead have been shown to think Sally will go to the new location, unlike control children matched for age or general IQ (Baron-Cohen, Leslie & Frith, 1985); they are thought therefore not to comprehend that Sally has a 'false belief', suggesting that they think she knows what they know.

In their original paper, Baron-Cohen, Leslie and Frith (1985) reported that 16 out of 20 children with autism failed to attribute a false belief to the Sally doll on this task. As Bloom and German (2000) state, though, a child may fail the task for reasons of attentional (failure to follow the two-character narrative fully), perceptual (failure to see that Sally had not seen the switch event), memory (first location of the object) or linguistic (confusion between where the doll will look with where the doll should look) constraints.

Also, assessing performance of second order theory of mind tasks by adults with Asperger Syndrome (Bowler, 1992) has revealed that processing chains of belief such as 'I think that she thinks that he knows...' was possible for the majority of participants (73%). Colvert, Cusance and Swettenham (2002) found a correlation between embedded reasoning skills and false belief task performance in a group of high-functioning individuals with ASD, implying that any 'default' innate ability to form metarepresentational beliefs about the contents of others' minds (Leslie, 2004) may be substituted by logical analysis. Use of logic could therefore account for performance on both first-and second-order belief tasks by both adults with Asperger Syndrome and children with autism in the earlier studies.

The Theory of Mind theory has therefore been undermined as the causal explanation of social domain behaviours in ASD as, if an abstract metarepresentational cognitive process (logic) can substitute for 'natural' theory of mind cognition, then it may be that this form of cognition is less reliant on metarepresentations and more reliant on input from downstream perceptual/attentional processes.

Mindblindness, however, is a wider concept, extending beyond false-belief processing. It incorporates many other autistic behaviours, such as literal, non-imaginative rule-based play in children (Boyd, Conroy, Mancil, Nakao & Alter, 2007), and the tendency of individuals with ASD not to pay attention to what is salient to someone else (children with ASD show reduced joint attention from an early age; Naber et al., 2007).

Tests of mindblindness relating to emotion (e.g., the 'Reading the Mind in the Eyes' task; Baron-Cohen, Wheelwright, Hill, Raste & Plumb, 2001) reveal that emotional comprehension is challenged in adults with HFA/AS. This finding relates to reduced accuracy of recognition of subtle emotional expressions from eye region information in ASD, which implies that visual emotional representation is poor. This interpretation, however, provides no explanation as to why emotional representational function is deficient in ASD.

As emotion in everyday social interaction is communicated by a complex set of auditory and visual information, it is reasonable to suggest that perceptual integration of multiple signals is a pre-requisite for the formation of accurate emotional representations. Support for this idea is provided by the finding that adults with ASD are inferior to controls when reading emotion from dynamic faces, but that they display the same drop in performance as controls when the eye information in these displays is frozen (Back, Ropar & Mitchell, 2007). This finding suggests that dynamic eye information is of equal importance in online emotional comprehension in people with ASD as it is in others; hence an alternative explanation is required for reduced emotional recognition in autism, and one

possibility is that emotion template representations are not easily formed because cross-modal signal integration is weak.

To summarise, within the social domain it would appear that the autistic phenotype should be considered not as one social processing deficit, but of several system and subsystem atypicalities at both high and low levels of processing. A developmental account is required to consider how early difficulties between co-operative processes recruited by social stimuli might interact to produce escalating problems in the emerging autistic mind. The studies in this thesis therefore investigate a putative link between autism and compromised cross-modal perceptual integration (Experiments 4, 5 and 6).

1.3.3 Executive Dysfunction

Of all the unitary cognitive theories of autism, Executive Function (EF) is perhaps the most difficult to relate directly to the heterogeneity of behaviours associated with autism spectrum conditions. Executive Function has myriad definitions, and has been argued by some simply to be a term that reflects problem-solving behaviours which depend on many domain-general executive processes (Zelazo, Carter, Reznick & Frye, 1997). Hence, Hill (2004a) describes EF as an umbrella term encompassing general processes such as planning, inhibition and mental flexibility, all of which are required for goal-directed behaviour. With such a broad definition, it is unsurprising that the neural locus for EF cannot be constrained to specific regions, but it is thought instead to relate generally to frontal lobe function.

With respect to autism, Executive Dysfunction is the unitary account that has been most closely associated with repetitive behaviours and restricted interests. However, in a review of extant research, Hill (2004b) stated that the nature and specificity of the relationship of EF with autism is unclear; results of many studies using biomarker EF tasks are inconsistent, and poor EF has also been associated with other developmental conditions such as Attention Deficit Hyperactivity Disorder (and the prevalence of ADHD comorbidity is high in ASD).

Assessment of planning ability has produced evidence that children and adolescents with autism show long-term impairments. For instance, the Tower of Hanoi task involves identifying and executing the shortest chain of moves needed to transfer three disks across three pegs, one at a time, to match a target pattern. Children with autism experience more difficulty with this task than do children with dyslexia, ADHD and Tourette's syndrome when matched on intellectual ability (Hill, 2004a). The deficit does not improve with age, and is present whether or not the participants have normal levels of intelligence. However, although all of the group means in these studies were within the normal intelligence range, the spread of abilities in the ASD groups mean that the results may reflect poor functioning in only those target individuals with below average IQ levels, rather than representing impairment across the entire ASD sample in this study.

Autism has also been studied with respect to inhibitory control, where a prepotent over-trained response has to be suppressed in favour of execution of a less established behaviour. With the Stroop test (Stroop, 1935), the ability to suppress interference from a dominant modality whilst processing information from another

modality is tested. For instance, stating the colour of the word red when it is written green assesses the ability to process visual information whilst suppressing semantic meaning. Many variants of the colour/word Stroop task have been used to investigate inhibitory control in ASD, but overall results indicate that people with ASD do not have reduced ability to inhibit irrelevant information, as children and adolescents with autism show levels of dominant information interference equivalent to typically developing controls (Eskes, Bryson & McCormick, 1990; Ozonoff & Jensen, 1999). When autism is compared with ADHD, however, this latter condition has been found to be associated with exaggerated interference (Ozonoff & Jensen, 1999), which suggests that these two development conditions differ in that inhibitory control is preserved in ASD.

Mental flexibility has also been found to be restricted in ASD. In the Wisconsin Card Sorting Task (WCST), participants have to sort cards according to an unknown category rule based on one card feature such as shape, or colour. Participants determine the rule through the feedback given after each card categorised. At random intervals, the rule is changed, which participants discover by being told that their last card was wrongly sorted. Autism is associated with perseveration errors on this task; participants with ASD continue to sort cards according to a prior rule after being given more feedback that the rule has changed than is needed by control participants. Perseveration errors are significantly more numerous in autism, whether comparisons are made between ASD and typical development, dyslexia or ADHD (Liss et al., 2001; Ozonoff & Jensen, 1999; Ozonoff et al., 1991). Also deficits during childhood were found to be maintained into adolescence in ASD (Ozonoff & McEvoy, 1994). Problems in WCST

perseveration in ASD have been related to repetitive behaviours, although WCST errors do not predict the severity of such symptoms at the individual level (Hill, 2004b).

It is hard, given the disparate cognitive processes recruited by the three tasks described above, to identify the neural candidates for those aspects of executive function that are impaired in autism, but the deficits indicated by the Tower of Hanoi task and the WCST identify in goal-directed behaviours have been related to failure of the frontal lobes to connect to other brain regions during maturation in children with ASD (Zilbovicius et al., 1995). Such neuro-anatomical disconnectivity during brain maturation provides the framework for a developmental model of executive dysfunction, and it is possible that restricted feed-forward signalling at an early age from the perceptual system may contribute to failure of the pre-frontal cortex to develop typically. However, compromised cross-modal perceptual integration can only be conceived of as one of myriad possible contributory components that could be implied in such a disrupted maturational process. Therefore, this thesis does not include any tests of relationships between cross-modal perceptual causality and executive cognitive function, as any hypothesis generated would have little specificity.

1.3.4 Universality is not attainable at the cognitive level

The conclusion to be drawn from the review of the three main theories of autism presented here is that, as no cognitive account describes all behavioural features of autism, none sufficiently explains autism and its associated spectrum of

conditions. Rather, they each describe aspects of cognition which may, in turn, be the consequences of autistic genotype expression across the course of brain development.

Happé, Ronald and Plomin (2006) have stated that evidence of fractionation within the diagnostic behavioural triad, and the independent relationships observed between each characteristic behaviour and contributing genetic factors, are indicative of the need to segregate lines of enquiry so that each triadic aspect is independently investigated. Furthermore, Pellicano, Maybery, Durkin and Maley (2006) have presented evidence that theory of mind, central coherence and executive function deficits appear unrelated to each other at the individual level, once age and verbal/nonverbal abilities have been controlled, adding weight to the suggestion that a 'multiple deficit account' of ASD is required.

No cognitive account includes a comprehensive development model to explain failure of its proposed deficit to emerge, instead presenting its deficit as static across time. A 'dynamic and developmental' model has been called for by researchers such as Rajendran and Mitchell (2007), one which provides a neurodevelopmental account of autism in line. This proposal chimes with the neuroconstructivist perspective of Karmiloff-Smith (2007).

Perceptual development is one factor that may be of great importance to the maturation of the brain; perceptual abnormalities across several sensory modalities have recently been reported in relation to ASD (section 1.4), and evidence exists that sensory deprivation severely affects brain development, particularly with

respect to neural region differentiation. In this thesis therefore, cognition is considered in terms of perceptual development and function. In particular, in Chapter 2 the focus is on a form of perceptual integration (cross-modal perceptual causality) that is hypothetically related to a specific cognitive function found to be superior in autism (intuitive physics). Consideration of developmental and individual effects in relationships between these two very different processes is an attempt to understand whether perceptual and cognitive development are yoked together.

Perception/cognition relationships are also examined in Chapter 3.

Extending the proposal by Jarrold et al. (2005) that EFT performance in ASD is the product of superior visual processing of single features, weak central coherence is re-examined in relation to atypical perceptual integration processing in Experiment 5. Support for the 'weak perceptual coherence' hypothesis would provide impetus to the call for longitudinal examination of perceptual function on individual outcomes in autism.

1.4 The Perceptual Phenotype of ASD

To suggest that perceptual processing is of fundamental importance to the emergence of the autistic mind inherently reframes the cognitive phenotype of autism as an outcome of development, rather than the cause of the condition. That is not to say that behaviour and cognitive abilities are independent of each other in ASD, but rather that the limits of cognitive processing are developmentally determined by perceptual functioning and attentional training from an early age.

Research interest directed at sensory behaviours and perceptual processing is beginning to converge; the consensus is that sensory sensitivities are generally abnormal for individuals with ASD, that these are associated with atypical perceptual processes, and that both may be linked to the general autistic phenotype and symptom severity at the individual level.

1.4.1 Sensory and Multisensory Processing in ASD

Sensory Imbalance

A recent review of biographical, anecdotal and empirical literature on sensory behaviours (Iarocci & McDonald, 2006) concludes that, potentially, a unique sensory profile of autism might differentiate the condition from other developmental disorders. The authors estimate the prevalence of abnormal sensory thresholds among persons with autism to be between 30% and 100%, and draw attention to the fact that parents frequently report noticing atypical sensory behaviours at an early stage of life. Indeed, anecdotal and autobiographical evidence of the association between sensory processing and autism conditions has existed since their original identification. Kanner (1943) found that many of his cohort showed hypersensitivity to sound, although they were unresponsive to social approaches made by their parents.

Sensory behaviours are not included in DSM-IV-R diagnostic criteria and are only described as associated symptoms within ICD-10 (Bogdashina, 2003). This exclusion of sensory responsiveness and behaviours from diagnosis means that they

have been largely disregarded in past empirical ASD research, although these factors remain an important part of diagnostic assessment tools (Tadevosyan-Leyfer et al., 2003). Occupational therapists have stated for some time that many children with autism display 'sensory dysfunction' and/or have sensory integration issues. Also, many individuals with high-functioning autism or AS have described their sensory experiences (e.g., Grandin, 1992; Williams, 1994) although such accounts cannot be generalised across all individuals with ASD.

Research analysing questionnaire responses has indicated high prevalence of unusual sensory responsivity in early life in association with autism (Dahlgren & Gillberg, 1989; Gillberg et al., 1990). Early empirical investigation attempted to produce a definitive autistic sensory profile, but encountered difficulties as considerable heterogeneity in hypo- and hyper-sensitivities have been between individuals (e.g., Ornitz, 1989). Sensory dysfunction in general was found to relate to symptom sensitivity, however (Dawson, 1983). For a review of these studies, see O'Neill and Jones (1997).

In a more recent study by Kern et al. (2007), data from 103 individuals with ASD aged between 3 and 56 years old was collected using the Sensory Profile (Dunn, 1999). Across 125 items provided by the scale, high threshold items measured obliviousness to stimuli and low items measured sensitivity to stimuli. High and low sensory threshold scores were obtained by parental or teacher report of typical response to frequent environmental stimuli.

The conclusion that Kern et al. (2007) reached was that a general sensory impairment was present in most individuals with autism. More specifically, high (obliviousness) threshold scores for audition and vision were significantly related to symptom severity, but in opposing ways. It was found that, at the individual level, the greater obliviousness to auditory stimuli, the more severe the behavioural symptomatology in the target group. Conversely, symptoms worsened as visual *over-responsivity* increased. A reason for this dissociation between the two modalities was not given, although the authors provide a caveat that a distinction between observing social versus object stimuli is not made in the symptom assessment tool used, and so the positive correlation between visual function and symptoms obtained may be misleading.

Reported in the same study was the finding that age is important in terms of the relationship between sensory dysfunction and symptom severity. Dividing the sample into 3-12 years, 13-25 years, and >25 years revealed an age-dependent pattern; analysis produced a significant correlation between general sensory dysfunction and symptom severity in the youngest group only, whereas no such statistical relationship was found for the older groups. Hence the relationship between general sensory dysfunction and symptoms was apparent only before puberty. This discrepancy between groups may reflect either neurological maturation or adaptive processes, or an interaction between the two. The youngest group showed overall the lowest mean scores in symptom severity, yet this same group had the greater sensory abnormalities, an observation that adds weight to the idea that early sensory difficulties may have a long-term effect on behaviour. This thesis proposes that this connection is mediated via perceptual processes such as

cross-modal integration, and seeks to find evidence that perceptual integration influences cognitive maturation (Chapter 2).

Multisensory Difficulties and Perceptual Incoherence

Donna Williams, an artist with autism, describes her early years as incoherent: “My senses and perception were chaotic, fragmented and constantly shifting and fluctuating” (Williams, 2008). The experiences of individuals like Donna Williams suggest that subjective incoherence in perceiving the world may be the result of sensory processing abnormalities. It remains unknown as to how sensory stimulation and maturation of perceptual systems within the brain interact, but evidence of poor integration across the sensory modalities would challenge the idea that coherence is predominantly a weakness at the cognitive level in ASD, in contradiction of WCC (Happé & Frith, 2006). Iarocci and McDonald (2006) propose that dedicated neuroscientific research based on a theoretical multisensory integration platform is warranted by both evidence of sensory dysfunction and perceptual atypicalities (section 1.4.2), and that this area should not remain of interest solely to practitioners and clinicians.

The Developmental Role of Multisensory Processing in Cognition

The availability of research examining the ongoing development of cross-modal processing beyond the first few years of life is limited. Little longitudinal research can be found examining infant perceptual integration and socio-cognitive or cognitive functioning at a later age. However, some longitudinal studies have

found relationships in individual differences between cross-modal development, impairments and cognitive outcomes. For instance, Rose, Feldman and Wallace (1992) found cross-modal transfer scores (in which discriminating between intensities of stimuli in one modality generalises to confer the same discriminatory ability in another modality) measured at one year of age were related to IQ scores at the age of six years. It would appear then that amodal information (i.e., intensity of touch and light in this study) is shared across modalities at a young age, and that the better such sharing is in infancy, the better the cognitive outcome for the child. In addition, in this study infants with poor cross-modal transfer processing were found to express learning difficulties later in life. Cross-modal signal transfer therefore appears to support general cognitive development (although it is unclear whether information sharing is a function of the perceptual system).

In addition to the contribution of cross-modal integration to the emergence of general cognitive functions, it has been found that arithmetical addition/subtraction ability in young children of five or six years can be predicted by such perceptual factors as sensori-motor (especially visuo-tactile) processing at an earlier age, irrespective of developmental effects (Fayol, Barrouillet & Marinthe, 1998). The specificity of this longitudinal relationship concords with the neuroconstructivist idea that domain differentiation is the product, in part, of partial processing of perceptual information from birth (Karmiloff-Smith, 1991; see Chapter 2 for elaboration).

Moreover, Fayol, Barrouillet and Marinthe (1998) conclude that neuropsychological signs of digital agnosia in the poorly-performing children in their study suggest that perceptuo-motor integration is important to representation of

quantity. Representational formation of abstract concepts (for example, quantity or emotion) has also been found to be facilitated by audio-visual processing in infants. Jordan, Suanda and Brandon (2008) have found that multisensory numerical information allows babies of six months to make more precise numerical discriminations than is possible when the amodal dimension of quantity is conveyed by one modality only. They conclude that “Multimodal stimuli may thus boost abstract cognitive abilities such as numerical competence” (Jordan, Suanda & Brandon, 2008). This same ‘intersensory redundancy’ effect (Bahrick, Lickliter & Flom, 2004) is found in infants below one year of age when testing sensitivity to emotional affect (Flom & Bahrick, 2007), and so cross-modal integration may have influences on representational formation across multiple domains.

Taken together, these studies suggest that cross-modal integration has a role to play in individual development, in terms of facilitating representational development. Should this be the case then its contribution to both general development and domain-specific cognitive abilities may be of importance with respect to atypical developmental conditions, such as autism spectrum disorder. This logic is applied to the main study presented in Chapter 2, in which the inter-relationships between development, individual differences, perception and cognition are explored. For this study, a domain-specific hypothesis is described that predicts experience of cross-modal perceptual causality (arguably another amodal property specified by intersensory redundancy) is related to physical causal cognition (as inferred from intuitive physics ability). Evidence of such inter-relationships then informs later studies (Chapters 3 and 4) in which cross-modal integration is investigated in relation to ASD and the broader autism phenotype (see 1.5) as a possible contributory factor to the atypical cognitive phenotype of autism.

1.4.2 Perceptual Models of Autism

Multiple theories that account for perceptual processing in ASD have been proposed, the majority of which have been developed on the basis of empirical findings from vision research. Research relating to cross-modal (particularly audio-visual) integration is limited. Investigation into unimodal perception has not, to date, generated any developmental theories of ASD that explicitly state perceptual integration as being of fundamental and causal importance to these conditions, although investigation of the theoretical developmental connection between perception and cognition in ASD has often been recommended in perception papers.

Two influential perceptual theories are reduced generalisation (Plaisted, 2001) and enhanced perceptual functioning (Mottron, Dawson, Soulières, Hubert & Burack, 2006), both of which challenge weak central coherence theory. Of particular relevance to this thesis, however, is Signal Integration Theory (Bertone & Faubert, 2006), as it can be extended to form hypotheses for cross-modal research in ASD.

Reduced Generalisation/Enhanced Discrimination

Children with autism show generalisation difficulties at a cognitive level; what they explicitly learn in one setting is not implicitly applied to the same set of contingencies in an alternative setting. There is also a superiority associated with ASD for individuals to be able to make finely-defined discriminations between similar objects in an array. Plaisted (2001) makes a connection between these two

observations by suggesting that perceptual skill in discriminations is related to poor ability to generalise outside of context. She reports findings that support such 'enhanced discrimination' processing as being related to both enhanced visual search, in which the superior performance of an ASD group is purported to originate in attention to the details which separate target from distractors, and to worse categorisation efficiency (compromised prototype acquisition) in the training phase of a prototype task (Plaisted, O'Riordan & Baron-Cohen, 1998; Plaisted, O'Riordan, Aitken & Killcross (submitted)).

Extending this line of argument to incorporate cognitive function across domains, Plaisted (2001) suggests that categorisation of all stimuli, social and non-social, or familiar or unfamiliar, is consequently affected by seeing differences instead of commonalities; hence the 'can't see the wood for the trees' tendency that originally generated ideas of weak central coherence in ASD. Whether these findings relate to bottom-up perceptual factors or attentional biases is under investigation, however I would argue that perceptual (signal) integration may be implicated in the mechanism that produces these effects (see below; this section).

Enhanced Perceptual Functioning

The enhanced perceptual functioning theory proposed by Mottron and Burack (2001) aims to account for both the social and non-social perceptual features of autism and to provide an alternative to WCC theory. It does so by recourse to eight principles (Mottron, Dawson, Soulières, Hubert & Burack, 2006), which all relate to the potentially perceptually-driven life experiences of people with ASD,

their superiorities on 'lower-level' cognitive tasks (e.g., EFT performance), and autistic emphasis on perceptual strategies to complete complex cognitive tasks. They suggest that EPF theory explains the development of difference in autism in terms of the "priority of perceptual flow of information in comparison to higher-order operations", stating that this information bias generates an atypical relationship between high and low order cognitive processes. Thus prioritisation of perceptual over cognitive processing from birth causes perception to disrupt the natural emergence of both cognitive abilities and responsive behaviours over time.

Enhanced perceptual functioning is therefore a 'true' developmental account of autism, and is firmly embedded in empirical evidence of atypical auditory and visual perceptual processing in autism. For instance, pitch acuity is often found in people with ASD (Bonnell et al., 2003), as is acuity in discriminating between high/low luminosities defining static stimuli (Bertone, Mottron, Jelenic & Faubert, 2005).

A guiding principle (and one that is more hopeful for individual prognoses than static non-developmental theories of ASD) of EPF is that individuals with ASD have *optional* access to higher-order cognitive representations which are mandatory for 'neurotypical' people. This statement is supported by the research described above (e.g., Mottron et al., 1999) of intact global form processing and intact susceptibility to visual illusions (Ropar & Mitchell, 1999) in individuals with ASD.

Access to global information is not always possible in ASD, however. There are instances in which directing attention towards integrated information is

insufficient to overcome perceptual over-processing. For example, speech-in-noise tasks are used to identify the decibel level at which participants recognise speech against background noise on 50% of the trials presented. Alcantara, Weisblatt, Moore and Bolton (2004) demonstrated that adults with HFA and AS require louder speech (higher speech reception thresholds) against each of five different background noise types than controls. In this case, then, it would appear that the global representation of speech is inaccessible, which suggests that, when environmental stimuli are complex, EPF serves to denigrate representation formation.

Signal Integration Theory

Minshew and Goldstein (1998) posited that the primary deficit causing deficits within and across domains in ASD arises from complex stimuli that generate multiple subsystem processing demands. They therefore characterised autism as a disorder in which 'basic' processing is intact but high-order sophisticated processes are disrupted (Minshew & Goldstein, 1998). Although attractive in many ways, this 'complexity hypothesis' is flawed in that it provides no explanation as to why visuospatial abilities (such as those used in featural visual search or visual disembedding) should be spared on any other basis than the processes involved are evoked by stimuli that are simple, relative to social stimuli. Furthermore, Mottron et al. (2006) review considerable evidence that formation of complex visual representations is intact in ASD.

Bertone and Faubert (2006) have suggested that visuospatial superiority in ASD reflects an unique autistic perceptual phenotype, or 'signature' perceptual profile, in which simple information is prioritised over complex information at the perceptual level, as a consequence of perceptual integration failure. Integration failure is therefore not considered to be a cognitive level difficulty, as Minshew and Goldstein (1998) suggested, but originates at an early downstream phase of environmental stimuli processing.

The 'complexity-specific' hypothesis (Bertone & Faubert, 2006) therefore predicts that perception in autism reflects 'diffuse or non-specific neural dysfunction of neuro-integrative mechanisms affecting complex perceptual processing in autism in general'. The visual system is broadly organised such that primary neurons in specialised regions are responsive to single feature stimulation, and integration of separate signals is provided by secondary sites elsewhere within the visual cortex, such as the extrastriate region (Hadjikhani et al., 2004). By contrasting responses to first and second order sinusoidal gratings (see Figure 1.3), in which the visual 'noise' variable between stimuli recruits either visual area V1 alone or V1 plus V2/V3, Bertone and Faubert (2006) demonstrated that autism is *specifically* associated with enhanced processing of simple visual stimuli coupled with widespread reduction in sensitivity to complex visual stimuli.

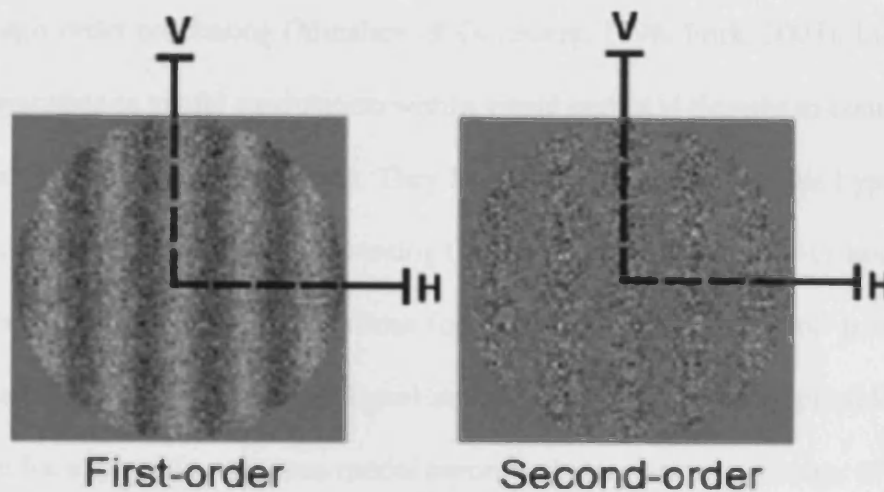


Figure 1.3: First- and second-order static sinusoidal grating stimuli (taken from Bertone, Mottron, Jelenic & Faubert, 2005).

The mechanism provided by Bertone and Faubert (2006) for their findings is one of atypical neural connectivity between visual areas. Neuronal organisation within primary cortex is columnar, such that neurons exhibit selective response patterns to aspects of visual stimuli; activation within one column suppresses activity in adjacent columns to heighten featural sensitivity. In autism, Bertone and Faubert (2006) suggest that reduced connectivity between visual cortex areas results in reduced modulatory feedback from secondary areas on V1 activity, producing excessive 'lateral inhibition'. Disconnectivity has been found between distal brain regions in association with autism (Castelli et al., 2002); Bertone and Faubert (2006) have provided evidence of its potential role in autistic perception in relation to visual cortex activity.

Consequently Bertone and Faubert (2006) have proposed a condition-specific aetiology for autism that relates to a 'signature' perceptual profile that does not position visuospatial superiority simply as a byproduct of poor integration

within high-order processing (Minshew & Goldstein, 1998; Frith, 2003). Instead, poor integration in signal modulation within visual cortex is thought to contribute to complexity difficulties in cognition. They have not as yet extended this hypothesis to consider abnormal auditory processing (pitch acuity versus speech-in-noise threshold elevation), or the implications for multisensory processing of poorly integrated unimodal information. Signal integration theory therefore provides both a rationale for exploration of cross-modal perceptual integration in autism, and a potential neurophysiological mechanism for any results produced by such research. Signal integration will be discussed again in Chapter 4, in relation to cross-modal perceptual integration in autism.

1.4.3 Perceptual Integration in ASD

The current volume of published research into integrative systems in relation to autism is small, but growing. Reports have, however, produced conflicting interpretations to date. This may possibly be because some tasks used involve complex cognitive stimuli such as vocal/facial speech or emotion, and others present simple, tone/object perceptual stimuli. Of note in the former category is a study by Hall, Szechtman and Nahmias (2003), which demonstrated that, irrespective of congruency/incongruency between facial expression and speech prosody, adults with autism exhibit difficulty in processing cross-modal emotional stimuli.

Using an fMRI technique, Hall et al. (2003) found that such stimuli evoked more recognition errors in the target group on trials in which emotions

communicated by the face/voice pairs were congruent, and diminished activity in the right fusiform region coupled with exaggerated activity in the anterior cingulate region whether the emotion signalled by the face/voice pairing corresponded or not. Recruitment of the anterior cingulate region is associated with selective attention to sensory features of the environment. In particular, it supports direction of attention to one modality or another under competing audio- visual conditions. Thus emotional cross-modal stimuli appear to be processed effortfully in the ASD group, producing competing rather than complementary signal patterns. The facilitatory effect normally produced by the intersensory redundancy inherent in such stimuli failed to support emotion recognition in ASD in this study.

Conversely, the Shams (or fission) illusion appears to be intact with respect to ASD. This phenomenon describes the influence of a series of beeps on the perception of a series of flashes presented in the visual periphery (Shams, Kamitani, Thompson & Shimojo, 2002). In typical subjects, when more beeps than flashes are presented they evoke additional illusory flickers. In the autism study based on this illusion (Van der Smagt, van Engeland & Kemner, 2007) fifteen adult participants meeting DSM-IV criteria for autism, and fifteen controls matched for age and IQ reported comparable numbers of illusory flashes in relation to the number of beeps presented. Van der Smagt et al. (2007) concluded that any multisensory integration difficulties discovered in association with Autism Spectrum Disorder must therefore originate in processing stages beyond low-level perception in high-functioning adults with autism.

The phenomenon utilised in the research in this thesis (cross-modal perceptual causality) is thought to be predominantly driven by perceptual integration activity, a choice that was made specifically to investigate this aspect of perception through minimising recruitment of multiple cognitive systems. A more comprehensive description of the neural mechanism underpinning this multisensory effect is provided in Chapter 4, alongside further description of empirical multisensory research in ASD.

1.5 The Behavioural Genetics of ASD and the Broader Autism Phenotype

1.5.1 Heritability and Familiality

Kanner (1943) reported that, through studying 200 children who evidenced autistic disorder to a greater or lesser degree, “we also got to know their parents and other relatives of theirs and found abnormal traits in their relatives”. This observation presaged the description of the Broader Autistic Phenotype (BAP), or the clustering of autistic-like traits in an individual to the extent that their behaviour can be described as existing somewhere on a continuum with ASD.

The heritability of ASD is well established through epidemiologic twin studies. Several studies have reported significantly different concordance rates for autism between monozygotic (MZ) and dizygotic (DZ) twins, indicating that shared genes are more important in the expression of the disorder than shared environment on the basis that monozygotic twins share 100% of DNA, whereas dizygotic twins have 50% of their genotype in common. The concordance rate between MZ twins

for ASD is high; the likelihood of the twin of a diagnosed proband also reaching diagnostic threshold for autism has been rated between 60 to 90%. For DZ twins, the concordance rate is estimated to be as low as 0 to 10%. Contemporary approaches to behavioural genetics (ref) now also account for the impact of shared versus non-shared environments, allowing for the life experiences of MZ twins to be more similar than those of DZ twins, however

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When a broader phenotypic criteria is applied, this genetic relationship becomes more apparent; Bailey et al. (1995) used a ‘softened’ phenotypic description to determine whether the MZ twins of probands also experienced unusual disruption of social functioning, and found a concordance rate of 90%. Furthermore, the recurrence risk of autism among the younger siblings of probands has been found to range between 2% and 6%. Although this does not appear high, when compared to current population incident rates of <0.5%, it indicates that siblings of children with autism are at a much higher risk of ASD than children in general.

Further examination of proband families suggests that the Broader Phenotype, in which relatives do not reach threshold of impairment for clinical diagnosis of ASD but are hampered in aspects of their social interaction, is a robust concept that argues for the redescription of ASD as being in continuum with the general population (Bailey & Parr, 2003; Baron-Cohen, 2008b; Dawson et al., 2007; Piven & Palmer, 1997).

1.5.2 The Broader Phenotype as an Analogue Model: The Autism Quotient.

The broader autism phenotype (BAP) construct concords with the understanding that heritability of ASDs is polygenetic. Therefore it should represent a proportion of the 'normal' population who have inherited several autism genes without achieving the threshold required for expression of diagnosable ASD; these individuals should manifest many of the traits associated with behaviours characteristic of autism spectrum conditions.

Identification of people with relatively high trait expression provides an opportunity to expand empirical ASD research; the BAP therefore represents an 'analogue' model of autism (Wakabayashi, Baron-Cohen, & Wheelwright, 2006), in which quantitative comparison of individuals expressing the BAP with controls can inform clinical studies.

One tool that identifies individuals with a trait profile comparable to the BAP is the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001a), which is a 50-item, 5 subscale self-report questionnaire. Studies validating use of the Autism Spectrum Quotient to measure autistic-like trait expression show that people with Asperger syndrome and high-functioning autism report significantly higher scores than adult controls, and that the total number of traits itemised in the AQ is normally distributed in the general population (Baron-Cohen et al., 2001a). Both the Japanese and UK distribution of total AQ scores have been found to resemble normality (Wakabayashi, Baron-Cohen, Wheelwright & Tojo, 2006). Hence, the AQ appears not to assess cultural behaviours, but instead

provides a measure of the degree to which normal adults express autistic traits at the individual level.

The AQ has good internal reliability in terms of the full-scale score and the social skills subscale (Austin, 2005), although four sub-scales (attention to detail, attention switching, social communication and imagination) fell short of the standard criterion value of 0.7. However, factor analysis of the 50 items in the questionnaire produced three significant factors (Austin, 2005). These factors accounted for 28% of the total variance in AQ scores obtained from 304 non-diagnosed adults, and were highly correlated with scores for the social skills, communication and attention-to-detail subscales. These analyses indicated that further development of the scale is required to ensure equivalence across subscales, but suggest that the AQ is sufficiently reliable to assess the presence of the broader autism phenotype at the individual level from total scores.

Wakabayshi, Baron-Cohen and Wheelwright (2006) have investigated the relationship between AQ scores and expression of the 'Big Five' personality factors (measured by the NEO-PR-I; Costa & McCrae, 1992), arguing that independence of variance in total AQ scores from these factors supports the idea that 'autistic-ness' is a personality dimension in its own right, and therefore ASD diagnosis equates to one extreme tail of the variance distribution for this dimension. A joint factor analysis was undertaken in which the eigen values of the five subscales of the AQ and six facets of each of the five personality factors were calculated in relation to six factors. This analysis showed that AQ subscales load onto one independent factor, suggesting that AQ scores are independent of established major personality

dimensions. It also showed, however, that two of the AQ subscales did not load onto the independent AQ total factor; these were attention-to-detail and imagination.

Similarly, Bishop, Maybery, Maley, Wong, Hill and Hallmayer (2004) found that these two subscales and attention-switching did not significantly differentiate between parents of probands with ASD and parents of control children. She concluded that, as social skills and communication scores both inter-correlated and independently discriminated between control and proband parents, that the 'true' broader autism phenotype was obtainable from the AQ as long as its criteria was restricted to these two subscales. Yet it is possible that individuals with conditions such as depression, or with schizotypal personalities, would also score highly on these two subscales. As evidence exists for a unique autism dimension that accords with presence of several traits across each of the five subscales of the AQ (Wakabayashi et al., 2006), and as fathers of autistic children self-report detail-focussed interests and abilities that correlate highly with their asocial tendencies (Briskman, Happé & Frith, 2001), it is argued that the BAP should not be reduced simply to describing asociality.

Given the paucity of cross-modal integration research and the relative rarity of individuals with ASD in child populations, two studies provided in this thesis (Experiments 4 and 5 in Chapter 3) therefore used the AQ to identify individuals with high autistic trait expression in order to utilise the BAP as an analogue model of ASD, prior to examining cross-modal integration in a clinical population (Experiment 6, Chapter 4).

1.6 The Influence of Gender: The Extreme Male Brain Theory of Autism

1.6.1 Comparative Neurobiology, Cognitive Phenotypes and Gender

Gender differences have been established with respect to many disparate areas of human functioning. The neurological explanation for such differences is that the male brain shows a greater degree of morphological asymmetry than the female brain, with a greater white matter to corpus callosum volume ratio (Allen, Damasio, Gabowski, Bruss & Zhang, 2003). This exaggerated male asymmetry reflects a more strongly lateralised organisation of the neural architectures supporting specific cognitive (and possibly perceptual) systems, with less inter-connectivity between hemispheres and distal regions (Baron-Cohen, Knickermeier & Belmonte, 2005). The psychological consequences of asymmetrical lateralisation differences are that the male cognitive phenotype shows a tendency for domain-specific focus. The reduced lateralisation in the female brain, however, generally produces a different cognitive profile, including an ability to distribute attention across domains.

The cognitive differences found between genders have been psychometrically defined by Baron-Cohen in terms of two general dimensions: Systemising and Empathising (Baron-Cohen, 2002). Systemising refers to a general preference for deconstructing complex stimulus/event material according to its perceived regularities to determine the rule set that defines its underlying system (and, conversely, to construct such systems in a drive to create organisation). Empathising is defined as the ability to understand and associate with others on the

basis of their emotional and social mental states, an ability that incorporates both 'theory of mind' and affective comprehension. Both general dimensions reflect how an individual makes sense of their environment. However, empathising is considered to be the overarching dimension that supports social interaction, whereas systemising relates to all non-social domains (mathematics, mechanics and business analysis, for example).

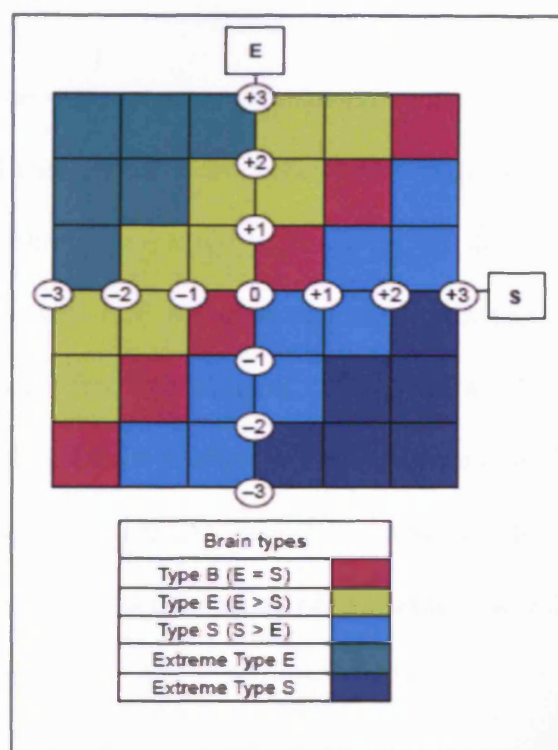


Figure 1.4: Systemising versus Empathising dimensional distribution (taken from Baron-Cohen, 2002).

Defining 'types' on the basis of the balance between empathising and systemising, it is possible to construct a model to account for cognitive processing preferences between genders (Figure 1.4). As this figure shows, all individuals can be defined as being one of five types. People whose cognitive styles suggest that they process stimuli more on the basis of empathising than systemising are denoted

$E>S$, and are said to have a 'female brain', whereas the reverse construct ($S<E$) represents people with a preference for systemising, who could be said to have a 'male brain'. Baron-Cohen is careful to state that the model does not support prediction of brain type according to an individual's gender, as not all women will be found to have a bias towards the empathising dimension, nor will all men rely more on cognitive processes relating to the systemising dimension. Some individuals are balanced between the two styles ($E = S$).

People who rely on one system *at the expense of* the other should show quantifiable behavioural and cognitive differences. The extreme empathisers ($E \gg S$) may be 'system-blind'; unable to process sufficient detail to determine rules in any regularly organised structure, but good at generally extracting relevant emotional and social content from situations that produce considerable 'signal noise', such as work, school, family or other social environments. The extreme systemisers ($S \gg E$) should therefore demonstrate the reverse relationship (i.e., a focus on regularity between details to produce rules) to the extent that systemising is detrimental to empathising.

In his 'Extreme Male Brain' theory, Baron-Cohen (2002) proposes that individuals with ASD express this extreme systemising phenotype. The 'extreme male brain' (EMB) type is therefore a cognitive characterisation of ASD underpinned by neurobiological differences between men and women. It is a theory of ASD that accommodates the cognitive phenotypes described by both the 'theory of mind' and weak central coherence theories. The difficulties with effective processing of social and affective stimuli for a person with a high drive for

systemising but low empathising may be because these types of information fail to reduce to robust rules; such a person might then exhibit 'mindblindness' (Baron-Cohen, 1995). The attention to detail at the expense of the global picture described by the weak central coherence theory of ASD marries cleanly with the drive to recognise order. Yet the construction/deconstruction aspect of systemising accommodates the finding that global order can be recognised when attention is explicitly directed towards it in ASD (unlike WCC theory, which originally predicted global meaning to be compromised in ASD).

1.6.2 An 'Extreme Male Brain' Perceptual Phenotype in ASD?

Evidence that, at a population level, the systemising/empathising model accurately reflects the distribution of these two dimensions is provided through reframing existing cognitive/behavioural research on gender differences in terms of either dimension. For instance, women are generally superior to men in terms of emotional recognition (Thayer & Johnsen, 2000). Male infants, conversely, demonstrate a preference for gazing at mechanical mobiles rather than faces from the day of their birth (Connellan, Baron-Cohen, Wheelwright, Batki & Ahluwalia, 2000) which may indicate that a bias towards systemising is innate in males and responsible for the over-representation of men in science vocations (for a review, see Halpern et al., 2007).

Many perceptually-driven tasks exhibit sex differences, including the Embedded Figures Task (Witkin, 1950), and many cognitive tasks are resolved using different strategies which have a more perceptual bias in men than in women

(e.g., men use visuospatial working memory on navigation tasks, whereas women use verbally-mediated landmark strategies; Voyer, Voyer & Bryden, 1995; Soucier et al., 2002). If, therefore, autism reflects the operation of an extreme male brain, then women with several autistic traits should behave like exaggerated men, and vice versa, when tested on perceptually-driven tasks known to exhibit gender differences.

Furthermore, if perceptual cross-modal integration is important for female-style cognitive processing (language and emotion), cross-modal function should evidently be stronger for women. It should also be relatively weaker in men and participants with the broader phenotype. If, however, it is of equal developmental relevance to both genders, the information produced by perceptual integration may support different cognitive functions known to exhibit sex differences, such as psychological versus physical causal reasoning.

The main study in Chapter 2 (Experiment 3) looks for evidence of sex differences either at the perceptual integration level, or in relation to perceptual/cognitive inter-relationships in typically developing (TD) children, using cross-modal perceptual causality and intuitive physics tasks. Gender differences and the perceptual male/female phenotypes are also examined in Chapter 3, in which the performance of individuals with and without several autistic traits (as measured by the AQ) is also contrasted; Experiment 3 relates EMB theory and the BAP to cross-modal perceptual causality and intuitive physics, and in Experiment 4 the same approach is applied to a study using the Embedded Figures Task.

1.7 Summary

It has been argued that no single cognitive account has yet been found to account for the multiplicity of behaviours linked to autism, and the range of abilities found between individuals diagnosed with ASD. Many atypicalities in vision and audition have been established in association with autism, some of which appear to be specific to an autistic perceptual ‘signature’. They may also be associated with task performance superiorities in ASD (e.g., on visuospatial tasks such as the EFT). Perception research has, further, challenged cognitive theories such as weak central coherence and mindblindness, leading to the proposal that the developmental phenotype of autism is perceptually-dependent (e.g., Enhanced Perceptual Functioning theory; Mottron et al., 2006).

However, little research has yet to be reported that considers whether integration of sight and sound information is of fundamental importance to cognitive development in autism spectrum conditions. This is surprising as the perceptual feature density of stimuli such as emotion and speech implicate weakened cross-modal (audio-visual) integration as being a possible root of cognitive difficulties in the social domain. The hypothesised mechanism for this proposed Weak Perceptual Coherence autistic phenotype is enhanced salience of single feature processing, due to reduced feedback modulation/enhanced lateral inhibition within primary sensory cortices (by extension of Signal Integration Theory; Bertone & Faubert, 2006). The resulting reduced salience of integrative cross-modal signalling over single-mode perceptual processing would mean failure

of intersensory redundancy mechanisms to facilitate complex representational processing.

Multisensory processing weakness provides an explanation for the ‘developmental’ aspect of autism, as disruption to domain-specific relationships between perceptual function and cognitive development would produce the spiky cross-domain heterogeneity often found in individuals with ASD. Both EPF theory (Mottron et al., 2006) and neuroconstructivist accounts of development (Karmiloff-Smith, 2007) support this interpretation.

Furthermore, reconceptualisation of autism both as a condition that exists in continuum with ‘normal’ phenotypes along an independent ‘autistic’ dimension, and as the product of ‘extreme male brain’ function together suggests that a) any cross-modal integration system thought to develop atypically in ASD should be demonstrable in individuals with several autistic traits, and b) any sex differences on classic tasks associated with superior performance in ASD should not differentiate between men and women who express the broader autism phenotype.

This thesis therefore presents a series of studies relating to cross-modal development and functioning, in relation to cognitive superiorities found in ASD. In Chapter 2, a hypothesised domain-specific relationship between cross-modal perceptual causality and intuitive physics is investigated in typically developing children, and sex differences in physics ability are also examined. Chapter 3 focuses on the broader phenotype, and investigates cross-modal perceptual causality and its relationships with intuitive physics and visual disembedding, in order to consider

whether deficiencies in perceptual integration exist, and whether any differences found might provide support for EMB theory. The final studies in Chapter 4 investigate cross-modal perceptual causality in ASD, and across autism and AS.

As Iarocci and McDonald (2006) conclude “The next step in the quest for a comprehensive theory of perception in autism is to address the consequences of enhanced feature detection or discrimination, weak central coherence or temporal binding, and atypical neural modulation or connectivity on perception in the context of the multisensory world”.

Chapter 2: Perceptual Development and Cognitive Outcomes

2.1 Overview

O’Riordan and Passetti (2006) stated that “Although there are numerous reports of unusual perceptual processing in autism, the mechanisms underlying such phenomena and the possible relationship between these and the characteristic social and communicative deficits remain poorly understood”. By suggesting that atypical perception may be related to atypical behaviours and cognitive functioning in ASD, O’Riordan and Passetti presuppose that aspects of perceptual processing impact on the development of specific higher-level cognitive systems. If this assumption is valid, then evidence of universal relationships between perception and cognition should be available from typical developmental studies. However, the impact, generally or specifically, of perceptual development on cognitive development is a matter of considerable debate.

This chapter introduces two novel tasks designed to explore whether a specific perceptual function is related to a defined cognitive ability. One task is designed to test children’s development of cross-modal perceptual causality, and the second to assess their physical causal cognition (i.e., intuitive physics). As evidence of a relationship could also be interpreted as reflecting a universal, rather than specific, aspect of development, the cognitive task is one in which males should demonstrate superiority over females; a difference between gender subgroups in terms of the relationship between perceptual causality and intuitive physics would

argue against it being the consequence of general brain maturation, as if this were the case no sex differences should be discernible.

In this chapter, the literature regarding general theories of perception/cognition relationships is overviewed, prior to consideration of the impact of experiencing causality on development of intuitive physics, and presentation of an argument regarding the likely influence of gender. The design constraints of the two new tasks involved are provided in advance of reporting three studies. Experiments 1 and 2 verify that the novel tasks effectively measure the abilities under investigation. Experiment 3 addresses the relationship between them (and its hypothesised modulation by gender) using data obtained from typically-developing children across a wide age range.

The motivation for developing these tasks and exploring the theoretical inter-dependence of these particular processes is to provide a basis for investigation of the same abilities and relationships in autism spectrum disorders (Chapter 4). Finding a difference between sexes in the hypothesised perception/cognition relationship during development (Experiment 3) would support the hypothesis that the emergence of domain-specific abilities is reliant, at least in part, on perceptual development.

2.2 Introduction

2.2.1 *Developmental relationships between cognition and perception*

Most researchers accede that cognition is hierarchically organised to a greater or lesser extent (Demetriou & Raftopoulos, 2004). Models draw on ideas of either Fodorian modules (Fodor, 1983) or cognitive domains (Wellman & Gelman, 1992), to distinguish between specialist cognitive systems that have evolved independently of general cognitive systems and over-arching processes, such as executive function or working memory (Hirschfeld & Gelman, 1994). In developmental terms, the relationship between perceptual organisation and the emergence and operation of such modules or domains is not clearly specified. For instance, at one extreme, modular models state that the environment provides 'triggers' that identify and set module parameters, the prototypic example being the development of grammar through exposure to local language in human speech (Pinker, 1994). Such a nativist stance is based upon the *a priori* assumption that the specific modular representational knowledge which guides thought and behaviour is held independently, is genetically specified and is impervious to modulation by perceptual processing.

The alternative view is that all representational knowledge is acquired through sensory interaction with the environment, irrespective of knowledge type. The classic model for such a general learning theory was provided by Piaget (1964), whose central thesis assumed that the earliest stages of cognitive development are only obtainable through sensorimotor interaction with the world. This initial stage

of exploration (from 0 to 2 years of age) facilitates the gradual formation of representations based on perceptual experience; hence 'concrete' representations are the basis of cognition from 6 to 10 years, and act to constrain conceptual thinking (about number or volume, for instance). Perceptually-dependent thought is gradually replaced by perceptually-independent abstract representations, allowing more sophisticated theoretical cognitive capabilities from age 12 onwards. Piaget therefore links children's attainment of conceptual thought to their perceptual processing (Spelke, 1991, page 133).

The original assertion by Piaget (1964) that cognition is developmentally achieved via perception has been challenged by evidence that infants are sensitive to some highly specific conceptual properties of environmental stimuli, such as causality (Scheier, Lewkowicz & Shimojo, 2003), or quantity (Xu, Spelke & Goddard, 2005), indicating that humans are capable of abstract representational manipulation at a very young age.

Evidence of domain-specific cognition in infants has been interpreted to mean that innate cognitive representational knowledge exists which serves to parse perceptual information, allowing differentiated cognitive processes to operate on different aspects of environmental stimulation from birth. For instance, the 'core knowledge' model describes innate principles that rule each domain and serve to "individuate the entities in its domain and to support inferences about the entities' behaviour" (Spelke & Kinzler, 2007, page 89). According to this model, cognitive expertise increases as knowledge is captured; development in a specific ability

therefore reflects the enrichment of the core principles governing that domain from birth.

Karmiloff-Smith (1991) considers nativist approaches such as the core principle model (Spelke & Kinzler, 2007) to lack clarity regarding developmental process. She argues that building upon original knowledge demands learning from the environment, and so proposes that development is governed by innately determined biological constraints which serve to parse stimuli into classes of inputs according to specific cognitive function. She states that “The human infant is biologically set to process constrained classes of inputs that are numerically relevant, linguistically relevant, relevant to the physical properties of objects, of cause-effect relations, and so forth” (Karmiloff-Smith, 1991, page 172).

Hence Karmiloff-Smith (1991) considers perceptual system organisation and its maturation to be crucial for development of cognition. She also proposes that cognition is initially undifferentiated, but specialises over time to produce dissociable domains as a consequence of processing environmental information that is sub-divided on this domain-by-domain basis. In terms of knowledge, Karmiloff-Smith (1991) stated representational reorganisation is brought about by progressively-defined separable sets of perceptual information. Neurobiological constraints on maturation are therefore put forward as the developmental mechanism here; genetically-specified neurological maturation patterns generate increasingly sophisticated architectures that each support a specific domain’s function. Karmiloff-Smith therefore espouses a Piagetian constructivist argument for the emergence of cognitive abilities, in that sensori-motor interaction with the

environment is essential for both neural paths and representational processing to develop, but she does not ascribe to the idea of a general learning mechanism.

Neuroconstructivist theory is relevant to the study of developmental disorders such as ASD. Karmiloff-Smith (2007) posits that the high interconnectivity between neural regions in very young brains mean that small variations in perceptual development may have widespread disparate consequences for cognitive differentiation. Development itself therefore is thought to have a crucial role in shaping phenotypical outcomes, in both typical children and those with developmental conditions.

With the neuroconstructivist approach, individual differences in perceptual functioning supporting the development of a given domain should be related to individual differences in that cognitive ability, because the two are interdependent. Individuals with a heightened perceptual processing efficiency should therefore demonstrate elevation of a related cognitive ability. This point is important, in that such an individual differences effect might, in part, explain why some children display aptitudes for specific cognitive skills, such as physics, from an early age. Further, differences between the genders in particular perception/cognition relationships might partly account for differing patterns of behaviours and skills in males and females (see 2.2.5), with exaggeration of such gender-based biases within an individual related to a cognitive profile of deficiencies and superiorities. Extreme Male Brain theory (Baron-Cohen, 1999; 2002) posits that an exaggeration of this nature may explain an association apparent between families of ASD probands and

scientific vocations (see also Baron-Cohen, Bolton, Wheelwright, Short, Mead, Smith & Scahill, 1998).

2.2.2 Perceptual causality and the development of intuitive physics

To investigate perceptual and cognitive developmental interdependence, it is necessary to consider a single cognitive domain. Causal cognition is the production of multidimensional representations capturing causal relationships that we derive from our environment. Some theorists consider causal analysis to be domain-specific (Leslie, 1984), so that the cognitive process for explaining causal relationships between people and their actions involves psychological constructs of intention and motivation, whereas analysis of an umbrella being blown out of a hand involves the action of forces on physical objects.

The development of causal reasoning about physical objects has been linked to perceptual causality by Michotte (1963). Perceptual causality is the process by which spatio-temporal correspondences between sources of sensory information give rise to percepts of physical relationships. Michotte (1963) observed that particular spatial and temporal contingencies in physical events consistently produce the phenomenon of causality, such that one object is perceived to act on another in order to evoke change in its behaviour or state. In particular, he described 'launching' events in which one object seen to approach a second is perceived to cause it to move (launch) only if the objects touch and the second moves off immediately on contact.

The spatio-temporal constraints on visual properties required for perceptual causality to be generated led Michotte (1963) to the idea that a perceptual analyser mechanism existed to transform these 'privileged' visual inputs into a 'genuine causal impression'. That this mechanism operates at the perceptual rather than the cognitive level is indicated by the fact that explicit representational knowledge does not detract from subject experience. For example, when the visual stimuli provided are lights playing across a wall, not solid objects or images of objects, a launch percept can be induced by recreating the necessary spatio-temporal contingencies, despite the known impossibility of a physical collision occurring between the stimuli (Michotte, 1963).

Michotte (1963, as cited by Spelke, 1991, page 136) made the strong claim that the origin of *all* causal representations lay in the formation of causal impressions via operation of this innate perceptual system; object-based causal cognition is produced from early perceptual causality experience, and this then facilitates generalised thinking about abstract causal relations outside of the physical realm. In a sense this idea mirrors Piaget's sensori-motor stage, but posits a specific perceptual learning mechanism exists that is restricted to causal cognition, in line with the neuroconstructivist perspective (Karmiloff-Smith, 1991).

Perceptual causality and causal representations have been tested in infants using looking-time habituation methodologies. Responses to launch events show that adult-like spatio-temporal sensitivities to visual object properties do exist in infants (Leslie, 1984; for a review, see Cohen, Amsel, Redford & Cassola, 1998). The habituation methodology adopted in these studies is simple. By repeatedly

watching stationary object B start to move upon being contacted by moving object A, babies are habituated to launching. They are then shown either more launch events, or events in which expectations of 'contact produces motion' are violated by the introduction of either a temporal or spatial gap between object A's motion desisting and object B's motion commencing. These violation events retain the same information in terms of motion trajectory/durations and sequence, but do not give rise to the percept of causality in adults. Infants as young as 4 months have been found to pay increased attention (as measured by gaze durations) to both spatial and temporal violations of cause and effect, and so it has been concluded that the perceptual causality mechanisms operating in adults also function in infants (Leslie, 1984; Cohen, Amsel, Redford & Casasola, 1998).

As Michotte (1963) predicted, the representations generated by perceptual causality stimuli in infants are more complex than simple associative learning of correspondences between sight and sound events. Babies' causal representations also include concepts of agent and recipient, such that the agent *causes* the recipient to move. Leslie and Keeble (1987) demonstrated that reversing causal launch events so that B causes A to move after contact is surprising to babies habituated to A launches B events, but those who have been habituated to non-causal events in which A stops and then B moves after a temporal gap do not exhibit dishabituation when this event sequence is reversed. Reversing the sequence of causal events appears to reverse the agent/recipient assignments for the first group of infants, which is why they show recovery from habituation. Leslie and Keeble (1987) concluded that this research supported the idea of an innate perceptual causality

analyser, redefining it in Fodorian module terms (see also Kovotsky & Baillargeon, 1998).

It could be argued that such cognitive knowledge is accessible too soon in life for it to be the consequence of perceptual experience (Spelke, Breinlinger, Macomber & Jacobson, 1992). Therefore, the suggestion that causal cognition is developmentally dependent on perceptual causality (Michotte, 1963) appears overly strict. It can be argued though that the perception of causality derived from object interaction is a potential source of information that allows causal knowledge of the world to be enriched over time from birth. If so, consideration of perceptual causality and physical causal cognition during development should provide evidence of a perception/cognitive relationship, in support of the perception-dependent neuroconstructivist view (Karmiloff-Smith, 1991). If physical causal cognition depends on perceptual causality processing, then a positive correlation should be demonstrable between the two. Furthermore, individuals with enhanced perceptual causality processing should demonstrate enhanced physics knowledge above and beyond any developmental effects that may simply represent general brain maturation. Experiment 3 therefore presents a multiple regression analysis that investigates the relationship between the perceptual causality task and the intuitive physics tasks at the individual level, after controlling for age.

2.2.3 Cross-modal Perceptual Causality

Much of the research into perceptual causality has been undertaken using ambiguous stimuli, in which the similarity of stimulus components is sufficient to impair generation of causal percepts. For an example, when an object moves along

a horizontal plane towards an identical stationary object, occludes it and continues without pausing or varying speed (Figure 2.1), only 15% to 20% of events are perceived as collisions by observers (Scholl & Nakayama, 2002).

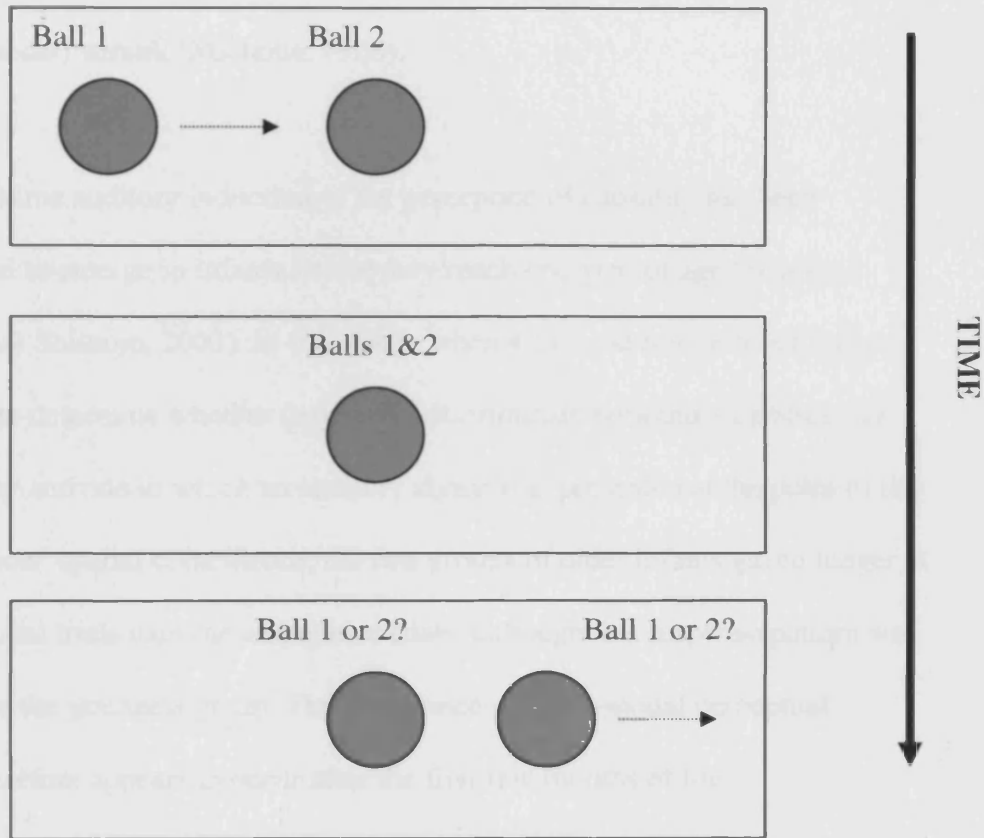


Figure 2.1: Schematic representation of an ambiguous launch/pass event

However, manipulation of dimensions such as spatial and temporal relationships between stimuli elements, or the presence or absence of contextual cues (Scholl & Nakayama, 2002; Guski & Troje, 2003), causes the frequency of causal percepts reported in response to ambiguous stimuli to vary. For example, Sekuler, Sekuler and Lau (1997) reported that an auditory signal can reorganise visual perception of an ambiguous perceptual causality event to generate a causal percept, i.e. the sound can make two balls that seem to pass through each other

(‘pass’) appear to collide and reverse (‘launch’). By varying the timing of auditory signal presentation in relation to the point at which two converging disks occlude, this study therefore demonstrated that cross-modal reorganisation occurs under spatio-temporal constraints that parallel those originally determined for purely visual (unimodal) stimuli (Michotte, 1963).

The same auditory induction of the perception of causality has been demonstrated to emerge in infants before they reach one year of age (Scheier, Lewkowicz & Shimojo, 2003). In this study, when 4-, 6- and 8-month old babies were tested to determine whether they could discriminate between an ambiguous visual display and one in which an auditory signal was presented at the point of the moving objects’ spatial coincidence, the two groups of older infants gazed longer at the cross-modal trials than the ambiguous trials, although this response pattern was not found for the youngest group. The emergence of cross-modal perceptual causality therefore appears to occur after the first few months of life.

By using cross-modal perceptual causality stimuli to test a wide age range of typically developing children, it should be possible to determine if this particular cross-modal effect increases in strength from mid-childhood into adolescence. Further, if perceptual integration facilitates physical causal cognition (as tested by assessing intuitive physics ability), strength of cross-modal perceptual causality effects should be related at the individual level to physics reasoning during this period. Evidence of a specific perception/cognition relationship is important to this thesis because such a finding would suggest that extant findings of autistic superiority in physics ability (see Baron-Cohen et al., 1998) may be related to

heightened cross-modal integration, which counters the current thinking that *disrupted* multisensory processing may be of fundamental importance in this developmental condition (Iarocci & McDonald, 2006). This possible contradiction will be returned to in Chapters 3 and 4, in which cross-modal perceptual causality and intuitive physics ability is tested in individuals either displaying the broader autism phenotype, or with a diagnosis of ASD.

2.2.4 Relationships between Gender and Cognitive Domains

Exploration of any putative perception/cognition relationship in isolation could be argued to be of little relevance to the developmental domain differentiation model proposed by Karmiloff-Smith (1991); any correlation found might merely reflect universal brain growth, or general improvement in neural processing efficiencies with age. One way to address this difficulty is to look for evidence of a sex difference moderating the perception/cognition relationship under investigation. Evidence of gender moderation of the relationship under study would counter the objection that its basis lies with any general factor that develops across childhood as, if this were the case, the influence that factor exerts would apply equally to the performance of both genders on both tasks.

Many cognitive differences have been empirically established to exist between the sexes, with men thought to have a profile favouring spatial and numerical abilities and women exhibiting superiorities in verbal and socio-cognitive skills (for a review, see Halpern, Benbow, Geary, Gurn, Hyde & Gernsbacher 2007). One developmental explanation for disparities between the genders'

cognitive phenotypes is that males and females are predisposed from birth to learn about different facets of the environment, with male infants focused on objects and their mechanical relationships, and female infants instead attending to social stimuli; people, emotions and relationships (Baron-Cohen, 2003; Brody & Hall, 2008).

When male and female infants are compared with respect to selective attention, males showed a preference for an inanimate object next to an active and expressive human face, whereas females were seen to direct their attention more to the animated face (Connellan, Baron-Cohen, Wheelwright, Batki & Ahluwalia, 2000). However, Shutts and Spelke (2004) outline several limitations to the study, querying whether these relationships generalise to other object/face pairs, or whether using an alternate still face/animated object pairing would produce different results. Spelke (2005) also asserts that the finding of these attentional biases in infants has not proved replicable.

Counter to the object salience rationale, Spelke (2005) argues that there should be no cognitive developmental reason as to why men should show any advantage over women in science-based tasks, as no differences in object *perception* appear present at birth, and no sex-based differences in mechanical representation formation are discernible either (Baillargeon, 2004). Furthermore, in tasks testing knowledge of basic physics (such as an object travels further when hit by a heavier object) females have been shown to access such information before males (5.5 months, as opposed to 6.5 months; Kovotsky & Baillargeon, 1998). Spelke (2005) concludes that early representational knowledge of physical systems is available to both male and female infants, and that other factors, such as societal

expectations, are primarily responsible for the idea that men are generally superior to women in this regard.

It remains, though, that men and women do show distinct neurobiological differences by adulthood (Baron-Cohen, Knickermeier & Belmonte, 2005), and that beliefs about simple mechanical principles are more often erroneous in women than men (Baron-Cohen, 2002). For instance, more women than men fail the water-level task where participants shown a tipped glass of water are asked to indicate the orientation of water if it were placed upright (Robert & Ohlmann, 1994), reflecting better processing of physical systems in males. Also, men, who generally have superior visio-spatial representation skills, use geometric environmental information for navigation, whereas women prefer to rely on salient landmarks in the visual scene (Rahman, Andersson & Govier, 2005).

If perception is important to cognitive development and the cognitive profiles of men and women are distinct, then, hypothetically, developmental differences between genders should be demonstrable when testing a perception/cognition relationship where the cognitive ability exhibits an advantage for one sex. The relationship between cross-modal perceptual causality and intuitive physics is a good candidate for testing this hypothesis, given the bias towards systemising in males suggested by Baron-Cohen (2002), and evidence of object-orientated selective attention preference in male infants reported by Connellan et al. (2000). Experiment 3 therefore presents separate multiple regression analyses for each sex, so that any moderating effect of participant gender on the developmental relationship between perceptual causality and intuitive physics can be examined.

Evidence of a gender dissociation in this relationship would support the 'privileged relationship' argument within the neuroconstructivist model of cognitive development (Karmiloff-Smith, 1991).

2.2.5 Hypotheses: Developmental effects of perceptual integration on intuitive physics, and the influence of gender

In this chapter, the experiments report data from measuring cross-modal perceptual causality and intuitive physics in children across a wide range of ages. The perceptual causality task used is an adaptation of the paradigm described by Sekuler, Sekuler and Lau (1997), and the intuitive physics task is a novel test that assesses physical causal cognition. Hypothetically, it is suggested that sensitivity to the phenomenon of audio-visual perceptual causality will be shown to increase with age (Experiment 1). It is also proposed that knowledge of physical causality will increase with age (Experiment 2).

In terms of the putative relationship between them, it is argued that children who are more prone to experiencing cross-modal perceptual causality will also have better access to physical causal representations, and will hence demonstrate superior intuitive physics above and beyond any age-mediated relationship. The hypothesis is tested in Experiment 3.

Evidence of correlation between the two tasks both across age *and* between individuals would provide partial substantiation that perceptual processing is important to cognitive development. Evidence of gender dissociation would strengthen this argument. Any evidence of differential perceptual causality/physical

causal cognition relationships between genders would suggest male and female brains develop along different trajectories with respect to domain differentiation. Furthermore, as the particular domain chosen is a cognitive function related to physical systems, any sex difference obtained would support the idea that male and female brains are organised to support different interactions with the environment, which is the basic concept behind the Extreme Male Brain theory of autism (Baron-Cohen, 1999).

Establishing that a perception/cognition relationship exists will partly justify the hypothesis that the behavioural and cognitive profiles seen in autism may be the consequence of perceptual atypicalities during development, as suggested by O’Riordan and Passetti (2006) and by Karmiloff-Smith (2007). Results from Experiment 3 reported here will therefore be used to generate hypotheses in Chapters 3 and 4, where cross-modal integration is considered in the broader autism phenotype and in autism spectrum disorders in relation to perceptual causality and physical causal cognition. Autism as an expression of an extreme male brain (Baron-Cohen, 2002) will also be considered in Chapters 3 and 4 in the light of the gender analysis presented in this chapter.

2.3 Cross-modal Perceptual Causality: Task development

2.3.1 Task constraints

Sekuler, Sekuler and Lau (1997) developed an ambiguous perceptual causality stimulus in which two identical two-dimensional disks approach each

other at the same rate, spatially coincide and then continue along the same paths. This dynamic event can either be perceived as streaming (one passing over the other at coincidence) or bouncing (each reversing direction as a consequence of collision). By introducing a click at the point of spatial coincidence, the experience of bouncing was induced in over 60% of trials observed by ten naïve participants, compared to a frequency of 22% produced when no click was presented. When a click was sounded at 150 milliseconds prior to or after occlusion of one object by the other, the numbers of bounce percepts reported were approximately 45% and 37% respectively (exact data not provided). Hence Sekuler et al. (1997) demonstrated that the cross-modal bouncing effect was dependent on the temporal relationship between presentation of the auditory signal and spatial coincidence of the two dynamic objects onscreen.

This effect has been replicated with alternative disambiguating cues in several adult psychophysical studies. These have identified many of the parameters necessary to generate the illusion of causality (Remijn, Ito & Nakajima, 2004; Sanabria, Correa, Lupianez & Spence, 2004; Sakurai & Grove, 2006). Dishabituation research with infants has also indicated that the cross-modal perceptual causality phenomenon is experienced in the first few months of life (Scheier, Lewkowicz & Shimojo, 2003).

Consideration of the neural regions and comparative weightings of stimulus component properties involved in producing the experience of bouncing suggests that these percepts reflect integration of perceptual signal information, rather than any cognitive response biases (Bushara et al., 2003; Zhou, Wong & Sekuler, 2007).

The perceptual causality paradigm is therefore a good vehicle for examining the development of cross-modal perceptual causality in typical children and its relationship to causal cognition, as it satisfies the following criteria: Bounce percepts reflect integration within the perceptual system; they are inducible from an early age (and so may be related to cognitive development); recruit object perception systems and so are related, in theory, to intuitive physics, and the cross-modal effect in adults is large, thereby allowing for detection of large degrees of variation across individuals and ages.

Stimulus property considerations

Temporal parameters are obviously important to the task. Sekuler et al. (1997) selected stimulus offset synchronies (SOAs) of 150 milliseconds before and after disk occlusion, in addition to a simultaneous condition. Here it was decided to extend these offsets of the auditory signal to 250 ms before and after the point of visual coincidence, the reasoning being that children may not have the same temporal resolution of cross-modal integration as adults, and so age might moderate any SOA effect.

Most psychophysical research on cross-modal perceptual causality has related to dynamic convergence, with two identical objects approaching each other. However, simply replicating these stimuli might introduce possible attentional confounds. Although adults have been shown to be able to track up to five visual objects at a time (Pylyshyn & Storm, 1988), research into development of attentional spread across object number and space in older children and adolescents

suggests that increasing the area over which dynamic objects are simultaneously tracked can affect this ability in pre-adolescents (Trick, Audet & Dales, 2003). Also, tracking two converging items across a wide screen area might be difficult for children with autism, who have been shown to experience difficulty in shifting attention from smaller to larger spatial areas in a cross-hair length discrimination task (Mann & Walker, 2004), thus to use disks that converge and then separate might influence their performance of this task (Chapter 4). A launch rather than bounce version of the illusion, in which one dynamic object could be perceived to either pass over or launch a second, stationary object, was therefore developed so that difficulties with spatial flexibility and simultaneous object tracking that might influence responses differentially between ages or groups were avoided (see Figure 2.1 above).

The difficulty with altering the paradigm in this way was that it could lead to two strategies for observing the events; observers could either track the dynamic object across the screen, or focus on the stationary object. The dynamic object flickered three times before moving to attract exogenous attention away from the stationary object to minimise the effect of strategy choice between participants.

Recent investigations (Zhou, Wong & Sekuler, 2007) of the stimulus properties that are required to induce perceptual causality indicate that auditory influence is, in part, a product of signal intensity. This factor had been anticipated as a possible contributor of error variance, and so it was decided to calibrate decibel output prior to each testing session to ensure consistency between participants. It was also decided that auditory signal duration should be brief in order not to exceed

the duration of visual object occlusion, as bounce illusions disappear when the duration of the auditory stimulus exceeds duration of visual coincidence (Remjin, Ito & Nakajima, 2004).

Developmental considerations in task design

Given that only two responses are possible in a perceptual causality task, learning response rules was not considered to be onerous for young or less able participants. However, there are several problems presented by adapting the paradigm reported by Sekuler et al. (1997) for testing perceptual integration in children across a wide range of ages and intellectual abilities. Paramount of these is related to the ambiguous nature of the stimuli. Data obtained from children can be influenced by their over-sensitivity to demand characteristics, in that they often strive to produce the 'right' answer and so want to be told exactly what constitutes a correct response when tested. Percepts are inherently neither right nor wrong, so participation could induce anxiety in some participants unless it is made clear that no correct response exists. Rather than evoke the sense of being tested in children, the task was designed to look and sound like an easy computer game, called the Crash or Miss Game (CoMG). The simple instructions (Appendix A) were provided by voice-over supported by simple visual graphics onscreen to minimise any social demand characteristics.

Demand characteristics sensitivity could be exacerbated by a desire for response consistency; having decided that a particular response to certain stimulus characteristics is 'right', a child may attempt to apply an heuristic rule in order to be

correct on most trials. Given that one hypothesis to be tested is that perceptual integration will develop as a consequence of perceptual experience, the task had to be carefully designed so that learnt associations would be hard to acquire.

Development of personal rules was made difficult by varying the event start positions; trials began with the dynamic object either moving from the right or left of the screen.

In the original design (Sekuler et al., 1997), each of the four stimulus types was presented twenty times. Below this number of trials, significant differences between conditions would be hard to obtain for reasons of statistical power, although the effect size induced by simultaneous presentation of the sound signal at the point of occlusion is large. Our final design had to include comparable trial numbers, in order to allow for comparative analysis in studies using group categorisation as an independent variable (for instance, when comparing response patterns between children with ASD and age-matched controls). The obstacle here is that ability to continue to pay attention during a repetitive task is limited at young ages, and some individuals are unable to maintain attention consistently no matter what their ages. The task therefore had to be designed to minimise boredom and motivate children to complete multiple repetitions. This was achieved by dividing trials into five blocks of twenty trials, interspersed with rest screens that presented ticks and stars indicating how many blocks had been completed; these were accompanied by motivating voice-over messages.

The instructions simply asked participants to press a red mouse button when they saw a 'crash' or the yellow button whenever they saw a 'miss'. Experimental

trials used either identical green or identical white disks to generate ambiguity. In addition, to provide a means to identify individuals who failed either to acquire the task rules or to apply them consistently, unambiguous control trials were included (see Figure 2.2). These trials used non-identical (differently-coloured) disks to provide within-task controls; children who inconsistently followed the rules produced low accuracy scores for these conditions, and so their data could be removed post-hoc from analysis. For unambiguous misses, a white or green disk passed over the alternate colour disk without stopping, and for unambiguous crashes one disk stopped as its outer boundary touched the alternately-coloured stationary disk, which moved on contact.

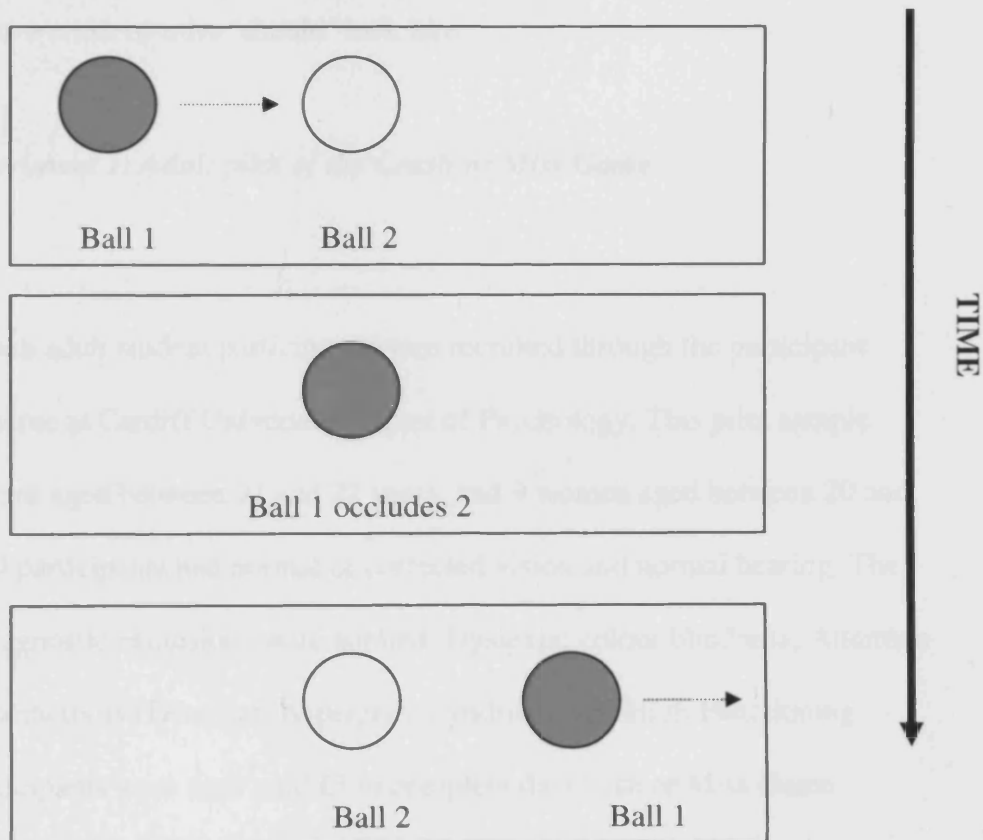


Figure 2.2 : Schematic representation of an unambiguous pass event

Inclusion of unambiguous trials in itself generated a further problem as the experimental trials became obvious as they were accompanied by sound. An early explorative pilot of the task with very small groups of typical and autistic children strongly suggested that differentiation between experimental cross-modal trials (with sound) and unimodal control trials (without sound) led to development of a rule-based heuristic in some children that was related to world knowledge (i.e., objects that contact usually make a sound, and so hearing a sound must mean that those objects crashed). By including the auditory signal on all control trials irrespective of whether the objects crashed or missed, this heuristic was implicitly demonstrated to be false. Further, the instructions included examples of control and experimental stimuli that were presented without labelling to avoid teaching children what a crash or miss 'should' look like.

2.3.2 Experiment 1: Adult pilot of the Crash or Miss Game

Participants

Sixteen adult student participants were recruited through the participant payment scheme at Cardiff University School of Psychology. This pilot sample included 7 men aged between 21 and 22 years, and 9 women aged between 20 and 25 years. All participants had normal or corrected vision and normal hearing. The following diagnostic exclusions were applied: Dyslexia; colour blindness; Attention Deficit (Hyperactivity) Disorder; Asperger's Syndrome and High Functioning Autism. Participants were each paid £3 to complete the Crash or Miss Game (CoMG), which took between 5 and 10 minutes.

Apparatus

The CoMG was written in Python and presented using VisionEgg software. The game was presented on a Toshiba SPM30 laptop, with a flatscreen refresh rate of 60Hz and high specification RAM and video and sound cards for reduced variance in trial presentation timings. Sound was output via Sennheiser HD-205 headphones. Data from this task were recorded via laptop internal mouse button presses; red and yellow stickers were used to highlight the mouse key to push for either a crash or miss response, respectively.

Stimuli

Trial stimuli were two-dimensional green, white or a combination of green and white disks, each subtending a visual angle of 2.1 degrees, presented against a black background, moving along the horizontal plane. The speed of the moving disk was set at 24 degrees per second (at a viewing distance of 57cm). The start position for the moving disk varied between left and right screen positions, and the position of the stationary disk was consistently set at the central point of the vertical plane. All trial durations were set to 800ms. The auditory stimulus used was a 'click' noise with peak frequency of 2137 Hz and duration of 5.5 milliseconds. To ensure that sound presentation intensity equivalence, the system sound level was set to an average level of 68 decibels (range 63 – 72 dBs) for each testing session by measuring nine decibel readings taken from practice session trials, using a Precision Gold N05CC sound meter, and resetting volume controls accordingly.

Unambiguous crash or miss events involving one green and one white disk were coded as control crash and control miss trials. Ambiguous trials involving two disks of the same colour were coded as experimental trials. Three levels of SOA

were used to define click presentation timing for each trial type. These were at 0ms, -250ms and +250ms relative to the point at which the disks were occluded. The number of trials per trial type is provided in Table 2.1 below. Over the session an equal number of trials began from left and right starting positions, with the moving disk coloured green in half the presentations and white in the other half. These two factors (starting position and colour of moving disk) were counter-balanced within each trial type. Equal numbers of each trial type were allocated to each of five test blocks, so that blocks were equivalent in terms of the number of unambiguous and ambiguous events they each presented. The trials within each block were then pseudo-randomised before fixing their order, so that no trial type was presented twice in a row. All trials started with a 200 ms offset, after which the first moving disk in the horizontal plane ‘flashed’ three times for 500 ms (with two stimulus offset durations of 50 ms between flashes); flashing served to direct attention exogenously to this ball prior to the start of the trial. Participants completed a total of 9 practice trials (one of each trial type/SOA combination) and 100 test trials (see below for details).

SOA	Unambiguous Control Trials:		Ambiguous
	Crash	Miss	
<i>-250 ms</i>	5	5	10
<i>0ms</i>	20	20	20
<i>+250ms</i>	5	5	10
<i>Totals</i>	<i>30</i>	<i>30</i>	<i>40</i>

Table 2.1: Trial type distribution in the CoMG (Experiment 1: Adult Pilot).

Procedure

All test sessions were completed within a well-lit sound-proofed laboratory.

Participants read and completed an informed consent form prior to starting. Each

participant sat approximately 57cm from the presentation laptop, as measured from the bridge of their nose to centre-screen, in order to ensure that subjective disk speed and size were partially controlled. Participants were given the headphones to wear and told to press the spacebar to begin the onscreen instruction presentation when they were comfortable. The instructions were provided as a slow voice-over with participants watching static graphics that reiterated the rules (Appendix A). These were to press the red mouse button whenever they saw an onscreen event they perceived as being a crash (launch), or the yellow mouse button for a miss (pass). Participants completed a practice set of nine trials (one of each trial type/SOA combination in fixed pseudo- randomised order) before proceeding to the experimental session. After each response, the message 'press the space bar to continue' was presented. This message did not appear until a response had been made; each trial's presentation had to be completed before a response was accepted, and pre-emptive button presses were implicitly trained out of early responders as the session did not continue until they responded again after the disks stopped moving. After the practice session participants were prompted to start the experimental session by pressing the space bar; this break between practice and test sessions allowed any misunderstandings to be corrected.

During the experimental session, red and yellow response prompts remained onscreen during each trial. The trial order was invariant to prevent repeat presentation of any one trial type (as this could generate a perceptual learning confound or lead to development of a response strategy). Trials were divided into five blocks, each of which comprised 20 trials. Participants proceeded through all five test blocks until all 100 test trials had been presented. Blocks were delineated

by the presentation of onscreen graphics and voiceover messages, allowing participants to rest briefly and to choose (by pressing the spacebar) when they wanted to continue. The experiment concluded with onscreen presentation of a thank you message. Following completion, the purpose of the pilot was explained.

Results and conclusion

The purpose of the pilot was to determine whether this novel cross-modal perceptual causality task produced an illusory launch percept comparable to the bounce effect originally reported by Sekuler et al. (1997).

Control Trial Type	Auditory Timing	Mean Accuracy Score	Std. Deviation	Range
<i>Unambiguous Crash</i>	-250 ms	.96	.08	.60 – 1.00
	0 ms	.97	.04	.65 – 1.00
	+250 ms	.95	.09	.50 – 1.00
<i>Unambiguous Miss</i>	-250 ms	.95	.12	.80 – 1.00
	0 ms	.91	.12	.90 – 1.00
	+250 ms	.96	.11	.80 – 1.00

Table 2.2: Accuracy scores for Unambiguous Crash and Miss Control Trials, by Auditory Timing (Experiment 1: Adult Pilot).

Control trial analysis indicated that one participant's accuracy scores for both unambiguous launch (crash) and pass (miss) conditions lay outside two standard deviations of the mean, and so their data were removed. Means and standard deviations for accuracy scores obtained from the unambiguous crash and miss control trials are provided in Table 2.2; these values indicate that accuracy across both control trial types and all three levels of auditory signal timing were high, with little variance across the sample (n = 15). A two-factor repeat measures 2 x 3 ANOVA, with control trial type (unambiguous crash or miss) and auditory timing (-250ms, 0ms or +250ms relative to disk occlusion) as the within-group

factors was performed. No main effect of trial type ($F < 1$), or auditory timing condition ($F < 1$), or interaction between trial type and auditory timing condition ($F(2, 28) = 1.23, p > .05$) was obtained.

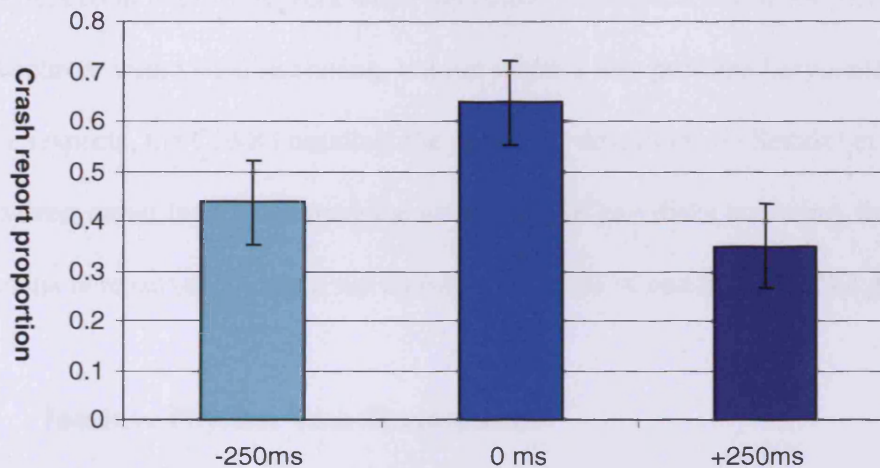


Figure 2.3: Crash reports produced by Crash or Miss Game ambiguous stimuli, by SOA condition (Experiment 1: Adult Pilot).

Figure 2.3 shows that the highest mean crash report score was produced in response to the simultaneous (0 ms) experimental trials (i.e., those ambiguous trials in which the auditory signal was presented as the moving disk occluded the stationary disk). Presentation of the auditory signal before or after the point of occlusion produced comparatively fewer crash reports.

A repeat measures one-way ANOVA with auditory signal timing as the repeat factor produced a significant main effect; $F(2, 28) = 42.67, p < .001$. Pairwise post-hoc analysis (t-tests adjusted using the Bonferroni method for multiple comparisons) indicated that all conditions significantly differed from each other, $p < .001$.

These findings demonstrate that the ambiguous stimuli used in the Crash or Miss Game frequently induce the phenomenon of cross-modal perceptual causality. Furthermore, the data indicate that a higher number of crash percepts was experienced in adult observers when the auditory stimulus was spatio-temporally co-occurrent with visual occlusion, but not when it was presented asynchronously. In these respects, the CoMG parallels the paradigm developed by Sekuler et al. (1997). However, rather than generating the impression of two disks bouncing, the auditory stimulus here serves to create the causal impression of one disk launching the other.

2.4 Intuitive Physics: Task Development

2.4.1 Existing methodologies

Much research into physical causal cognition has involved testing infants' representational abilities using habituation-dishabituation methodologies (for example, Baillargeon, 2008). Tasks measuring children and adolescents' physical causal reasoning beyond infancy range from a 'single concept' test (e.g. Hood, 1998), to small sets of causal reasoning trials (e.g., Binnie & Williams, 2003) to tests that resemble a physics multiple-choice exam (e.g., Baron-Cohen, Wheelwright, Scahill, Lawson & Spong, 2001b; see Figure 2.4 below). Although suited to the research purposes for which they were designed, the former two types of test are limited in terms of evaluating generalised causal physics reasoning, and would not allow sufficient variance in scores for continual measurement across a wide age range. The latter is overly-sophisticated with regards to conceptual breadth, reliant to some extent on language ability with a high degree of trial

difficulty. Neither type of task is therefore suitable to measure the *development* of intuitive physics.

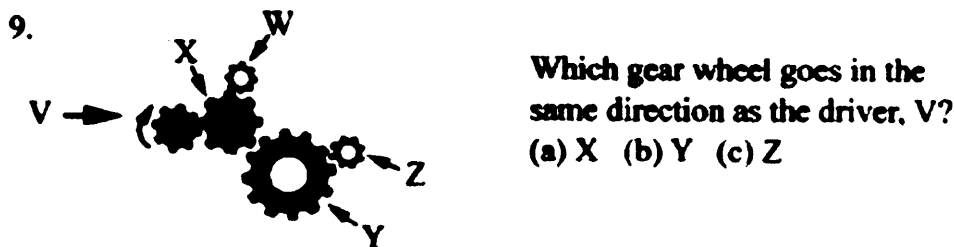


Figure 2.4 : Sample question from Intuitive Physics Task (taken from Baron-Cohen et al., 2001)

2.4.2 Task design considerations

In order to examine the development of physical causal cognition over a wide age range, task design had to allow for visual presentation of a range of physical concepts, with trials graded according to levels of difficulty. Verbal instructions had to be kept to a minimum so that younger children and children whose physical reasoning exceeded their verbal abilities were not disadvantaged. Multiple choice answers were restricted to two, rather than four, options to avoid mapping difficulties in younger and less able children. A stop criterion needed to be included so that less able children would not be frustrated by having to complete trials beyond their competence, and so that total score distribution would not be overly affected by guessing. To test general rather than specific physics knowledge, trial content relating to several physical phenomena and mechanical functions (including friction, gravity, refraction, fulcrum mechanics, density, and cog operation) was compiled. Examples of each of the forces or systems selected were

redrawn from teaching materials used at primary, secondary and higher levels of education (see example, Figure 2.5).

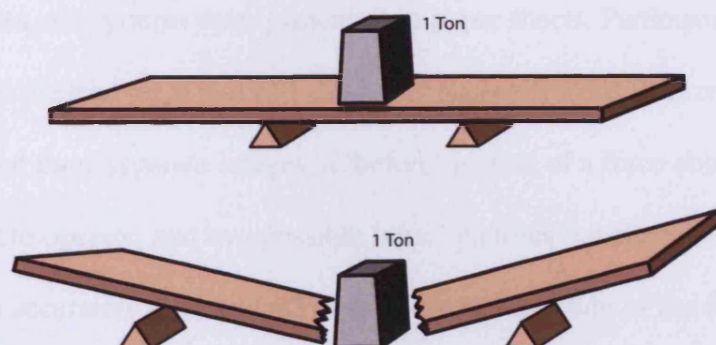


Figure 2.5: Sample trial illustration showing possible effects of a heavy weight on identical wooden planks supported in different positions (adapted from Baron-Cohen, Wheelwright, Spong, Scahill & Lawson, 2001).

2.4.3 Trial ranking data

Introduction

The trial material developed was tested on adult psychology students to obtain difficulty rankings, prior to piloting with typically developing children. This allowed trials of comparative complexity to be assigned to difficulty levels, so that young children in the pilot were not made to feel anxious by being tested on material far beyond their ability.

Participants

Eleven adult psychology students, three male and eight female and aged between 18 and 21 years, were recruited from the School of Psychology's participant panel, and received 1 credit for their participation.

Materials and stimuli

The ranking task comprised 24 trials in which coloured illustrations of physical forces and systems were presented on paper sheets. Participants were provided with the trial set, a pen and an answer sheet to record their responses. Each trial comprised three separate images; a 'before' picture of a force about to act or a system about to operate, and two possible 'after' pictures (labelled A and B), only one of which accurately represented the outcome of the action of the force or operation of the system depicted. Trial order was randomised between participants.

Procedure

Participants were asked to read and sign an informed consent form before starting the ranking task. They were verbally briefed to look at the 'before' picture, and its two possible 'after' pictures for each trial, and then record either A or B on the answer sheet to indicate which picture they considered to be an accurate representation of the outcome of the event depicted (see Figure 2.6). Participants were allowed to work through the trial set in isolation, before being debriefed as to how the trials would then be ranked by difficulty.

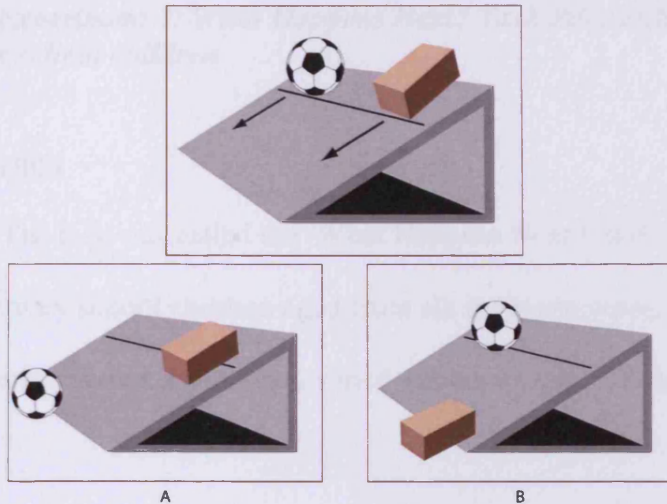


Figure 2.6: Trial example; participants select either A or B as the picture that accurately represents the action of friction on different objects moving down a slope.

Results

Participants' accuracy scores ranged from 12 to 23 out of a possible 24 points, suggesting that trials varied in difficulty. The total number of correct answers was summed for each trial, allowing a ranking according to difficulty to be obtained. The trials were then allocated to one of six difficulty levels for use in the pilot with typically developing children. Wherever ranking failed to produce a discrete boundary, trials were arbitrarily assigned to a lower or higher level. For levels with trials of mixed difficulty, higher-ranked trials were placed after lower-ranked trials in presentation order.

2.4.4 Experiment 2: What Happens Next? Task Pilot with typically developing primary school children

Introduction

The task was called the ‘What Happens Next?’ task (WHN?T), and piloted with primary school children aged from six to eleven years, to determine whether the accuracy scores it produced varied systematically with age.

Participants

Two primary schools were approached for participant recruitment for the WHN?T child pilot. Information letters were distributed to all children in years 1 to 6; parents who agreed to their children participating signed and returned consent forms. Parents were asked not to consent if there was any familial history of developmental disorders. Consequently, 37 participants (19 males; 18 females) were recruited.

Materials and stimuli

The trial difficulty ranking obtained from adults was used to allocate the twenty-four trials to one of four levels of difficulty, so that six trial sets were produced.

Procedure

Children were tested individually in a quiet room at their school. They were sat at a desk with the researcher and informed that they were going to look at a puzzle game called ‘What Happens Next?’ as part of a science experiment that their

parents had agreed to let them help with; it was made clear to the participants that they were not being tested and that their school would not know their individual scores.

The first trial was used to explain the instructions (Appendix B). After having examined the ‘before’ image, the participant was prompted to say whether picture A or B showed ‘what happened next’ on each trial. Presentation order remained consistent between participants. A stop criterion was applied to prevent any individual performing at chance level from progressing through the levels (i.e., no more than 2 mistakes per level were allowed). Responses were recorded by the researcher on a sheet with response spaces colour-coded by correct answer, to allow number of right answers to be assessed covertly at the end of each level. Age in months and gender were also recorded, and response sheets coded to ensure anonymity. Test sessions were terminated as soon as the stop criterion was reached, or all the trials had been presented. Each child was reassured at the end of each test session that they had performed very well.

Results and conclusion

Age group (years)	n	Age mean (years; months)	Score mean (/24)	Std. Deviation	Range
<i>6 – 7</i>	15	7;5	7.53	3.04	4 – 15
<i>8 – 9</i>	8	9;3	10.25	5.31	3 – 20
<i>10 – 11</i>	14	11;1	15.43	4.65	8 – 21
<i>Total</i>	37	9;2	11.12	5.45	3 – 21

Table 2.3: Participant profile and task score data by Age Group (Experiment 2: WHN?T Child Pilot).

Table 2.3 provides age ranges, mean ages and mean scores by age group for the WHN?T pilot, suggesting that mean WHN?T scores do increase as children become older. A one-way ANOVA with age group as the between group factor and score as the dependent variable confirms this observation ($F(2, 34) = 12.82, p < .001$).

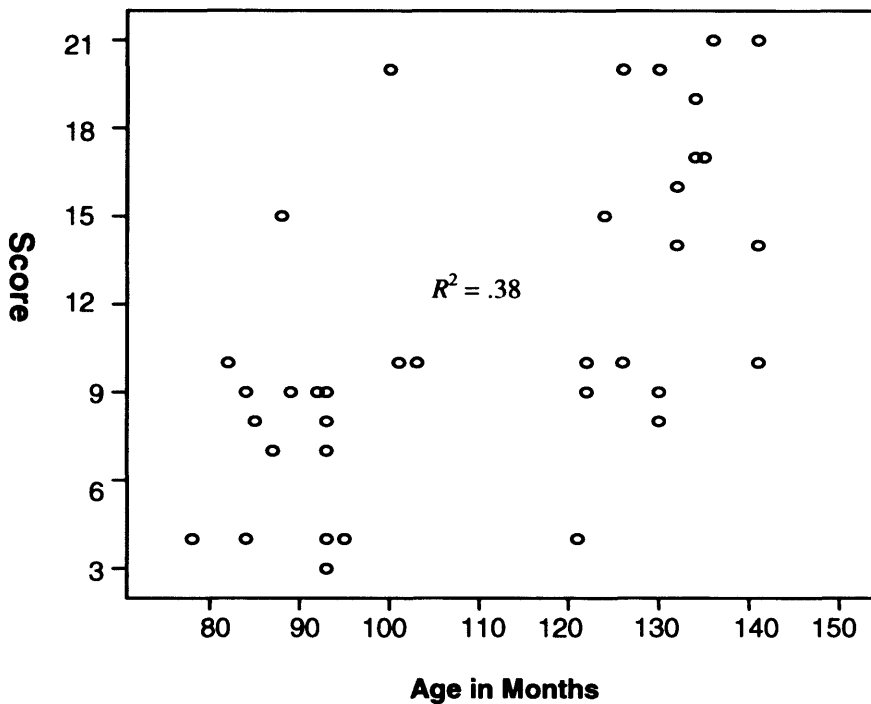


Figure 2.7: Scatterplot of Age in Months versus WHN?T scores

A scatter plot of the data from the pilot is provided in Figure 2.7. Analysis of the data using the Pearson Product Moment Correlation (PPMC) method produced a positive correlation between age of participant and total score ($r = 0.62, p < .001$) across all participants, with age accounting for 38.7% of the variance in scores. From this result, it can be concluded that the task accurately measures the development of intuitive physics in children.

Participants	n	Age range	Age mean	Score mean (/24)	Std.Dev.	Range
<i>Male</i>	19	6;10 – 11;9	9;1	11.16	5.26	4 – 21
<i>Female</i>	18	6;6 – 11;9	9;3	11.06	5.79	3 – 21
Total	37	6;6 – 11;9	9;2	11.12	5.45	3 – 21

Table 2.4: Participant profile and task score data by Gender (WHN?T Child Pilot).

Age ranges, mean ages and mean scores are comparable between genders (see Table 2.4). Independent samples *t*-tests between the between male and female subgroups in the sample support this observation ($t_{Age(35)} = -0.33$, $t_{Score(35)} = 0.06$; $p > .05$ in both cases). However, the relationship between age and task performance appears to differ between them, with $r = .75$, $p < .001$ for the boys and a value of $r = .50$, $p < .05$ obtained for the girls. A comparison of these values using Fisher's *r*-to-*z* transformation method indicated, however, that they are not significantly different ($z = 1.18$, $p > .05$); hence their distributions are comparable. It can be concluded from the pilot that the method devised for this task is appropriate for measuring developmental effects, in that it does not introduce any bias that might advantage one gender over the other.

2.5 Experiment 3: Cross-modal perceptual causality, intuitive physics and gender

2.5.1 Introduction

Having determined that both novel tasks fulfil their design objectives, typically developing children could then be tested to investigate the hypothesis that the development of susceptibility to cross-modal perceptual causality stimuli and the development of intuitive physics ability are related.

This study was conducted at the Techniquet Science Museum in Cardiff.

An advantage of recruiting from this unique participant pool was that both the boys and girls recruited could be assumed to like engaging with science, thereby ensuring to some extent that motivation levels and enjoyment during participation were controlled across genders. Any moderation of the hypothetical relationship between gender subgroups found is therefore less likely to be confounded by social factors, than would be the case if the study was undertaken in schools.

2.5.2 Method

Participants

Children aged between 5 and 13 years old visiting Techniquet Science Museum (Cardiff) were recruited by approaching their parents for consent to participate. Participation requests were not made at random; wherever possible, recruitment of a girl was followed by approaching a family with a boy of equivalent age, so that the age range and number of children in the sample were balanced between genders. Parents were requested not to agree to participation if there was evidence of any developmental disorder in their family history, or if their child had had any hearing or sight difficulty that required medical intervention. On this basis, 67 children participated (see Table 2.5 below).

Group	N	Age range (months)	Mean age (months)	Std. Deviation
<i>Male</i>	34	67 – 157	106.4	24.0
<i>Female</i>	33	72 – 155	106.7	25.5
<i>Total</i>	67	67 - 157	106.5	25.1

Table 2.5: Sample age distribution by Gender (Experiment 3).

Apparatus, Materials and Stimuli

Apparatus, materials and stimuli were identical to those used in the pilots for both the CoMG and the WHN?T (see sections 2.3.2 and 2.4.4, respectively), the only differences being that the average decibel output for each experimental session was set to between 62 to 65 decibels (to avoid possible startle responses in younger children), and the inclusion of a feedback questionnaire (Appendix C) following the Crash or Miss Game. The purpose of the questionnaire was to assess whether or not participants had consciously adopted a rule-based response strategy.

Procedure

All testing took place in a quiet, well-lit laboratory. Parents were asked to read an information sheet and sign the consent form while the children were verbally briefed on what they would be doing. Task order was counterbalanced within gender, and counterbalancing matched between genders. Following participation, the child and accompanying family were provided with both a verbal and written debrief, and any questions they had were answered. The children were also given a small Techniquist gift.

2.5.3 Results

Outlier analysis and accuracy data

Analysis of standardised z-scores for the both the unambiguous crash and unambiguous miss control trials of the CoMG led to the removal of five participants (three male and two female) on the basis that their accuracy scores lay more than two standard deviations outside of one/both of the control trial accuracy means for

the total sample. Outlier removal reduced the sample size to 62, generating an equal number of male and female participants but producing no marked change in either the range or mean age of the sample distribution². No participants reported developing any individual response rules, and so none was removed on this basis.

Control Trial Type	Auditory Timing	Mean Accuracy Score	Std. Deviation	Range
<i>Unambiguous Crash</i>	-250 ms	.94	.08	.65 – 1.00
	0 ms	.95	.11	.60 – 1.00
	+250 ms	.98	.07	.60 – 1.00
<i>Unambiguous Miss</i>	-250 ms	.95	.07	.70 – 1.00
	0 ms	.95	.10	.60 – 1.00
	+250 ms	.98	.06	.80 – 1.00

Table 2.6: Accuracy scores for Unambiguous Crash and Miss Control Trials, by Auditory Timing Condition (Experiment 3).

Means and standard deviations for accuracy scores obtained from the unambiguous crash and miss control trials are provided in Table 2.6. As was observed for the pilot with adults, these values suggest a high degree of accuracy across both control trial types and all three levels of auditory signal timing, with little variance across the sample ($n = 62$). A two-factor repeat measures 2×3 ANOVA, with control trial type (unambiguous crash or miss) and auditory timing condition (-250ms, 0ms or +250ms relative to disk occlusion) as the two within-group factors was performed to validate this observation. No main effect of trial type, or interaction between trial type and auditory timing condition (both $F < 1$), were obtained. However, a main effect of timing was determined; $F(2, 122) = 8.32$, $p < .001$. Post-hoc pairwise comparisons between means (adjusted for multiple comparisons) indicated that the +250 ms condition (in which the auditory signal is

² Mean ages per gender are not significantly different; $t(60) = .11$, $p > .05$.

presented after the moving disk has passed over the stationary disk) produces greater response accuracy in observers than is found for the either of the other two levels of this factor. Repeating this analysis separately for each of the gender subgroups revealed the same pattern of results as reported for the entire sample, with only the auditory timing factor producing a significant main effect, and post-hoc tests confirming that the +250 ms generated the highest accuracy levels for both sexes.

Experiment 3a: Crash or Miss Game Crash Report Analysis by Auditory Timing Condition and Gender

Group	n	Mean crash reports			Range		
		-250ms	0ms	+250ms	-250ms	0ms	+250ms
Male	31	.41(.31)	.45(.34)	.29(.31)	0 – 1.0	0 – .95	0 – 1.0
Female	31	.36(.29)	.40(.30)	.24(.25)	0 – 1.0	0 – 1.0	0 – .90
Total	62	.39(.30)	.43(.32)	.26(.28)	0 – 1.0	0 – 1.0	0 – 1.0

Table 2.7: Descriptive statistics for Crash or Miss? Game Experimental Trials (Experiment 3a).

The means and standard deviations of crash report scores for the experimental trials are supplied in Table 2.7. It can be seen from these data that the simultaneous (0 ms) auditory timing condition of the CoMG produced the greatest number of crash reports across both genders, and that the male participants reported more crashes across all timing conditions than were reported by the females. The pattern of response apparent across conditions for the entire group was broadly equivalent to that obtained from the adult pilot (see Figure 2.3, section 2.3). However, the increase in crashes (launches) reported in response to the simultaneous (0 ms) condition compared to presentation of the auditory signal prior to occlusion (-250 ms) was of a lower magnitude than that seen for the adults (4%

increase over the predictive +250ms condition mean response, as opposed to 21% in adults).

A repeat measures one way analysis of variance (ANOVA) of the auditory timing factor was conducted to determine whether the elevated number of crashes reported in response to the simultaneous condition trials was significantly larger than those elicited by the other timing conditions. A main effect of trial was found for this analysis ($F(2, 122) = 31.70, p < .001$).

Timing Condition 1	Timing Condition 2	Mean Difference	Std. Error
-250 ms	0 ms	-.04	.02
	+250 ms	.12*	.02
0 ms	+250 ms	.16*	.02

* The mean difference is significant at the .05 level, after Bonferroni adjustment.

Table 2.8: Pairwise comparisons between means from Auditory Timing Conditions (Experiment 3a).

Bonferroni-adjusted post-hoc mean comparisons in Table 2.8 show that the + 250ms condition differed significantly from both the -250ms and simultaneous (0ms) conditions, confirming that trials from both these conditions elicit more crash responses than trials in which the auditory signal is presented after the moving disk has passed over the stationary disk. However, the other two auditory timings generate crash reports to comparable extents, as responses do not significantly differ between the simultaneous (0 ms) and -250 ms conditions. This finding differs from analysis of the adult pilot data, in which these two conditions did differ significantly; co-occurrence of the auditory signal and the point of occlusion



producing significantly more crash responses than presentation of the sound prior to occlusion.

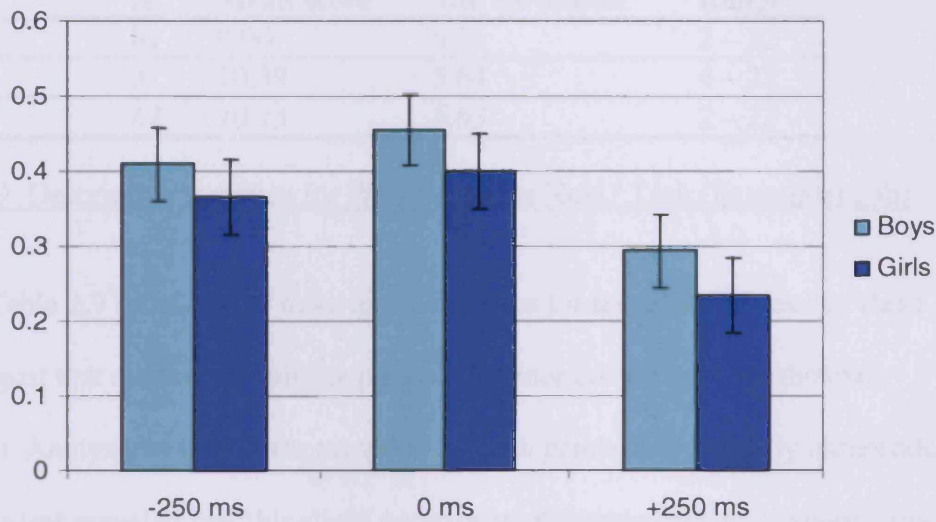


Figure 2.8: Crash report means by Auditory Timing Condition and Gender (Experiment 3a).

Figure 2.8 represents the mean numbers of crash reports obtained from each gender at each level of auditory timing condition. A mixed 2 x 3 ANOVA, with gender as the between-group factor and auditory timing as the within-group factor, was performed to assess whether the general increase in crashes reported by the boys over the girls was significant. This analysis, however, showed no significant main effect of gender, or interaction of gender and timing condition ($F < 1$), and so no effect of gender on either the total number of crashes reported, or the pattern of crash reports across auditory timing conditions, was evidenced.

Experiment 3b: What Happens Next? Task Gender Analysis

Group	N	Mean score	Std. Deviation	Range
<i>Male</i>	31	9.90	5.71	2 – 22
<i>Female</i>	31	10.39	5.64	4 – 22
Total	62	10.15	5.63	2 – 22

Table 2.9: Descriptive statistics for What Happens Next? Task (Experiment 3b).

Table 2.9 provides the descriptive statistics for the WHN?T results; these data suggest that the female subgroup shows a minor advantage over the male subgroup. Analysis of the scores provided by each gender subgroup by independent samples *t*-test revealed that this slight superiority of female over male scores was not significant ($t(60) = -0.34, p > .05$).

Experiment 3c: Relationships between simultaneous auditory signal presentation, age and intuitive physics scores.

Variable		Age	WHN?T Score	Crash Reports
Age	<i>R</i>		.64**	
	<i>P</i>		.000	
WHN?T Score	<i>R</i>			.38**
	<i>P</i>			.002
Crash Reports	<i>R</i>	.33**		
	<i>P</i>	.008		

** Correlation is significant at the .01 level (two-tailed)

Table 2.10: PPMC correlations (*r*) between key variables (Experiment 3c).

The largest effect of auditory signal presentation was found for the simultaneous (0ms SOA) condition³, and so data from this condition were selected for the purpose of considering correlations amongst the three main variables of

³ This same result was reported by Sekuler, Sekuler & Lau (1997), and was found for the adult pilot data (Chapter 2, section 2.2).

interest: CoMG crash reports; age in months, and WHN?T scores. As can be seen from Table 2.10, each of these correlations was found to be significant. Moderate positive effects were found for the relationships between the proportion of crashes reported in the simultaneous condition of the CoMG with age in months ($r = .33$, $p < .01$), and with WHNT scores ($r = .38$, $p < .01$). A large effect size was found for the positive relationship between age and WHNT scores ($r = .64$, $p < .001$), replicating the results from Experiment 2.

Variable		Age	WHN?T Score	Crash Reports
Age	<i>R</i>		.74**	
	<i>P</i>		.000	
WHN?T Score	<i>R</i>			.46**
	<i>P</i>			.01
Crash Reports	<i>R</i>	.29		
	<i>P</i>	.12		

** Correlation is significant at the .01 level (two-tailed)

Table 2.11: PPMC correlations (r) between key variables for the male subgroup (Experiment 3c).

Variable		Age	WHN?T Score	Crash Reports
Age	<i>R</i>		.55**	
	<i>P</i>		.001	
WHN?T Score	<i>R</i>			.31
	<i>P</i>			.09
Crash Reports	<i>R</i>	.38*		
	<i>P</i>	.03		

** Correlation is significant at the .01 level (two-tailed)

*Correlation is significant at the .05 level (two-tailed)

Table 2.12: PPMC correlations (r) between key variables for the female subgroup (Experiment 3c).

Tables 2.11 and 2.12 show that correlation of WHN?T scores with age is significant for both gender groups, replicating the findings from Experiment 2. However the results presented in these tables also show that the pattern of

relationships yielded by the group data is not replicated within the gender subgroups. Within the male data, significant correlations are apparent between the CoMG and WHN?T scores ($r = .46, p = .01$). No significant relationship was found between age and simultaneous CoMG crash reports. Analysis of the female data, however, indicated that age significantly correlated with both WHN?T score ($r = .55, p < .001$) and CoMG crash reports ($r = .38, p < .05$), but no significant relationship between CoMG crashes and WHN?T scores was derived.

Removing the variance in WHN?T scores attributable to age allowed the variance of WHN?T in relation to CoMG crash report proportion data to be analysed. The first-order partial correlation obtained between these two variables in the group data was found not to be significant after controlling for the effect of age ($r = .23, p = .07$); this result suggests that age is generally a mediating factor.

For the male subgroup ($n = 31$), removal of variance relating to age simply *reduces* the partial correlation between crash reports and WHN?T scores to $r = .38, p < .05$. As this result is significant, age only partially mediates the relationship in typically developing males. The equivalent partial correlation in the female data is $r = .13, p > .05$. Testing the difference between male and female partial correlations using the Fisher's r -to- z transformation produces $z = -1.01, p > .05$, indicating that the values of r between the male and female groups are not significantly different.

Effect of gender on the relationship between CoMG crash reports and WHNT scores

The original hypotheses were that both age and CoMG crash report scores would predict WHNT scores. As both these variables were found to be significantly correlated with WHNT scores, they both attained criteria for inclusion in a regression model. A stepwise multiple linear regression analysis for the entire data set was therefore conducted to determine the best fit model for the dependence of WHNT scores on the predictor variables, age and crash reports. Using an entry parameter of $p < .05$ and a removal parameter of $p > .1$, the only predictor to be included in the model was age; $\beta = .639$, $t(60) = 6.44$, $p < .001$. This variable predicted a significant amount of variance in WHNT scores ($R^2 = .41$, $F(1,61) = 41.45$, $p < .001$).

Categorising the data according to participant sex allowed for comparison of linear regression models on the basis of gender. Sex differences in the predictor variables were first examined using independent samples t -tests (equal variances assumed). No significant differences were found between male and female participants for either age ($t(29) = 0.105$, $p > .05$), or number of crashes reported ($t(29) = 0.677$, $p > .05$). For means, standard deviations and ranges for both predictors by gender, see Tables 2.5 and 2.7, above.

Conducting step-wise regression analyses within each sex (using the same entry/removal criteria) investigated the role gender plays in moderating these predictive relationships. In the stepwise regression model for boys, both age ($\beta = .661$, $p < .001$) and crash report scores ($\beta = .267$, $p < .05$) were retained as significant

predictors, and together accounted for a large significant proportion of the variance in WHN?T scores ($R^2 = .61$, $F(2,30) = 21.91$, $p < .001$). Analysis of the female subgroup data produced results equivalent to the pooled-gender data model. Age was the single predictor included in the linear regression model, $\beta = .546$, $p = .001$. The variance in WHN?T scores accounted for by age was 30% in this group ($R^2 = .30$, $F(1, 30) = 12.34$, $p = .001$).

For all analyses presented here, generalisation assumptions were met; there was no evidence of multicollinearity, heteroscedasticity or autocorrelation in the models generated for either the entire sample, or for the gender-based subsets. Case diagnostics indicated that the entire sample contained two cases (both female) for whom the standardised residual values of the outcome variable (WHN?T score) had values greater than two. These cases could therefore be considered outliers, but tests of the degree to which they had influenced analyses showed that neither affected the models produced, and so they were not excluded⁴.

2.5.4 Results Summary and Discussion

This study was designed to investigate the developmental courses of perceptual causality and intuitive physics, their possible inter-dependence and the role of gender within this context. The predictions that both intuitive physics ability and perceptual causality processing would increase systematically with age were tested (Experiments 2 and 3c, respectively). In the initial children's pilot of the WHN?T (Experiment 2) scores were significantly and positively correlated with age, with $R^2 = 38.7\%$. In Experiment 3c, the significant amount of variance in

⁴ Cook's, Mahalanobis and leverage distances were examined (Field, 2005)

WHT scores ($R^2 = 41\%$) accounted for by age also confirmed this hypothesis. In the same experiment, crash reports in the simultaneous condition of the CoMG task were also found to increase systematically with age, albeit to a lesser extent ($R^2 = 11\%$). More importantly, in Experiment 3c, susceptibility to cross-modal perceptual causality stimuli was found to be positively related to intuitive physics ability ($r = .38, p < .05, R^2 = 14.5\%$).

Further regression analysis indicated that age mediates the relationship between cross-modal induction of perceptual causality and intuitive physics. However, although age is a mediator in the general model, the two sexes were found to differ, in that the correlation between perceptual causality and cognitive physical causality scores remains significant after controlling for age in the male subgroup alone.

This sex difference is also found when comparing the gender subgroup regression models; in the male model, after the effect of age has been controlled, the number of crashes reported is retained as a significant predictor of intuitive physics score. The positive regression coefficient in this model indicates that, above and beyond age, the more frequently a boy experiences cross-modal perceptual causality, the better his understanding of physical causality at the cognitive level. However, prediction of intuitive physics scores by cross-modal perceptual causality sensitivity is not apparent from the female data, after controlling for age.

With respect to perceptual causality, the significant main effect of auditory signal timing found for the group sample ANOVA indicated that sound influenced

visual processing to produce the percept of causality in this sample. The effect of co-occurrence of the auditory signal and occlusion was not as pronounced in the study sample as it had been for the adult pilot (Experiment 1). This difference might be a consequence of the lower level of auditory signal intensity used in the child study, as decibel variation has been recently shown to increase the probability of experiencing cross-modal causality (Zhou, Wong & Sekuler, 2007).

Alternatively, reduced response levels could be indicative of incomplete maturation of the distributed neural system activated by these stimuli. This suggestion appears valid in that CoMG crash reports are significantly and positively correlated with age in this sample (Experiment 3c), indicating that the strength of the perceptual causality induction under these circumstances increases over the course of development (although this relationship is significant only in the female subgroup data, when the gender subgroup data are analysed). The finding of developmental change in sensitivity to cross-modal illusory phenomena (Experiment 3c) has previously been demonstrated with respect to the McGurk effect in infants and children (McGurk & McDonald, 1976; Massaro, Thompson, Barron, & Laren, 1986; Rosenblum, Schmuckler & Johnson, 1997). This effect describes how auditory presentation of one syllable can be distorted by visual presentation of an alternative syllable, so that the syllable experienced is a blended distortion of the two (for instance, auditory presentation of /ba/ as lips are seen to mouth the syllable /ga/ produces the percept of /da/).

Developmental McGurk effect studies reported that sensitivity to the illusion is generally weaker for children than for adults, as reported in Experiment 3a.

Tremblay, Champoux, Voss, Bacon, Lepore and Theoret (2007) have recently reported similar findings of reduced effect strength during development with respect to cross-modal perceptual phenomena. They found that, by comparing three groups of children and adolescents (aged 5 – 9, 10 – 14 and 15 – 19 years), maturational evidence for the McGurk effect was replicated, in that the youngest age group perceived significantly fewer blended syllables than found for the older categories. They also found that the Shams illusion (where auditory presentation of a series of beeps increases the number of flashes observed in a stream of light; Shams, Kamitani & Shimojo, 2002) could be induced in these participants. In addition, induction of the fusion illusion, in which a single auditory stimulus causes two visual flashes to be perceived as a single event (Andersen, Tiipana & Sams, 2004), was found at each age category level. However, Tremblay et al. (2007) found no evidence of developmental trajectories for either the Shams or fusion phenomenon; homogeneous performance on the non-speech illusory tasks used was observed across the three age categories tested.

Tremblay et al. (2007) argue that perceptual integration is established early in infancy, and therefore is invariant by the age of 5 years in typical individuals. They then cite evidence of neural substrates implicated in both audio-visual speech processing (Champoux et al., 2006) and non-speech perceptual integration (Stein, 2005) to suggest that the three illusory effects they tested have early perceptual mechanisms in common, but conclude that audio-visual integration required for speech comprehension continues to develop, as it involves structures not recruited by the non-speech cross-modal stimuli. Therefore, susceptibility to the McGurk

phenomenon continues to increase in line with brain maturation across development.

The findings from Experiment 3c contradict the study by Tremblay et al. (2007); susceptibility to cross-modal stimuli that generate causal percepts (a non-speech phenomenon) was found to increase with age. The early emergence of this specific causality illusion (Scheier et al., 2003) therefore does not appear to preclude its further development. A possible explanation for the conflict between studies is that the non-speech Shams and fusion phenomena may recruit simpler neural networks than that activated by the cross-modal perceptual causality stimuli in the CoMG task. Connectivity with areas beyond the perceptual system may continue to mature during childhood so that subjective experience of the cross-modal perceptual causality phenomenon strengthens during development.

In terms of theoretical inter-relationships between the development of cognition and perception, as proposed by Michotte (1963) and Karmiloff-Smith (1992), the results of Experiment 3c could be interpreted to mean that the operation of perceptual causality processing serves the development of intuitive physics (a cognitive function). Continual development of audio-visual integrative pathways in the brain beyond early childhood would therefore be important to this specific perception/cognition relationship, much as the developmental trajectory of the McGurk effect implies that early perceptual integration supports the development of a complex distributed neural network for speech comprehension.

The findings that age is correlated with *both* perceptual causality and intuitive physics, and that the two are also significantly inter-related are ambiguous (Experiment 3c). Once unique variance attributable to age is controlled, the remaining partial correlation between perceptual and cognitive task performance is no longer significant (although a trend in the hypothesised direction is obtained). More importantly, the regression model for the group data indicates that there is no significant unique contribution of perceptual causality variance that accounts for variation in intuitive physics scores.

Age mediation between the perceptual predictor and cognitive outcome may therefore reflect parallel *or* conjoined developmental trajectories. One parsimonious explanation of age mediation here is that general neurological maturation takes place during development that affects both perceptual and cognitive processing. This view would position relationships between perception and cognition as an epiphenomenon, contradicting the prediction of a privileged relationship between the subjective experience of causality and the ability to understand physical cause-and-effect made by Michotte (1963). There are empirical precedents for such a 'universal factor' interpretation of the data. Nettlebeck and Wilson (1985), Hale (1990) and Kail (1991) have all proposed that processing speed improves developmentally, facilitating improvement in universal intellectual ability. Processing speed is derived from inspection time tasks, which measure the time required to discriminate between two simple visual stimuli (e.g. two lines of differing length) at a given level of accuracy under varying presentation durations. Systematic decrease in inspection time thresholds (ITs) is negatively related to chronological age, and inversely correlated with mental age.

Given the basic perceptual nature of the stimuli used in IT tasks, a simple explanation of the age-mediated relationship between perceptual causality and physical causal cognition in Experiment 3c is that as processing speed increases, audio-visual integrative efficiency improves, as does development of neurological processes supporting faster recall of stored information. However, the 'general factor' interpretation fails to account for the gender difference found between subgroup regression models, which suggests that male and female developmental trajectories differ in terms of the relationships between perceptual causality and intuitive physics. A gender-specific individual difference effect exists for boys; elevated experience of cross-modal perceptual causality predicts better aptitude in the causal physics task in the males alone. No unique relationship between perceptual causality and intuitive physics measures was found for the girls after controlling for age variance, and so there is no evidence of an individual differences effect within the female data. If the correlation between scores on the CoMG and WHN?T tasks in the overall analysis was simply the product of a general factor that improves with age, then no such gender-specific finding should be obtained.

Michotte (1963) predicted that the perceptual causality and causal cognition would be related, although he asserted that this association between perceptual experience and generalised representational knowledge would hold across all domains, physical and psychological. That this perception/cognition relationship appears to relate to boys' development alone (or is more tightly yoked together during development in boys than in girls) argues against this idea. Spelke and Kinzler (2007) maintain that a privileged relationship between object perception and

physical causal cognition has its basis in innate knowledge. Use of geometric relationships, numerosity discrimination, and knowledge of the physical properties of objects do not emerge at significantly different times or demonstrate significantly different levels of achievement at any given age between sexes during early development (Newcombe, Huttenlocher & Learmonth, 1999; Xu & Spelke, 2000; Kotovsky & Baillargeon, 1998). On the basis of this evidence, Spelke (2005) states that the innate knowledge that initiates concept enrichment and representational flexibility across development is common to both sexes, and hence there is no 'innate' male predisposition towards science at the cognitive level.

Karmiloff-Smith (1992) alternatively speculated that relationship between perception and cognition in the physical domain is driven by perceptual processing of environmental stimuli. As neurobiological differences are established in adult male and female brains (Baron-Cohen, Knickermeyer & Belmonte, 2005), the finding that boys and girls differ in terms of relationships between age, perceptual causality and intuitive physics could be argued to support her arguments; variation in male aptitude for physical science appears to have its origins in individual differences in recovering causal organisation from perceptual stimuli, but women's scientific ability appears to be related to brain maturation and development of general intelligence. This interpretation leaves open the question of whether perceptual processing generates maturation of cognitive architectures, or whether cognitive processing of perception supports maturation of neural connections, so that perceptual signalling is enhanced by top-down factors, as Spelke and Kinzler (2007) imply.

Issues of neural connectivity will be discussed in greater depth in Chapter 5, within the context of developmental disorders. If such a feedback/feedforward subsystem exists so that subjective experience and cognitive ability are inter-related with respect to the physical domain, then it can be inferred from the data obtained in Experiment 3 that this architecture is more relevant to the general male phenotype than the female, as indicated by evidence of a unique significant individual difference effect between CoMG and WHN?T scores in the male subgroup only. Innate representational knowledge of physics may be equivalent between genders (Spelke, 2005), but implicit knowledge acquisition through perceptual causality experience would provide a natural male advantage in later development, or at least orientation of larger numbers of boys than girls towards physical sciences. Review of statistics and research into the relative proportions of each gender represented in science academia and related career fields (Halpern et al., 2007) concords with such an extrapolation.

The alternative explanation of the sex difference found between the regression models in Experiment 3c is that an undetected sampling bias may exist between the gender subgroups, such that more intellectually talented boys than girls were recruited. The sexes are known to vary in that the normal frequency distribution curves for IQ scores contain a disproportionate number of men at both tail ends, with greater variance in male IQ than in female IQ across the population (Jackson & Rushton, 2006; Deary, Thorpe, Wilson, Starr & Whalley, 2003), and so this is a possible alternative explanation.

By no means can the data presented here be said to point unequivocally to the interpretation presented of sex differences in maturational development of cognitive domains. Experiment 3 represents solely an exploration of the hypothetical relationship between perceptual and cognitive development in a specific domain in which males are thought to exhibit superiority. The interpretation of the findings from Experiment 3 is that physics knowledge is naturally acquired in males from processing causal spatio-temporal relationships between objects, but that females have to learn this same knowledge explicitly. Such an implicit acquisition process would generate substantially more knowledge in male individuals with more efficient cross-modal processing, and so individual difference effects would arise across time in boys, leading to a positive correlation between the subjective experience of cause and effect and explicit knowledge of physical causality. Evidence of this individual difference effect was obtained in boys, but not girls.

Given the fact that IQ was not controlled in this study, it remains to be seen whether the findings represent a 'true' gender difference; the male perception/cognition relationship may be mediated by a cognitive factor such as non-verbal IQ, which has not been controlled in this study. Development of a universal processing factor and general neural maturation common to both genders but masked by a sampling bias (caused by higher frequency of talented boys amongst the science museum visitors) may also have distorted results. Further research is suggested in which talented individuals with high verbal and non-verbal IQs of both genders are tested on measures of cross-modal integration and a battery of socio-cognitive and cognitive tasks. However, assuming that the two gender

groups are equivalent in this study, this exploration has been fruitful, as it has yielded early evidence that perceptual differences may be related to cognitive performance variation, and that cross-modal perception does develop (in some sub-populations at least) outside of infancy.

2.6 General Discussion and Conclusion

At the start of this chapter, the view that autism reflects a developmental perceptual phenotype that generates the specific behavioural and cognitive profile characteristic of ASD (O’Riordan & Plaisted, 2006) was considered in terms of what is currently understood about the inter-related development of perception and cognition, within the context of brain maturation (Karmiloff-Smith, 1992; 2007). As a research area, neuroconstructivism is far from established, and so the study presented in this chapter represents an early exploration of some of the issues pertinent to typical development implicit within this idea.

The cognitive domain chosen to examine was that of intuitive physics. This is relevant to this thesis in general because it is thought that individuals with ASD may generally exhibit superiority in this ability, relative to other skills. Furthermore, this function is considered to relate more to the male cognitive phenotype than the female (Baron-Cohen, 2002). Given the evidence of neurobiological differences between genders and their disparate cognitive profiles (Baron-Cohen, Knickermeier & Belmonte, 2005; Halpern et al., 2007), it is plausible to suppose that biases exist in cross-modal integration systems such that integrative products activate socio-cognitive processes in ‘female type’ brains, and non-social cognitive processes in ‘male type’ brains. This conjecture is an extrapolation from the Extreme Male Brain

theory of autism (Baron-Cohen, 2002), in which he asserts that the biology of the male brain is distorted in ASD to the extent that small differences in neural architecture biasing some cognitive processes over others in males are exaggerated. Individuals with ASD, irrespective of gender, therefore generally present a cognitive phenotype that reflects an extreme version of the typical functioning of the 'male-type' brain, in which intuitive physics is over-developed to the detriment of development of socio-cognitive functions such as emotional comprehension.

Applying that logic to results from Experiment 3 generates a theoretical conflict. The original motivation for this thesis was to consider whether, as Iarocci and McDonald (2006) predict, the 'perceptual incoherence' reported by many people with ASD reflects multisensory processing problems at the perceptual level that are related to the distinctive cognitive and behavioural phenotypes associated with ASD. If, however, ASD is related to a superior male ability that is in part the product of perceptual integration, as concluded in Experiment 3, then tests of cross-modal perceptual causality should reveal no difference between groups of children matched for age, gender and intelligence. Yet if cross-modal integration is generally compromised at the perceptual level, then the facilitating effect cross-modal perceptual has on development of intuitive physics found in boys (Experiment 3) should not apply. Therefore, any superiority an individual with ASD exhibits with respect to intuitive physics must have developed through an alternate maturational process, in which case such they would not represent an 'extreme male'.

Consideration of this theoretical conflict is the motivation for examining cross-modal integration in relation to the Broader Autism Phenotype (Chapter 3)

and ASD (Chapter 4). In both chapters, cognitive performance on tasks in which ASD is thought to confer an advantage is measured in addition to assessing cross-modal perceptual causality, so that both cross-modal perceptual integration in relation to ASD, and hypothetical 'privileged' perception/cognition relationships relevant to ASD can be investigated.

Chapter 3: The Broader Autism Phenotype, cross-modal integration and cognitive superiorities.

3.1 Overview

Autism is known to have a strong genetic component (Bailey et al., 1995). Many relatives of individuals with ASD have been shown to exhibit the Broader Autism Phenotype (BAP; Bailey, Palferman, Heavey & Le Couteur 1998), in which behavioural aspects of the spectrum are represented in milder form as traits. If cross-modal perceptual integration is broadly deficient in ASD, then it should be possible to identify a weakness in this respect within BAP adults.

It has also been argued that aggregation of autistic traits is related to scientific talent (Baron-Cohen, 2008b), and superior visual disembedding with respect to the EFT (Happé, Briskman & Frith, 2001). Hence the BAP provides a non-clinical analogue model sample for testing both perceptual integration, and its relationships with the autistic cognitive phenotype (Wakabayashi et al., 2006). Autistic traits are distributed normally across the population (Baron-Cohen, 2008b), and so individuals expressing the BAP should be identifiable in a student sample using the Autism-Spectrum Quotient (AQ; Baron-Cohen et al., 2001a).

In the first study, the perceptual causality task from Experiment 3 is adapted in Experiment 4 to incorporate trials with visual cues known to evoke causal percepts. This adaptation allows audio-visually induced perceptual causality to be contrasted with its generation by visual 'causal capture' (i.e., where an unambiguous visual cue elicits the same phenomenon; Scholl & Nakayama, 2002),

to establish whether any deficit found is specific to cross-modal integration. This study also includes data from the Intuitive Physics task (Baron-Cohen, Wheelwright, Scahill, Lawson & Spong, 2001), in order to determine whether heightened ability in physics is associated with the BAP, and to explore whether it relates to perceptual integration both within and across modes.

Experiment 5 repeats the task used in Experiment 3 to determine the temporal pattern of response to cross-modal perceptual causality stimuli associated with the broader autism phenotype, to determine whether spatio-temporal contingencies constraining autistic perceptual integration might be atypical. Reported superiority of people exhibiting the BAP in terms of Embedded Figures Task performance (Happé, Briskman & Frith, 2001) is also re-investigated in this experiment. Weak central coherence theory (Happé & Frith, 2006) states that elevated accuracy levels and reduced response latencies on this task reflect a general cognitive bias towards detail processing. However, performance of the EFT by participants with ASD could be argued to be perceptually-driven (Jarrod, Gilchrist & Bender, 2005; Pellicano, Gibson, Maybery, Durkin & Badcock, 2005). Enhanced visual detail processing is potentially related to compromised audio-visual integration; hypothetically performance on the EFT should show an inverse relationship with performance on the cross-modal perceptual causality task. The study therefore also allows exploration of a proposed link between weak central coherence, the BAP and perceptual integration.

Given evidence of sex differences with respect to both cognitive tasks used, the analytical approach taken includes consideration of male versus female

performance as well as BAP vs. non-BAP group performance on both the EFT and the Intuitive Physics tests, in order to determine whether results are simply indicative of male: female ratio biases in low and high AQ scoring groups. Comparison of male versus female performance within these groups is also undertaken in order to evaluate the claim within Extreme Male Brain theory (Baron-Cohen, 2002) that autism represents an exaggeratedly male brain. Many of the concepts relating to this chapter have not been provided in Chapter 1, and so Chapter 3 includes a literature review prior to presentation of Experiments 4 and 5.

3.2 Introduction

Across the last decade, the parameters and components of Broader Autism Phenotype have been widely debated. The triad of behaviours at the centre of ASD diagnosis has been evidenced in the BAP in relation to pragmatic and formal/cognitive aspects of language, impaired social skills (ability to form friendships and atypical social play) and repetitive or obsessive tendencies (Bailey et al., 1998; Fombonne, Bolton, Prior, Jordan & Rutter, 1997; Murphy, Bolton, Pickles, Fombonne, Piven & Rutter, 2000). The repetitious and obsessive traits discovered generally appear in association with either social or communication challenges (Bolton et al., 1994). In addition, behavioural self-report of parents with sons with autism indicate that some parents and siblings have patterns of social and non-social preferences and abilities similar to the affected child (Briskman, Happé & Frith, 2001).

Similarly, outside of triad-related behaviours, Happé, Frith and Briskman (2001) investigated whether cognitive markers associated with ASD are also found in relation to the BAP. Their research has indicated that family members of children with ASDs tend to exhibit a similar cognitive profile in relation to tests for weak central coherence, including the Embedded Figures Task and the Block Design Test (Kohs, 1923, cited in Shah & Frith, 1993). Performance on both of these tasks was found to be superior in fathers in comparison with mothers of target children, and with control parents of either TD or dyslexic children.

Generally, then, continuity exists between the fundamental cognitive and behavioural profiles typifying ASD and the BAP. It is thought that the continuum between individuals with ASD and their families extends into the general population, in which case it should be possible to identify the BAP in individuals whose families do not have direct connections with the diagnosis of ASD. A proportion of the 'normal' population who have inherited several autism genes without reaching the threshold required for expression of diagnosable ASD should be identifiable; these individuals should manifest many of the traits associated with diagnostic criteria. Such people can be identified through screening using the Autism Spectrum Quotient, a scale used by Wakabayashi et al. (2006) to determine that 'autistic-ness' is an independent personality trait. Most people (93%) without a diagnosis have an AQ score between 0 and 25, and 99% of individuals with ASD score 26 or above, with 80% scoring above 32 (Baron-Cohen, 2008b). Mapping the broader phenotype onto the top 10% of the 'normal' range of autistic trait expression therefore provides an opportunity to expand empirical ASD research using the BAP as 'analogue' model (Wakabayashi et al., 2006).

3.2.1 The Broader Autism Phenotype and perceptual causality

Research into the broader phenotype has been focused on relating behavioural and cognitive characteristics with the autistic genotype, and so little extant research can be outlined here regarding the BAP and perceptual processing. However, there is early evidence that perceptual differences associated with ASD can also be found at an attenuated level within families of affected individuals. For instance, Dalton, Nacewicz, Alexander and Davidson (2006) have used eye-tracking techniques to show that the unaffected siblings of children with autism produce fewer fixations to the eye regions when viewing static pictures of faces than do controls.

This finding has been supported by a study of eye fixation during social interaction, in which at-risk six month old infants were found to gaze less than controls from unaffected families at their mother's eyes and more at their mouths (Merin, Young, Ozonoff & Rogers, 2007). Similarly, scores on the AQ were found to negatively correlate with reflexive attentional shifts when viewing faces with averted eye gaze in a student sample (Bayliss, di Pellegrino & Tipper, 2005), suggesting insensitivity to this perceptual cue. Fathers of autistic children have also been shown to have general reaction time delays relative to control fathers on a task assessing reflexive attentional responses to visual cues, irrespective of the social (eyes) or non-social (arrows) nature of the cues (Scheeren & Stauder, 2008).

Although these studies mainly use social stimuli, together they suggest that the BAP may represent an intermediate stage along a continuum with ASD in terms

of a common perceptual-attentional profile. This suggestion is supported by recent evidence (McCleery, Allman, Carver & Dobkins, 2007) showing a link between familial risk of ASD and enhanced low-level perceptual processing (as assessed by luminance contrast sensitivity).

Induction of perceptual causality phenomena by unimodal and cross-modal cues has not been examined in relation to ASD previously, to my knowledge. With respect to unambiguous perceptual causality, however, recent comparison of the ability of children with ASD, TD children and children with MLD to correctly discriminate between movies of causal launching events and non-causal control events (in which launching was delayed) produced evidence of atypical causal perception in the target group alone (Ray & Schlottman, 2007). The children with ASD in this study were equally likely to categorise the control and launching events as being physical in nature, unlike both groups of control children who viewed the causal trials as being physical more frequently than the delayed launch trials. Ray and Schlottman (2007) concluded that the critical factor influencing autistic performance in their study was the short duration of the information critical to generating causal percepts in their stimuli (an interval of 21 milliseconds), hence suggesting that the temporal encoding of perceptual information may be corrupted in ASD. On the basis of this interpretation, varying auditory signal presentation in cross-modal perceptual causality stimuli is hypothesised to generate an unusual pattern of causal percept experience in individuals with high autistic trait expression (Experiment 5).

Taken together, these studies suggest that the frequency of experiencing causal perception may be reduced in relation to the BAP, given that children with ASD may have unusual temporal parameters constraining perceptual causality and that individuals with the BAP have been shown to have some perceptual atypicalities in common with ASD. Both Experiments 4a and 5a measure sensitivity to perceptual causality in the BAP under a range of conditions designed to consider the influence of perceptual and temporal factors.

3.2.2 The Broader Autism Phenotype and Intuitive Physics

Science aptitude is thought to be related at the genetic level to Asperger Syndrome and autism. Baron-Cohen, Wheelwright, Stott, Bolton and Goodyer (1997) found that fathers of children with autism are over-represented in professional engineering. Autism prevalence is also exaggerated in families of engineers, mathematicians and physicists (Baron-Cohen, Bolton, Wheelwright, Scahill, Mead & Smith, 1998; Baron-Cohen, Wheelwright, Burtenshaw & Hobson, 2007). Parents of ASD probands were also found to score highly on the social and communication subscales of the AQ (Bishop, Maybery, Maley, Hill, Wong & Hallmayer, 2004, but see also Scheeren & Stauder, 2008). Groups of students taking scientific degrees produce significantly higher total AQ mean scores than control groups of students whose subjects are not science-related (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Thus academic and vocational aptitudes may be related to autistic-like perceptual, attentional and social behaviours, reflecting an association between the broad autism genotype and

domain-specific cognitive abilities, found within both families and student populations.

The connection between science and the BAP is further substantiated by individuals with autism who exhibit dissociated ‘savant’ skills in relation to calendrical or mathematical calculation (Hermelin, 2002), high-functioning individuals with autism who excel in technical and mathematical fields (Baron-Cohen, Wheelwright, Stone & Rutherford, 1999) and empirical findings of spared or superior innate intuitive physics ability in several studies of children and adults with ASD (see Chapter 4).

Taken together, the evidence of science- and maths-related ‘islets of ability’ outside of general intellectual functioning, and the relationship between familial BAP and science aptitude suggests that specific alleles exist within the autistic genotype that confer scientific aptitudes. Students with relatively high autistic trait expression should therefore generally produce high Intuitive Physics task scores, irrespective of gender (Experiment 4b).

3.2.3 Weak central coherence and the Broader Autism Phenotype

Weakened central coherence, or the tendency to process local details at the expense of forming global representations, has been found to characterise the Broader Autism Phenotype in relation to fathers of diagnosed children (Bolte & Poutska, 2006; Briskman, Happé & Frith, 2001), although fathers within families

with an autistic child do not always do better on the Block Design Test (Fombonne, Bolton, Prior, Jordan, & Rutter, 1997; Piven & Palmer, 1997)

Evidence that global processing is not necessarily deficient in ASD (e.g. Mottron, Burack, Stauder & Robaey, 1999) led to weak central coherence theory being redefined as a cognitive preference or bias for processing detail (Happé & Booth, 2008). Local processing superiority, rather than a global deficit, may therefore be the mechanism underpinning elevated autistic performance, reflecting a particular *perceptual* profile specific to autistic perception. Jarrold, Gilchrist and Bender (2005) found that enhanced single visual feature search performance was correlated with EFT latencies in ASD, whereas it correlated with conjunction search in typically-developing controls, suggesting that this idea has merit. Also, Pellicano, Gibson, Maybery, Durkin and Badcock (2005) have tested the association of global motion coherence thresholds with EFT measures in children diagnosed with ASD. Relative to typically developing children, children with ASD took less time to resolve CEFT trials and showed higher global motion thresholds when tested with dynamic global dot matrix (GDM) patterns. These researchers also found that the two tasks to be inversely related in the ASD group; faster (i.e., superior) visual disembedding was found to be related to greater difficulty with processing motion.

This relationship between motion processing and EFT superiority is relevant here because the cross-modal perceptual causality stimuli are dynamic; weakened processing of motion information is therefore a potential mechanism for the audio-visual integration deficit predicted to be related to the BAP. In Experiment 5c, the inverse correlation between motion and detail processing in ASD reported by

Pellicano et al. (2005) serves to suggest that enhanced EFT performance will be related to decreased cross-modal perceptual causality sensitivity in the broader phenotype sample.

3.2.4 Extreme male brain theory and the Broader Autism Phenotype

In accordance with Extreme Male Brain theory and gender imbalances evident in ASD, the broader autism phenotype appears to be more prevalent among men than women. This gender bias towards males is corroborated by the fact that more male students than females score highly on the AQ (Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001), and in general males' AQ scores are significantly higher than females', although women with ASD score similarly to men (Wheelwright, Baron-Cohen, Goldenfeld, Delaney, Fine, Smith, Weil & Wakabayashi, 2006).

However, general gender differences in performance of tasks relating to ASD research have been well-established, and so consideration must be given to whether any BAP differences highlighted in Experiments 4 and 5 are due simply to gender effects reflecting sex imbalances between groups. Baron-Cohen (2002) is careful to argue that 'male brain' females (i.e., with the Broader Autism Phenotype) do exist, but that they are relatively rarer than men displaying this phenotype. Correlation between AQ totals and scores on the Systemising Quotient (SQ) which looks at tendencies to think at detail-level in systematic ways suggests that women with many autistic behavioural traits generally resemble extreme systemisers, just as high AQ scoring men do (Wheelwright et al., 2006). Therefore females with the BAP from a student population should perform similarly to equivalent males on cognitive

tasks in which autistic performance is generally superior, such as Intuitive Physics tests or the EFT (Experiments 4b and 5b).

3.2.5 Summary of Hypotheses

The primary aim of this chapter is to determine whether the BAP is associated with compromised perceptual integration, as evidenced by reduced susceptibility to cross-modal perceptual causality. The secondary motivation is to consider perceptual/cognitive relationships associated with the BAP.

The BAP group should manifest compromised sensitivity to cross-modal perceptual causality stimuli in Experiment 4 (by extension from Iarocci & McDonald, 2006). In Experiment 5 this group should produce an atypically flat response to varying temporal correspondence between auditory and visual components (by extension from Ray & Schlottman, 2007). Conversely, low AQ scorers should present relatively heightened sensitivity and normal temporal response patterns in these two experiments, on the basis that they represent the opposite end of the autistic continuum within the normal population.

According to EMB theory and known gender differences, performance on tasks in which individuals with autism generally show superiorities (Intuitive Physics and EFT) should be elevated in men, who should generally outperform women. Individuals with the BAP (high AQ scorers with exaggeratedly male brains) should show significant differences from low AQ scorers, (i.e., who

represent 'extreme female brains'). These hypotheses are tested in Experiments 4b and 5b.

A significant positive correlation between intuitive physics scores and perceptual causality responsiveness was found in TD boys in Experiment 3. However it is hypothesised that high AQ scoring participants will show both atypically low responsivity to cross-modal perceptual causality stimuli (Experiment 4a) *and* superior physics ability (Experiment 4b). If the same perception/cognition relationship found in Experiment 3 is obtained in typical men (Experiment 4c) then on the basis of EMB theory it should also be found in the BAP group, therefore the prediction for Experiment 4c conflicts with the hypotheses in Experiments 4a and 4b.

In Experiment 5c it is predicted that suppressed cross-modal perceptual causality responsiveness will be related to faster response latencies on the EFT with respect to the BAP data, based on findings from EFT/global motion processing research (Pellicano et al., 2005) that the degree of compromise in processing dynamic visual stimuli is negatively related to EFT performance in ASD.

3.3 Experiment 4: The BAP, Perceptual Causality and Intuitive Physics.

3.3.1 Introduction

The objective in this study was to determine whether cross-modal perceptual integration is compromised in relation to the broader autism phenotype. Responses

to audio-visual stimuli inducing the percept of causality were therefore contrasted with responses to simple ambiguous stimuli (in which no disambiguating cues were presented) across groups categorised by either Low, Medium or High total AQ scores (with high scores representing BAP). An additional visual condition was added to the task so that any cross-modal effects found between groups could be compared to the effects generated by a within-mode (visual only) cue. The visual cue used mimicked the causal capture stimuli developed by Scholl and Nakayama (2002; see Figure 3.1), in which an unambiguous causal launch event is presented immediately below the ambiguous event. In the original study, Scholl and Nakayama (2002) reported a launch percept percentage of 92.1% in response to similar stimuli, and concluded that an inference of causality automatically generalises to the ambiguous event when it is presented alongside an unambiguous contextual causal event. Such stimuli offer an opportunity to run a within-group comparison condition to ensure that any deficits in cross-modal perceptual causality found in relation to the BAP are specific to cue type, and not simply a reflection of poor perceptual causality *per se* in this group.

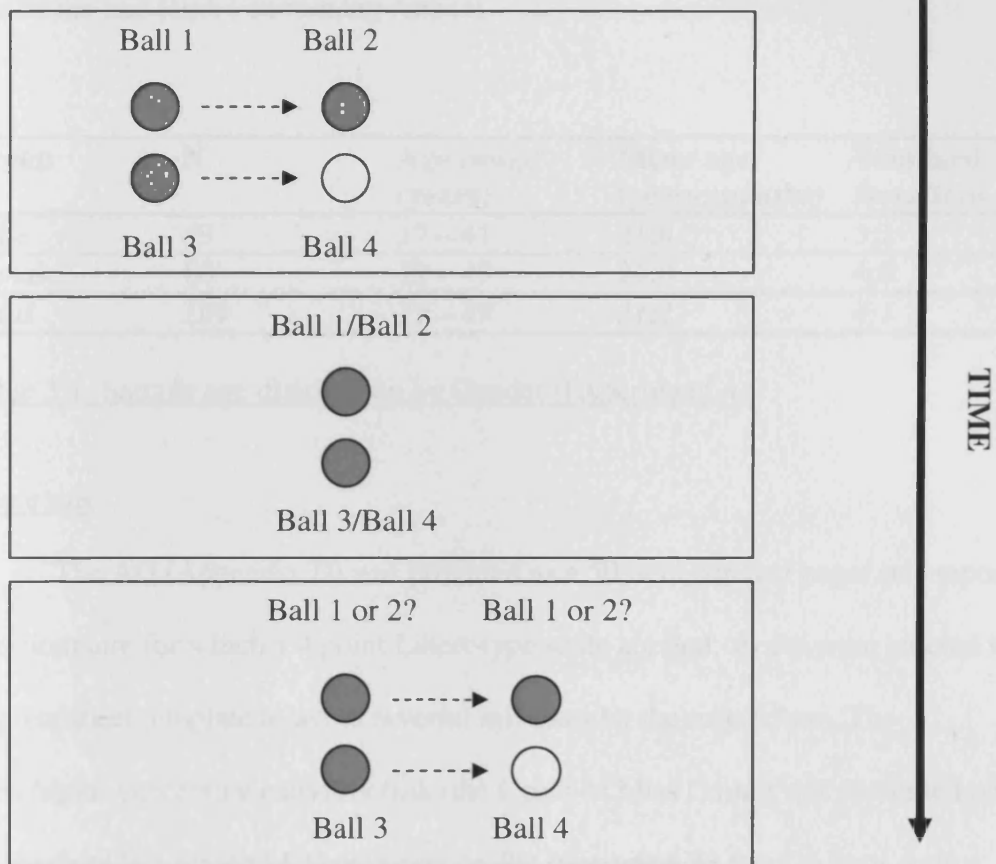


Figure 3.1: Visual capture stimulus (derived from Scholl & Nakayama, 2002).

3.3.2 Method

Participants

Participant recruitment and data collection in this study was supported in part by undergraduate psychology students under the supervision of L. Grayson and Prof. S. Killcross. A total of 114 Cardiff University undergraduate participants were recruited, 109 of whom completed all 3 tasks. This volunteer group comprised 48 males and 60 females aged between 18 and 49 years. All participants had normal or corrected vision and normal hearing. The following diagnostic exclusions applied:

Dyslexia; colour blindness; Attention Deficit (Hyperactivity) Disorder; Aspergers Syndrome and High Functioning Autism.

Group	N	Age range (years)	Mean age (years;months)	Standard Deviations
<i>Male</i>	49	19 – 41	21;0	3;2
<i>Female</i>	60	19 – 49	21;3	4;8
Total	109	19 – 49	21;2	4;1

Table 3.1: Sample age distribution by Gender (Experiment 4)

Apparatus

The AQ (Appendix D) was provided as a 50 item pen and paper self-report questionnaire for which a 4 point Likert-type scale applied; scores were entered into a spreadsheet template to avoid reversal mistakes by the researchers. The launch/pass perceptual causality task (the Crash or Miss Game) was presented on 20 identical flat-screen LCD monitors on flat measuring 33.8 by 26.9cm, with a screen resolution set to 800 by 600 pixels and screen refresh rate of 60Hz, running from generic PC hard drives. To ensure that sound presentation intensity was equivalent between participants, the system sound was set to a defined level for each experimental session, and sounds were presented via headphones at a pressure level of 68dB⁵. The task was presented in VisionEgg and programmed in Python. The programme collected data from each participant as a separate text file, allowing for collation in Excel. Data were recorded via PC mouse button presses; a standard IntelliMouse Optical 1.1A USB mouse was provided for each PC on which a red sticker had been placed to indicate the left button, and a yellow sticker had been attached to highlight the right button.

⁵ Dominant frequency 2719 Hz; auditory stimulus duration measured at 5.5ms.

The Intuitive Physics⁶ task (Baron-Cohen et al., 2001b) was provided as a pen and paper exercise (Appendix E). This task comprises 20 multiple-choice items, each asking the participant to identify which of four options correctly answers a question in relation to a diagram of a mechanical system. A correct score total was provided for each participant by marking responses against the answer set supplied by Baron-Cohen et al. (2001b).

Crash or Miss Game Stimuli

All trial stimuli comprised two-dimensional green, white or a combination of green and white disks, each subtending a visual angle of 2.1 degrees⁷, which were presented against a black background, moving along the horizontal plane. The speed for disk movement was set at a constant of 24 degrees⁸ per second for half the practice trials and 35 degrees per second for the remaining practice and all session trials. The ten practice trials were a mixture of trial types to be included in the experimental session and some unique trials included to prevent any explicit 'rule learning' that might evoke cognitive interpretation of later trials.

Control trials provided unambiguous launch displays and unambiguous pass displays. In the first of these, a disk in either green or white moved towards a second stationary disk in the alternative colour and stopped adjacent to it, at which point the second disk moved at the same speed for the same duration. For the second, a disk of one colour moved towards a second stationary disk in the

⁶ Downloaded from http://www.autismresearchcentre.com/tests/intuitive_physics_test.asp, on 23rd November, 2005.

⁷ At an estimated average viewing distance of 57cm (Viewing distance between participants could not be constrained).

⁸ At a viewing distance of 57cm

alternative colour until this disk was completely occluded, and then continued its trajectory.

Experimental trials were categorised as either Ambiguous (both disks being the same colour), or Visual (an ambiguous event presented in conjunction with a contextual unambiguous launch; Figure 3.1), or Audio-Visual (an ambiguous event in which a click was provided at the point of the disks' spatial coincidence). The context event in the Visual trials was presented one disk height below the horizontal plane, with the point of adjacency set to coincide with spatial occlusion of the ambiguous event above.

Trials within each trial type (10 crash; 4 miss; 30 Ambiguous; 20 Visual; 20 Audio-Visual respectively) were counterbalanced in terms of starting point (screen left or right) duration (either 650, 700 or 750ms) and first moving disk colour (either green or white). All trials started with a 200ms offset, after which the first moving disk in the horizontal plane 'flashed' three times for 5ms (with two stimulus offset durations of 500ms between flashes); this served to direct attention exogenously to this ball prior to the start of the trial. Starting positions also varied; three start points were provided for both right and left presentations of each trial type, with event distances for both the main and any context event calculated on the fly to maintain a speed constancy of 35 degrees per second, as prescribed by the specific duration set for each trial. The start positions of the context capture events were adjusted automatically at programme level to ensure adjacency of the colliding disks coincided with the point of total disk occlusion within the ambiguous event presented above, such that both events' stationary disks were

aligned at the trial start. The start and stop positions for all events, irrespective of trial type, were equidistant from the midline of the presentation screen. Variation in start positions, in conjunction with left/right presentation and random alternation between colours for the first moving disk, prevented observers from making pre-emptive judgements based on learnt associations from prior experience.

Experimental trials assigned to each trial type therefore varied according to the start position, disk colour and right/left screen presentation of the moving disk. As far as possible, these different factors were counterbalanced within and across trial types. For each trial type, the trials were randomised prior to being assigned to one of five blocks. Each blocked therefore comprised 17 trials (apart from the final block, which was reduced to 16 trials). Within-block order was then randomised for each participant. This method ensured that an equal number of trials of each type was presented per block, to avoid generating any perceptual biases that may have affected high and low AQ scoring participants differentially.

Procedure

Task presentation order was invariant across participants. The AQ was completed prior to the CoMG, which was followed by the Intuitive Physics task. The CoMG task was presented in a well-lit computer laboratory at varying times of the day. Instructions were provided onscreen. Participants were instructed to press the red mouse button whenever they saw an onscreen event they perceived as being a crash (launch), or the yellow mouse button for a miss (pass). Participants completed a practice set of 10 trials before proceeding directly to the experimental session. Red and yellow response prompts remained onscreen during each trial.

After each response, the message 'press the space bar to continue' was presented. This message did not appear until a response had been made. No response was accepted by the program until each trial had completed presentation; pre-emptive button presses were implicitly trained out of early responders as the session did not continue until they responded again after the disks stopped moving.

Blocks were delineated by the presentation of onscreen graphics and voiceover messages, allowing participants to rest between blocks and to choose (by pressing the spacebar) when they wanted to continue. The experiment concluded with onscreen presentation of a thank you message.

3.3.3 Results

Outlier analysis and group allocation

Four outliers (three female and one male) were identified through analysis of total errors produced by collapsing the 'crash' and 'miss' control trial data; total accuracy scores for each of these participants exceeded 2 standard deviations below the mean for the entire group. After outlier exclusion, all participants reported 10 out of 14 unambiguous trials correctly. Six participants were identified as having accuracy scores that fell more than 1 standard deviation below the group mean for the unambiguous control variable, but as this variable showed a strong ceiling effect it was considered that their removal would reduce power if an over-stringent exclusion criterion was applied. Mean accuracy scores between gender subgroups did not differ significantly ($\mu(\text{male}) = 1.87$; $\mu(\text{female}) = 1.79$; $t(103) = 0.85$, $p >.05$).

Group	N	Range	Mean AQ score (/50)	Standard Deviations
<i>Men</i>	48	2 – 27	14.3	5.7
<i>Women</i>	57	3 – 27	13.1	5.3
Totals	105	2 – 27	13.7	5.5

Table 3.2: Total AQ scores by Gender (Experiment 4).

The 105 remaining participants produced total AQ scores ranging from 2 to 27. Mean scores and standard deviations by gender are provided in Table 3.2 (for subscale statistics, see Appendix F). The mean and standard deviations obtained were comparable with those produced by testing a population of 174 adults (16.4 and 6.3, respectively; Baron-Cohen et al., 2001b), although the distribution derived from these data displayed a slight bias towards the lower end of the scale.

Assessment of values obtained for kurtosis ($\eta_2 = -.49$) and skewness ($\eta_1 = 1.01$) indicated that these data were normally distributed (as were the distributions obtained from each gender sub-group). Mean AQ scores obtained from each gender sub-group (Table 3.2) were not significantly different ($t(103) = 1.11, p > .05$).

It was decided to use one standard deviation above and below the AQ distribution mean as the method to define group boundaries for analysis. As the AQ produces integer scores, the decimal places criterion was set at zero meaning that the standard deviation of 6 produced an upper score limit of 20 and a lower limit of 8. Participants within and including these scores were considered as falling into the medium score group, participants with scores of 21 or above were allocated to the high AQ score (BAP) group, and those with scores of 7 or below were grouped as low AQ scorers. The groups obtained corresponded with those that would be

generated using top and bottom ten percentile criteria. Table 3.3 provides descriptive data for the groups generated on this basis.

Group	N	Gender ratio (M:F)	Range AQ scores	Mean AQ scores	Standard Deviations
<i>Low AQ</i>	12	1:2	2 – 7	4.9	1.7
<i>Medium AQ</i>	80	1:1.22	8 – 20	13.4	3.4
<i>High AQ (BAP)</i>	13	1.6:1	21 – 27	23.4	2.1
Totals	105	1:1.2	2 – 7	13.7	5.5

Table 3.3: Descriptive statistics by AQ Group (Experiment 4).

A one-way ANOVA of AQ scores by group confirmed that there was a significant effect of Group ($F(2,102) = 110.1, p < .0005$)⁹. Dunnett t-tests (using the medium AQ group as the control group) indicated that the mean total AQ scores for the high and low scoring groups both significantly differ from the mean obtained for the medium-range AQ score group. High (BAP) and Low AQ groups showed gender imbalances, with two-thirds of the high group being male, and two-thirds of the low group being female. There was comparatively equal distribution between genders for the medium-scoring group. Comparison of the means of the collapsed control trial data between genders indicated that there was no significant difference in overall accuracy when making unambiguous crash and miss judgements between the male and female participants in this study ($\mu(\text{male}) = 1.89; \mu(\text{female}) = 1.86; t(103) = 0.85, p > .05$). A one-way ANOVA with AQ Group as the between factor and total accuracy as the dependent variable also indicated that the groups categorised according to AQ scores did not differ in this respect ($\mu(\text{low AQ}) = 1.89; \mu(\text{medium AQ}) = 1.87; \mu(\text{high AQ}) = 1.86, F < 1$).

⁹ Levene's test for homogeneity of variance was significant, but no adjustment has been made on the basis that the F statistic obtained is very large.

Experiment 4a: Gender and AQ Group Crash Report Analysis for the CoMG task.

For the experimental data, there were three conditions of the within-subjects factor, Trial. These were defined by trial type: Ambiguous (no cue), Audio-Visual ('click' cue) and Visual ('capture' cue). The dependent measure was the proportion of crashes reported.

Analysis 1: Crash Reports by Gender

Trial type	Gender	N	Mean	Std. Deviation
Ambiguous	Male	48	.18	.22
	Female	57	.14	.15
	Total	105	.16	.19
Audio-Visual	Male	48	.66	.35
	Female	57	.75	.31
	Total	105	.71	.33
Visual	Male	48	.69	.34
	Female	57	.78	.26
	Total	105	.73	.30

Table 3. 4: Means and standard deviations of crash report proportions for each CoMG experimental Trial type, by Gender (Experiment 4a).

The descriptive statistics for the crash report proportions for each trial type according to gender are provided in Table 3.4. Performing a 2 x 3 mixed ANOVA with Gender as the between-group factor and Trial as the within-group factor demonstrated that gender is not influential; neither a main effect of Gender ($F(1,103) = 1.88, p >.05$) nor an interaction between gender and trial type ($F(2, 206) = 2.08, p >.05$) were obtained. However, a main effect of Trial (the within-subjects measure) was obtained ($F(2,206) = 165.48, p < .0005$)¹⁰. Bonferroni-adjusted post-hoc pairwise comparisons indicated that the Ambiguous trials produced

¹⁰ Statistic reported with Huynh-Feldt adjustment, as Mauchley's test of sphericity was significant.

significantly fewer crash reports than both cue-based trial types: ($t(104) = -16.62$, $p < .0005$ for Ambiguous vs. Audio-Visual trials; $t(104) = -19.59$, $p < .0005$ for Ambiguous vs. Visual trials). The Audio-Visual and Visual trial types were not found to be significantly different ($t(104) = -.55$, $p > .05$).

Analysis 2: Crash reports by AQ Group

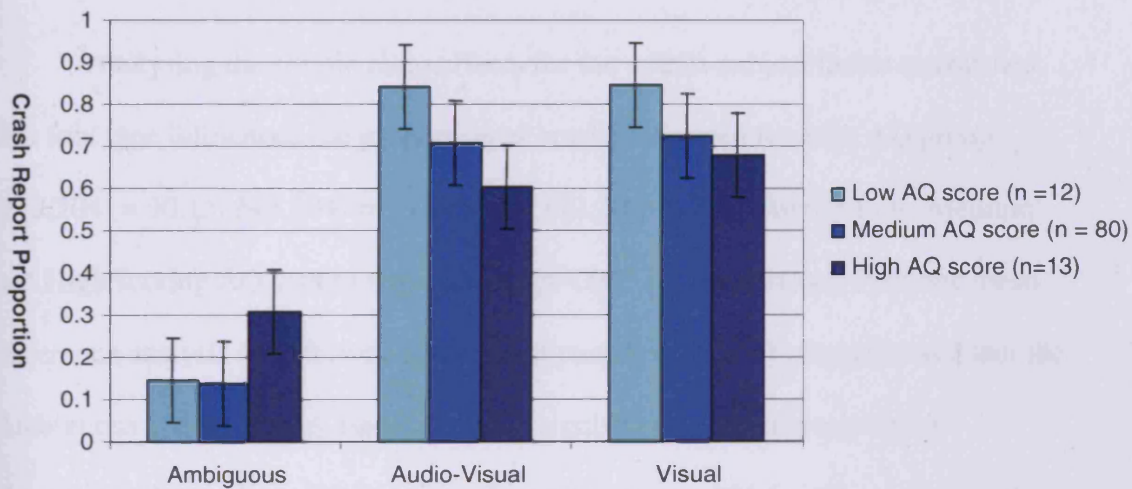


Figure 3.2: Crash Reports by Trial Type and AQ Group (Experiment 4a).

The cell means and standard error values of crash responses for each trial type obtained from each AQ group are represented in Figure 3.2. With respect to the Ambiguous trials (no cue) the High AQ group perceived more crashes than the other two groups, whose crash report scores were comparable. However, high scorers reported the fewest crashes in response to both cue-based trial types, more so in the audio-visual than in the visual condition. The low AQ group reported more crashes than medium range group in response to both types of cue-based trials.

A 3 x 3 mixed ANOVA was performed to test the effect of categorisation by total AQ score (the between-group factor) on crash reports obtained for each

trial type (the within-group factor). The main effect of Trial was significant ($F(2,204) = 78.10, p < .0005$), confirming that the scores between trial types differed. No main effect of AQ group was found ($F(2,102) = 1.21, p > .05$). However, a significant interaction between Trial and AQ group ($F(4, 204) = 2.46, p < .05$)¹¹ was obtained, indicating that the specific pattern of responses to trial types varied significantly between groups.

Analysing the simple main effects for the within-subject factor established that trial type influenced the proportion of crashes reported for each AQ group ($F(2,204) = 30.15, F(2,204) = 139.85$, and $F(2,204) = 7.84$, for the Low, Medium and High scoring AQ groups respectively, $p < .005$ for each value). Post-hoc mean difference analysis (Bonferroni-adjusted) at each level of AQ group showed that the Ambiguous condition was associated with significantly lower crash report proportions than either of the cue-based conditions ($p < .001$ for all comparisons), which did not significantly differ from each other.

Analysis of the simple main effects of AQ group (the between factor) at each level of the within-subject factor obtained a significant result only within the Ambiguous condition ($F(2,102) = 5.14, p < .01$). There were no significant effects of AQ group on the proportion of crash responses found for either the Audio-Visual or Visual trial types. Dunnett's method for testing responses against a selected group was used for post-hoc analysis of responses to the Ambiguous trial condition because the number of crashes reported by the High AQ group looked unusually elevated. The analysis established that crash response scores for both the Low and

¹¹ The large discrepancies between cell sizes resulted in Mauchley's test of sphericity being significant; Huynh-Feldt adjustment reduces this p value to a trend rather than significance ($p = .059$).

Medium scoring AQ group were significantly reduced in comparison to those obtained from the High AQ group for ambiguous trials.

As there was also some indication that crash response scores vary by AQ group with respect to the Audio-Visual condition, a direct comparison between crash report proportions for this condition obtained from the Low and High AQ groups was conducted. An independent samples *t*-test revealed a trend towards significance ($t(23) = 1.87, p = .07$). This trend is in the hypothesised direction, and the Cohen's *d* for this *t*-value is .78; an effect size of such high magnitude (Cohen, 1988) suggests that power was too weak in the general analysis for this comparison to be revealed as significant at post-hoc level, and so a Type II error cannot be discounted.

Experiment 4a: Gender and AQ Group Response Latency comparisons for the CoMG task

For this set of analyses, it was decided to include a reaction time measure derived from unambiguous trial types (the control conditions), in addition to latencies obtained from ambiguous trial types (the experimental conditions), to ensure that any differences in response latencies found between gender or AQ groups are not simply indicative of any general speed factor differences. Analysis of the reaction times for the unambiguous crash and miss control trials pooled across the entire data set indicated that they were not significantly different, but were correlated ($\mu(\text{crash}) = 360.9\text{ms}$; $\mu(\text{miss}) = 385.7$; $t(104) = -.93, p > .05$; $r = .58, p < .01$). Therefore data from these two control conditions were averaged to create a

baseline latency variable (Unambiguous), against which the experimental data could be compared.

Analysis 3: Latencies by Gender

Trial type	Gender	Mean	Std. Deviation	n
Unambiguous	Male	359.40	265.43	48
	Female	384.74	242.45	57
	Total	373.15	252.29	105
Ambiguous	Male	376.31	273.72	48
	Female	425.42	326.97	57
	Total	402.97	303.37	105
Audio-Visual	Male	514.58	446.71	48
	Female	533.93	509.95	57
	Total	525.09	479.90	105
Visual	Male	473.54	333.13	48
	Female	480.37	321.02	57
	Total	477.25	325.05	105

Table 3.5: Means and standard deviations of CoMG response latencies (milliseconds) by Trial Type and Gender (Experiment 4a).

Descriptive statistics for response latencies obtained for each trial type split by gender are provided in Table 3.5. Mean responses between genders and across trial types did not appear to vary considerably within genders or across trial types, the exception being that the audio-visual trials were generally longer (irrespective of gender). Analysis of response latencies using a 2 x 4 mixed ANOVA , with Gender as the between-group factor and Trial as the within-group factor, indicated that there was a main effect of Trial ($F(3,309) = 10.79, p <.001$ after Huynh-Feldt adjustment). There was no evidence of significant difference between male and female subgroups; no main effect of Gender, or significant interaction between Gender and Trial, were obtained ($F < 1$, in each case).

Trial type Pairs	Mean Differences (milliseconds)	T-test Values	Significance*
Unambiguous vs. Ambiguous	-29.82	-1.44	$p > .05$
Unambiguous vs. Audio- Visual	-151.93	-3.80	$p < .001$
Unambiguous vs. Visual	-104.10	-4.81	$p < .001$
Ambiguous vs. Audio-Visual	-122.11	-4.14	$p < .001$
Ambiguous vs. Visual	-74.28	-3.29	$p = .001$
Audio-Visual vs. Visual	47.84	1.26	$p > .05$

*Significance level of two-tailed paired t-tests after Bonferroni adjustment.

Table 3.6: Post-hoc comparisons between Trial Type response latencies means in (Experiment 4a).

The main effect of trial was analysed further (Table 3.6). Post-hoc tests adjusted for multiple comparisons between trial types showed that response took longer in relation to the two cue-based experimental conditions than when no cue (Ambiguous trials) or ambiguity was present (Unambiguous trials). However, no significant differences between either Audio-Visual and Visual experimental trial types, or Ambiguous and Unambiguous trial types, were found.

Analysis 4: Latencies by AQ Group

Prior to analysis of the effect of AQ group on response latencies, outliers whose average response times relating to the Unambiguous latency variable were greater than two standard deviations away from the entire sample mean were removed, in order to exclude data that might disproportionately distort means (given the low sample sizes for the High and Low AQ groups). This led to four women and two men being omitted, all bar one High AQ female belonging to the Medium scoring group.

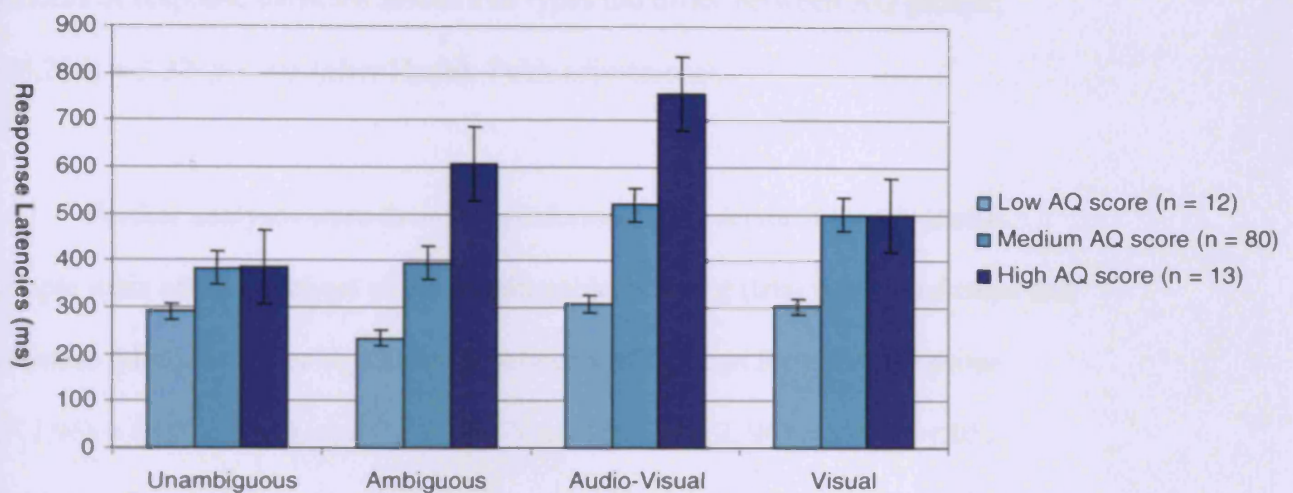


Figure 3.3: Response latencies (Milliseconds) by Trial Type and AQ Group (Experiment 4a).

As can be seen from Figure 3.3, the three AQ groups were broadly similar in terms of their averaged response times to unambiguous control trials. The Low AQ group latencies are generally consistent across all trials, and this group is shown to produce the fastest response times. Presentation of the audio-visual and visual cues appears to generate slower responses from the Medium AQ group. Across all three levels of ambiguous trials, the High AQ group produced the longest response times, particularly with respect to the audio-visual condition. Hence the pattern of latencies across trial types looks to vary between groups.

A 3 x 4 mixed ANOVA was conducted to consider the effect of AQ group (between-group factor) on response latencies by trial type (within-group factor) to test these observations. This analysis confirmed that there was a significant main effect of AQ group ($F(2,96) = 3.17, p < .05$). The main effect of Trial remained significant ($F(3,288) = 7.90, p < .005$ after Huynh-Feldt adjustment to correct for sphericity problems); time to respond generally varied across trial types. A significant interaction was also found between Group and Trial, verifying that

patterns of response latencies across trial types did differ between AQ groups; $F(6,288) = 3.32, p < .05$ (after Huynh-Feldt adjustment).

Further analyses were therefore performed to understand these patterns. Simple main effects analysis of the within-subjects factor (trial type) confirmed that response durations differ significantly between AQ groups for the Ambiguous ($F(2,96) = 6.09, p < .01$), and the Audio-Visual trials ($F(2, 96) = 3.40, p < .05$). Analysis of each AQ group across trial types produced significant simple effects for the Medium and High AQ groups, but not for the low AQ group ($F(3, 288) = 9.48, p < .001, F(3, 288) = 9.44, p < .001$ and $F < 1$, respectively). Thus the differing trial types had no significant effect on Low AQ group latencies, but did influence the pattern of latencies produced for these other groups. The significant interaction therefore reflects differences between Medium and High AQ groups, and between Ambiguous and Audio-Visual trials.

AQ Group	Trial type 1	Trial type 2	Mean Difference (ms)	Std. Error	Sig.
Low	Unambiguous	Ambiguous	57.33	56.56	1.00
		Audio- Visual	-16.75	112.65	1.00
		Visual	-11.42	56.34	1.00
	Ambiguous	Audio- Visual	-74.08	86.92	1.00
		Visual	-68.75	59.89	1.00
		Audio-Visual	Visual	5.33	109.14
Medium	Unambiguous	Ambiguous	-15.41	22.63	1.00
		Audio- Visual	-141.31	45.06	.01*
		Visual	-124.77	22.54	.00*
	Ambiguous	Audio- Visual	-125.89	34.77	.00*
		Visual	-109.36	23.96	.00*
		Audio-Visual	Visual	16.53	43.66
High	Unambiguous	Ambiguous	-229.17	56.56	.00*
		Audio- Visual	-428.58	112.65	.00*
		Visual	-119.67	56.34	.22
	Ambiguous	Audio- Visual	-199.42	86.92	.14
		Visual	109.50	59.89	.42
		Audio-Visual	Visual	-308.92	109.14

* The mean difference is significant at the .05 level, adjusting for multiple comparisons (Bonferroni)

Table 3.7: Comparisons between estimated marginal means of response latencies (Milliseconds) by Trial Type within AQ Groups (Experiment 4a).

Further post-hoc tests were undertaken to understand the results obtained from the simple effects analyses. Adjusted comparisons between marginal means for trial type latencies by AQ group are presented in Table 3.7. Confirming the fact that no simple effect was found for the Low AQ group, no significant differences were obtained when comparing latencies from any two trial types for this AQ category. For the Medium AQ group, the Unambiguous and Ambiguous trials differed significantly from both the Audio-Visual and Visual trial types (in that they elicited faster responses). However, Unambiguous and Ambiguous latencies did not

differ from each other for this group. This finding verifies the observation that cues elicit a time cost in conjunction with ambiguity for this group.

A different pattern was obtained for High AQ-scoring participants (the BAP group). Responding to Ambiguous and Audio-Visual trials took longer than responding to Unambiguous trials for participants with high AQ scores. A significant difference was also obtained between Audio-Visual and Visual trials within the High AQ group, with auditory cues eliciting slower responses than visual capture cues.

Trial type	AQ Group 1	AQ Group 2	Mean Difference (ms)	Std. Error	Significance
Unambiguous	Low	Medium	-43.28	56.67	1.00
		High	-53.67	74.45	1.00
	Medium	High	-10.39	56.70	1.00
Ambiguous	Low	Medium	-116.03	76.99	.41
		High	-340.17	101.10	.00*
	Medium	High	-224.14	76.99	.01*
Audio-Visual	Low	Medium	-167.84	139.95	.70
		High	-465.50	183.77	.04*
	Medium	High	-297.66	139.95	.11
Visual	Low	Medium	-156.64	85.84	.21
		High	-161.92	112.71	.46
	Medium	High	-5.28	85.84	1.00

* The mean difference is significant at the .05 level, after adjustment for multiple comparisons (Bonferroni).

Table 3.8: Comparison between estimated marginal means of response latencies by AQ group within Trial Type (Experiment 4a).

Table 3.8 provides differences between mean response latencies between AQ groups within each level of the within-group factor, trial type. No two groups differed in latency scores in relation to the Unambiguous and Visual trial types. Ambiguous trials produced significant between-group results; both the Low and Medium groups had significantly lower latencies than the High scoring (BAP)

group. This finding reiterates that the High scoring group took longer to respond to Ambiguous trials in the absence of cues than did the other groups. A significant difference ($p < .05$) was also found for the High-Low group comparison in relation to Audio-Visual trials; the High group response times were lower than those derived from the Low group.

Experiment 4b: Intuitive Physics task: Gender and Group comparisons.

Gender	N	Mean Score (/24)	Std. Deviation	Range
<i>Male</i>	48	12.48	3.02	6 – 18
<i>Female</i>	57	11.26	2.46	4 – 18
Total	105	11.82	2.79	4 – 18

Table 3.9: Mean scores for Intuitive Physics by Gender (Experiment 4b)

As can be seen in Table 3.9, performance of the intuitive physics was better in males than in females. An independent samples *t*-test obtained a significant difference in total scores by gender group ($t(103) = 2.27, p < .05$). The Cohen's *d* (.49) for the effect of gender indicates that it is medium-sized (Cohen, 1988). Using Pearson Product Moment Correlation (PPMC) method, it was found that total AQ scores did not correlate with intuitive physics scores (Appendix G), irrespective of whether the entire sample was considered, or whether male and female participants were assessed separately. A significant positive correlation was obtained between the Imagination subscale of the AQ and Intuitive Physics scores, meaning that as self-reported imaginative ability decreased, physics ability increased. This correlation was not found when gender subgroups were analysed separately.

AQ Group	n	Mean Intuitive Physics score	Std. Deviation	Range
<i>Low</i>	12	11.50	1.78	8 – 14
<i>Medium</i>	80	11.80	2.93	4 – 18
<i>High</i>	13	12.23	2.77	8 – 17
Total	105	11.82	2.79	4 – 18

Table 3.10: Mean scores for Intuitive Physics by AQ Group (Experiment 4b)

Table 3.10 indicates that there is little variation in means when the sample is categorised according to total AQ score, although the pattern of results follows the prediction that the low group would produce the lowest mean, and the high AQ group the highest mean. A one-way ANOVA with AQ Group as the between-group factor was not significant ($F < 1$). Testing the influence of gender for each AQ group with respect to intuitive physics scores revealed that no differences were found within the Low and High AQ groups; the effect sizes related to these independent sample *t*-test are small, which suggests that low power is not the reason for the null findings ($t(10) = -0.33, p > .05$, Cohen's $d = .22$, and $t(11) = 0.17, p > .05$, Cohen's $d = .10$, respectively). Men scored significantly higher than women in the Medium AQ group; this result has a medium-effect size ($\mu(\text{male}) = 12.6; \mu(\text{female}) = 11.1; t(78) = 2.38, p < .05$; Cohen's $d = .54$).

Examining correlations between Intuitive Physics scores and AQ subscales, independent analysis of each AQ group produced two significant results (Appendix H); the Imagination subscale within the Medium AQ scoring group correlates with intuitive physics scores ($r = .23$), whereas the High AQ group produced a significant inverse correlation between the attention-to-detail subscale and intuitive physics scores ($r = -.63$). Within this group, the greater attention-to-detail reported by an individual, the lower their score on the physics test.

Experiment 4c: Relationships between Intuitive Physics scores and CoMG responses by Gender and AQ Group.

Subgroup	Crash	Miss	Ambiguous	Audio-Visual	Visual
<i>Male</i>	-.17	.16	-.12	.05	-.21
<i>Female</i>	.13	.07	.05	.17	.17
<i>Low AQ</i>	-.06	-.24	.06	.15	.06
<i>Medium AQ</i>	-.06	.14	-.01	.11	-.07
<i>High AQ</i>	.17	-.05	-.26	-.09	-.16
Total	-.03	.08	-.03	.07	-.08

Table 3.11: PPMC correlations between Intuitive Physics scores and CoMG crash report proportions, by Gender and by AQ group (Experiment 4c).

Table 3.11 presents correlation values between intuitive physics scores and the crash reports from each of the trial types in the Crash or Miss Game. For the total data sample, no evidence that these two variables are related was obtained (no *r* value was found to be significant). The same was found when each gender was analysed independently on this basis. Consideration of relationships for each AQ group also resulted in non-significant findings.

Subgroup	Crash	Miss	Ambiguous	Audio-Visual	Visual
<i>Male</i>	.10	.16	.10	.22	.10
<i>Female</i>	-.10	.01	-.01	-.05	-.07
<i>Low AQ</i>	-.14	-.39	-.61*	-.49	-.55
<i>Medium AQ</i>	-.03	.21	.09	.14	.07
<i>High AQ</i>	.04	-.66*	-.30	-.20	-.29
Total	.09	.02	.08	.02	.01

* Correlation is significant at the 0.05 level (2-tailed).

Table 3.12: PPMC correlations between Intuitive Physics scores and CoMG condition response latencies (ms), by Gender and by AQ group (Experiment 4c).

Table 3.16 presents correlations between CoMG response latencies and Intuitive Physics scores. Response latencies were found not to correlate with

intuitive physics scores for the data set as a whole, or when separate analyses were performed for gender subgroups. Significant negative correlations were obtained between latencies in response to ambiguous trials and Intuitive Physics scores in the Low AQ group, and between these scores and latencies relating to unambiguous miss trials in the High AQ group. These inverse relationships indicate that superior intuitive physics ability is related to faster responding in both cases.

3.3.4 Results Summary and Discussion

Experiment 4a

This experiment successfully replicates studies reported by Sekuler, Sekuler and Lau (1997) and Scholl and Nakayama (2002). These researchers demonstrated that causality can be evoked as an automatic, perceptually-driven subjective experience through presentation of disambiguating auditory or visual cues in conjunction with an ambiguous dynamic visual event. As Ambiguous trials elicited significantly fewer crash percepts than were generated by either of the cue-based (Audio-Visual or Visual) trials, this version of the Crash or Miss Game successfully measures the disambiguating impact of both auditory and visual capture signals within one task. That neither cue evoked significantly more crashes than the other in general suggests that their power to generate causal percepts is broadly equivalent.

Categorisation on the basis of total AQ score created three groups; High, Medium and Low. The group of greatest interest is the High scoring group, as this is taken here to represent a Broader Autism Phenotype sample (i.e., a group of

participants with atypically high numbers of autistic traits but below diagnostic thresholds for ASD).

The main hypothesis in this experiment is that the BAP group would provide evidence of compromised cross-modal integration, as inferred from reduced crash reports. The number of crashes reported in the key cross-modal condition (Audio-Visual trials) for the BAP group was not significantly different to that found for the Medium AQ group. Further, within-group comparisons did not show a significant difference in crashes reported for the Audio-Visual condition in comparison to the Visual condition. The interaction effect found was driven by an *elevation* in crash responses in association with the High AQ group, above the levels reported by both the Medium (control) and Low (comparison) AQ groups, when observing ambiguous trials in which no cues were presented. Support for the hypothesis is therefore not apparent from this study when the crash report proportions alone are considered.

Better evidence of compromised cross-modal processing in the BAP arises from the analysis of response time means. For the Medium AQ group, responses are comparatively fast when trials are either unambiguous or ambiguous, suggesting that subjective experience of causality or non-causality is clear for this group, making crash or miss judgements easy. In the presence of a disambiguating cue, though, responses take substantially longer, irrespective of cue type, possibly because integrating cue and ambiguous event information is generally a slower process than processing simple dynamic events alone. Unlike the Medium group, however, an exaggerated cue-cost was found in response to the Audio-Visual trials

alone in the BAP group. Latencies for Visual trials, where an unambiguous crash was presented underneath the ambiguous event, did not significantly differ from those from the Unambiguous condition.

Furthermore, High AQ participants only responded rapidly when trials were unambiguous; ambiguity in itself generated significantly longer latencies. The mean duration for Ambiguous trials was also significantly longer than that produced by the Medium AQ group. Ambiguous responses were more closely comparable to Audio-Visual responses than Visual responses for the BAP group, with the Visual and Unambiguous condition generating similar response latencies.

The BAP group responded in much the same way as the Medium AQ group in terms of speed of response and accuracy when trials were unambiguous. BAP and control participants also responded similarly to the visual capture perceptual causality stimuli, in terms of latencies and subjective experience of crashes. However, the BAP participants experienced difficulty with processing ambiguous perceptual causality stimuli both when the auditory cue was present, and when it was not. As the visual capture cue is in fact an unambiguous launch event, it can be concluded that ambiguity *per se* resulted in judgement difficulties, and that cross-modal information that usually serves to disambiguate ambiguous causal events did not effectively do so in individuals who exhibit the Broader Autism Phenotype.

This conclusion is corroborated when comparisons with the Low AQ group are considered. According to Extreme Male Brain theory this group can be taken to represent the 'extreme female brain' type, just as the High AQ sample is taken here

to represent the broader autism phenotype, which in turn has been related to the 'extreme male brain' (Baron-Cohen et al., 2006). A trend was found towards significance when crashes in response to the cross-modal condition were compared between the BAP and Low AQ group in isolation. The effect size found for the trend, in which the BAP group reported fewer crashes than the 'extreme female brain' group, was moderate-to-large (Cohen, 1988) which implies that larger group sizes may have generated a significant result, as the power within this analysis is low. This trend was not replicated when comparing responses to the within-mode visual capture cues, suggesting that any potential difference between these two groups may be specifically related to cross-modal processing.

The Low AQ group showed *no* difficulty responding to ambiguous perceptual causality stimuli; the means across trial conditions vary very little. This group produced the lowest mean in response to every trial type, and although a cue-cost pattern similar to the one found for the Medium group was seen, neither cue-based condition was associated with latencies significantly longer than associated with the Unambiguous condition. The processes underpinning the experience of perceptual causality for this 'extreme female brain' type therefore appear to be fast, whether the information provided is ambiguous or not, and categorical in nature (with definite misses or crashes perceived). In direct comparison, the BAP group took significantly longer to process information with ambiguous components, especially when that information was cross-modal (response latencies between High and Low groups being significantly different for Ambiguous and Audio-Visual trials), suggesting that the percepts generated for these individuals are 'fuzzy' rather than categorical in the presence of ambiguity, and that the disambiguating power of the auditory cue is weaker than it is for the Low AQ group.

Taken together these conclusions support the idea that perceptual causality is experienced differently by individuals representing the broader autism phenotype, in comparison with people who manifest a few or an average number of autistic behavioural traits. Specifically, their responses to perceptual ambiguity lead to an exaggerated tendency to see crashes where others see misses, and they are not as readily influenced by auditory signals that generally generate percepts of causality as others are. Interestingly, their experience of causality in response to visual capture information (in which the causal information provided an unambiguous crash event generalises to influence perception of an ambiguous event) is similar in all respects to the control group, indicating that they are not generally impervious to disambiguating information.

However, people with few autistic traits appear to be perceptually efficient and consequently experience perceptual causality frequently and less equivocally than those with the Broader Autism Phenotype, suggesting a dissociation between these two groups which is particularly apparent when the stimuli presented are cross-modal in nature. This dissociation provides support for the Extreme Male Brain theory of autism. Whether this reflects differences at perceptual or cognitive level will be discussed in section 3.5.

The female preponderance within the Low AQ group and the dominance of males in the High AQ group generated male: female ratios equivalent to those found for equivalent groups in the original AQ distribution study (Baron-Cohen et al., 2001a). These gender imbalances could raise concerns about potential confounds in AQ group analyses if any gender effect was discernible from the data analysed in

Experiment 4a. However, no evidence was obtained that gender significantly influences the number of crashes reported, or the response latencies recorded, for any Trial type. It can be concluded from these observations that the gender imbalances within both the Low and High AQ groups are unlikely to have had an effect on group results.

Experiment 4b

In Experiment 4b it was hypothesised that individuals with the Broader Autism Phenotype (as defined by high total AQ scores) should be superior to individuals without BAP on a task of Intuitive Physics. The pattern of results for groups categorised according to AQ scores followed the expected pattern, with the Low AQ individuals scoring on average less than the Medium AQ group who were marginally worse at the task than the High AQ group. Scores across groups did not, however, differ significantly ($F < 1$), and so there is no statistical evidence to support the hypothesis.

There is evidence of a gender effect on the Intuitive Physics Task, as the mean scores between women and men are significantly different, with women performing worse than men overall. This male superiority adds weight to existing research findings in which men make fewer errors on tasks testing physics reasoning or knowledge about physical systems (as discussed in Chapter 2). The inclusion of women in the BAP group did not, however, influence the AQ group analysis, as their removal from this group reduces, not raises, its average score (from 12.23 to 12.13).

In terms of supporting or contradicting the extreme male brain theory of autism, the finding that women are generally worse at this physics task is equivocal. While the male/female score comparison supports the studies of gender effects that in part led to EMB theory, the same data fail to produce significant results when the female and High AQ group scores are compared. In this respect, the experiment here undermines a similar study undertaken by Lawson, Baron-Cohen and Wheelwright (2004) in which typical female adults were found to perform the Physical Prediction Questionnaire (PPQ) significantly worse than adult males with and without AS. Interestingly, there was no discernible difference between male groups in this PPQ study, either. As scores on both the PPQ and the Intuitive Physics Task (which are similar in design and content) between typical males and males classified as having autistic behaviours did not differ, it would appear that 'natural' physics ability previously associated with ASD does not produce greatly superior physics reasoning in BAP adults in comparison to well-educated non-BAP male adults.

The alternative interpretation of gender differences on intuitive physics tasks therefore is that 'female type' brains are not innately attuned to processing information about physical systems. This conclusion is supported by the finding that gender differences are only apparent within the Medium AQ group. The average numbers of autistic traits reported by the male and female subgroups within this category are similar, but their Intuitive Physics scores still differ significantly. No gender differences were found within either the BAP or Low AQ groups; means did not differ but effect sizes were small, suggesting that these findings were unlikely to be non-significant due to small cell sizes. Men and women within each of these

experimental categories therefore appear similar to each other; men with few autistic traits perform the physics task like women with similar behavioural styles, as is also the case for women with a relatively high number of such traits and their male equivalents. This inference partially supports the idea that 'extreme male' and 'extreme female' cognitive styles exist that are independent of gender, and that these phenotypes are associated with the number of autistic traits displayed at individual level.

Furthermore, it is interesting to find that imagination and intuitive physics ability are inversely related; scores on this physics task increase in line with increasing scores on the imagination subscale of the AQ (high scores on this subscale indicating difficulties with imaginative activities, such as visualising the physical appearance of characters in a book). The separate correlation values between genders and AQ groups indicate that this relationship holds true for men, but not women, within the Medium AQ scoring group only¹². It would appear from this result that the inverted connection between science ability and imagination is a male characteristic. As one of the diagnostic characteristics of ASD is limited imagination (American Psychiatric Association [APA], 1994) and enhanced science ability has been associated with the broader autism phenotype and ASD (DeLong, 2004; Wheelwright & Baron-Cohen, 2001), this finding provides additional support for Extreme Male Brain theory (Baron-Cohen, 2002).

¹² Imagination subscale scores amongst the 13 high AQ scorers were clustered around the mean of 3.69, which was significantly higher than that found for the Medium AQ group (1.98; $t(91) = -3.5, p = .001$). This may account for the lack of correlation between Imagination and Intuitive Physics scores for the High AQ group.

The final finding from Experiment 4b is that high AQ scorers (i.e., those expressing the BAP) exhibit an unusual *inverse* relationship between attention-to-detail and physics ability. Closer examination of the raw data suggests that the data points generating this relationship are almost exclusively male. In the BAP males, then, it would appear that local, detail-orientated processing of information is detrimental to understanding physics.

This inverse local processing/physics result conflicts directly with extant literature which supports the view that ASD is characterised at the cognitive level by detail-orientation, and that this processing style is related to natural, domain-specific science aptitude. There remains considerable debate regarding whether local detail processing is inflexible in ASD or whether it represents a 'default' cognitive style, as the contemporary account of weak central coherence theory describes it (Happé, 2006). Given the group size ($n = 13$) here, the negative correlation finding must be treated cautiously, but this study suggests that a local over global processing bias impedes physical cognition in relation to the BAP, which warrants further investigation. Certainly, a cognitive ability to integrate information at 'systems-level' is a pre-requisite for many of the scientific vocations attractive to individuals with BAP and AS, such as programming or engineering. With respect to Extreme Male Brain theory, Baron-Cohen, Knickermeier and Belmonte (2005) state that 'Systemising is the drive to analyse a system in terms of the rules that govern the system, in order to predict the behaviour of the system'. It is this cognitive facility, they aver, that characterises the ASD-science association. Too much constraint to operate at the local detail level would jeopardise such a facility, with consequences for domains such as physical cognition.

Experiment 4c

For Experiment 4c, it was thought that gender differences would be apparent in terms of relationships between perceptual causality response and physics task performance. Findings from Experiment 3 led to the hypothesis that a significant positive correlation would be found for the general male group between Intuitive Physics scores and perceptual causality responses. By extension, this relationship was also predicted for the BAP group, corresponding to the idea that autism is produced by extreme male brain functioning. Scores from the Intuitive Physics task did not correlate significantly with the crash report proportions obtained from the experimental conditions of the Crash or Miss Game for the entire sample. This observation was repeated when gender subgroup correlations were assessed, and again when relationships between CoMG measures and their physics scores were examined separately for each AQ group.

The only indications that perceptual causality and physical cognition are inter-related in this experiment come from a dissociation in response times apparent between Low and High AQ groups. Faster response times were found to be associated with physics scores for the unambiguous miss trials in the High AQ group. In the Low AQ group, the same relationship was obtained for ambiguous trials. Had response latencies shown a uniform pattern of correlation with physics scores across trial types within these groups, the interpretation would have been that the relationship merely reflects processing efficiency, suggesting that the participants within these groups generally have higher IQs than the medium-scoring controls (Neubauer, Grabner, Fink & Neuper, 2005). That this is not the case

suggests that specialised neural systems may exist that inter-relate specific perceptual and cognitive processes, and these might differ between extreme female and extreme male brains.

Generally, though, this latency/trial type relationship difference between High and Low AQ groups is only partial support for the hypothesis here that men differ from women in terms of relationships between perceptual causality and physics aptitude. Bertamini, Spooner and Hecht (2004) states that, despite considerable perceptual and interactive experience of the behaviour of objects, our default use of cognitive representations to guide our predictions about cause and effect in mechanical systems frequently fails us. They draw the broad conclusion that physical causal cognition is largely dissociated from perceptual processing; percepts generated from environmental interaction between/with objects are therefore not implicitly captured in terms of cognitive representations about those objects. These statements and the results of both Experiment 3 and Experiment 4c therefore conflict.

The main finding from Experiment 3 was that susceptibility to experiencing perceptual causality in response to audio-visual perceptual causality was related to intuitive physics in boys. This finding was not replicated with adult males in Experiment 4c. There are two plausible accounts as to why this might be so. The first is that the perception/cognition relationship found for science-orientated boys was driven by the inclusion of a subgroup of unusual individuals, in which case it would not prove replicable in a wide-ranging population of typical boys (or typical men). It can be supposed that a sample of Cardiff University students recruited from

several Schools will not be representative of the general population, in that IQ distribution is likely to be skewed towards the higher end of a normal distribution. Therefore, 'natural' physics ability might be indistinguishable from learnt physics knowledge, and logical reasoning ability (related to overall IQ). Relationships in which thinking about cause and effect in physical systems may be related to perceiving cause and effect in objects, as found in boys in Experiment 3, would therefore be masked by compensating factors. The second account is that this relationship is only identifiable during childhood; neurobiological rearrangement during adolescence might create a dissociation between the perceptual and cognitive processes involved (see Chapter 5 for further discussion).

3.4 Experiment 5: Weak central coherence, the BAP and cross-modal integration

3.4.1 Introduction

In Experiment 4a, the BAP group was found to respond atypically to perceptual causality stimuli, in that crash reports were elevated when the stimuli were visually ambiguous, but slightly reduced in number (with significantly longer response times) when the stimuli were presented with an auditory signal that coincided with the point of visual occlusion. It was concluded that the BAP is associated with poor resolution of visual ambiguity, and also that the disambiguating strength of the auditory signal was weakened in this group, possibly suggesting that cross-modal processing is compromised in some respect.

The main objective of this next study was to consider the temporal pattern of response to the auditory signal to generate causal percepts when its timing is varied. The study uses the perceptual causality task described for Experiment 3, in which the auditory signal is presented 250 milliseconds before and after the point at which the visual becomes ambiguous, (i.e., when the dynamic disk occludes the stationary disk). This experiment was therefore designed to investigate the underlying temporal parameters that produce causal percepts in response to cross-modal stimuli.

Spatio-temporal thresholds determine whether or not cross-modal perceptual causality phenomena are experienced (Guski & Troje, 2003; Lewald & Guski, 2003). Processing audio-visual perceptual stimuli was shown to be slow relative to visual capture stimuli in the BAP group in Experiment 4, and crash report responses slightly suppressed relative to other groups (particularly the Low AQ group). Hence, if multisensory processing is affected within the high AQ-scoring BAP group, results may show both a reduced crash report response in comparison to other groups, coupled with exaggerated response times *and* an atypically 'flat' response pattern when timing of the auditory component is varied in relation to visual occlusion; the other groups should generate heightened numbers of crash responses when the auditory signal is presented simultaneously with occlusion (and fewer crashes when this signal is presented asynchronously).

In section 3.2.3, evidence that BAP superiority over non-BAP individuals in terms of Embedded Figure Task performance (Happé, Briskman & Frith, 2001) was described along with research implying that performance of the EFT was

determined by perceptual processing biases (Jarrod, Gilchrist & Bender, 2005). Experiment 5 was therefore designed to assess whether EFT superiority could be evidenced from a BAP sample drawn from a student population, rather than from proband families. Given that gender differences are well-established for the EFT (e.g. Witkin, 1950) it was anticipated that non-BAP gender groups would show task performance differences. However, the fMRI BAP study of EFT performance (Baron-Cohen et al., 2006) suggests that no gender influence will be found with respect to BAP performance.

The original EFT task was modified for this study so that data collection could be computerised. This version of the EFT also removed the visuo-spatial memory component of the original task by presenting each simple target shape *alongside* its complex figure, hence making the task reliant more on perceptual processes (akin to single feature search) than on working memory function.

Evidence of faster response times and better accuracy scores on this modified embedded figures task would lend itself to a perceptual interpretation of BAP performance, in that it would suggest enhanced single feature processing. The findings and data from Experiment 5b then allow a hypothetical relationship between perceptual integration and EFT performance to be considered in the next analysis (Experiment 5c). Together these experiments were designed so that the perceptual basis of the weak central coherence theory of ASD could be explored using the broader phenotype as an analogue model. Weaker perceptual integration is therefore hypothesised to be associated with enhanced EFT performance within the Broader Autism Phenotype.

3.4.2 Method

Participants

Participant recruitment and data collection in this study was supported in part by undergraduate psychology students under the supervision of L. Grayson and Prof. S. Killcross. A total of 182 Cardiff University undergraduate participants were recruited by email, electronic participant panel and via social networking from social science, humanities, medical, engineering and science departments, ensuring that a range of disciplines were represented within each broad area of the AQ score distribution. The final sample comprised 66 males and 115 females aged between 18 and 46 years (see Table 3.13). The exclusion criteria used in Experiment 4 were also applied in this study.

Group	N	Average (Years:Months)	Std Deviation (Years:Months)	Range (Years:Months)
<i>Female</i>	116	21:0	3:2	18:5 - 38:11
<i>Male</i>	66	22:9	4:3	18:6 - 46:6
Total	182	22:0	4:0	18:5 - 46:6

Table 3.13: Descriptive Statistics of Participant Sample Age by Gender Subgroup (Experiment 5).

Stimuli

Stimuli for the Crash or Miss Game were exactly as described in Experiment 3. The AQ questionnaire in this study was provided online as a web survey, because computer use in self-report behavioural questionnaires has been shown to reduce impression management bias (Booth-Hewley, Larson & Myoshi, 2007). A selection from Form A of the adult version of the EFT task (Witkin, Oltman, Raskin & Karp, 1971) was used for the computerised adaptation, comprising ten complex figures

and eight simple target shapes (three of which were duplicated across trials)¹³. The adapted task was programmed using E-Prime software.

Apparatus

The majority of the participants in this study were tested using the same apparatus and under the same conditions as described for Experiment 4. A further 46 participants were recruited subsequent to the main testing sessions to expand the BAP group size, and these individuals were tested in a small, well-lit laboratory using the apparatus described in Experiment 3.

Procedure

Participants completed the AQ online as the first task, followed by the CoMG and finally the EFT (the additional participants completed the online AQ prior to attending CoMG/EFT test session). The data were collected by computer under anonymous participant codes that allowed the three data sets involved to be collated. Researchers remained blind to AQ scores throughout all test sessions. The instructions and procedures for AQ and CoMG completion were as described in Experiment 4. In the EFT task, participants were instructed to view the simple shape outline presented on the right-hand side of the screen and search for its location embedded within the coloured complex figure presented simultaneously on the left side of the screen (as shown in Figure 1.2). A practice trial was provided so that participants could demonstrate that they understood the instructions before starting. The trial set began when the participant pressed the spacebar in response to an onscreen prompt after the practice trial. As soon as the simple target was located

¹³ In the EFT version used for the additional participants, two extra trials were added at the end of trial set; these items' data has been removed from analysis (it was originally intended to replicate the entire study, but as this was made impossible due to illness, the two data sets have been merged).

within the figure, the participant pressed a highlighted button on the PC keyboard to record the response time. After each timed response, a screen appeared with a text prompt for the participant to trace the target location in the figure, after which the researcher recorded the accuracy response (0 for inaccurate; 1 for accurate), causing the next trial's start screen to appear. After completion, the experiment ended with a 'thank you' screen.

Data from the EFT was treated in the following way to ensure that fast but inaccurate responses did not bias results. Any response time that exceeded the average duration found across the group for inaccurate responses (30 seconds) was coded as inaccurate, whether the participant located the target correctly or not. Delays in tracing the outline beyond ten seconds generated a time-out of the accuracy response screen; these time-out trials were recoded as inaccurate responses, and response times recorded as 30 seconds. These data treatments were designed so that the both accuracy and reaction time measures more closely reflect perceptual processing. Long response durations suggest that cognitive strategies, such as checking/rechecking, are being employed, or that a participant is sensing rather than knowing the answer and is using the verification stage to work out the location consciously.

3.4.3 Results

Outlier analysis and Group Categorisation

Outliers were identified from the Crash or Miss Game prior to AQ group allocation. Identification was made on the basis of pooled accuracy scores across the

three auditory timing levels for each of the Unambiguous conditions (Miss and Crash) derived from the entire data set. Two standard deviations above the accuracy mean was the criterion for exclusion on the miss variable, and two standard deviations below the accuracy mean was the exclusion criterion for the crash data. The seventeen participants whose data were omitted included five males and twelve females, or 10 % of the total number of participants (12% of the females and 8% of the males). Four excluded participants (two male and two female) scored above 21 on the AQ.

Group	N	Mean AQ score	Std. Deviation	Range
<i>Male</i>	61	18.9	6.1	10 – 40
<i>Female</i>	104	16.7	5.1	7 – 31
Total	165	17.5	5.6	7 – 40

Table 3.14: AQ descriptive statistics for sample with CoMG outliers excluded (Experiment 5).

Table 3.14 provides descriptive statistics for the final 165 participants. These indicate that the AQ range here was restricted in comparison with that obtained in Experiment 4; there was little or no left tail, and so it included few low AQ scoring individuals. Both standardised kurtosis and skewness scores exceeded 3.29 ($\eta_2 = 4.55$, $\eta_1 = 5.63$, respectively; $p < .001$). The AQ score distribution for the total sample was therefore abnormally skewed, with higher frequencies for total scores at the lower end of the range. Significant positive (leftward) skewness was found for both gender subgroups (η_1 (male) = 4.08, $p < .001$; η_1 (female) = 2.86, $p < .01$) and the male subgroup had a significant kurtosis value ($\eta_2 = 3.34$, $p < .001$). For each sex, the AQ scores clustered towards the lower end of the scale, with long tails at the high-scoring end, and truncated tails at the lower end of the range. The male

distribution, in addition, was abnormally peaked. Overall, the total data AQ distribution was not Gaussian. The significant positive kurtosis represents a small standard deviation overall, and therefore any categories produced on this cut-off basis would be unlikely to be representative of a wider population. Subscale distributions for this sample are supplied in Appendix I.

Given these distribution characteristics, it was decided not to include a Low AQ comparison group in the analyses. Instead, Medium AQ male, Medium AQ female and High AQ categories were created. This grouping allows for gender differences on all measures to be considered without similarities between high-scoring men and women masking the effects. Also it facilitates comparison between the High AQ BAP group with each gender control group (Medium AQ males and Medium AQ females), in line with the prediction from EMB theory that systemising biases can be found in both individuals of either sex in association with autistic trait expression. The High Group cut-off level found in Experiment 4 (total AQ score = 21+) was used to define the BAP group, in order to allow for comparison between experiments.

Group	n	Mean AQ score	Std. Deviation	Range
<i>Medium Male</i>	40	15.4	2.7	10 – 20
<i>Medium Female</i>	85	14.9	3.3	7 – 20
<i>High AQ</i>	40	25.3	4.3	21 – 40
Total	165	17.5	5.6	7 – 40

Table 3.15: AQ distribution statistics by AQ Group (Experiment 5).

Table 3.15 provides the descriptive statistics for the AQ groups produced using total AQ values of 7 and 21 as the Low AQ and High AQ group cut-

offs. Total AQ scores differed significantly across AQ Groups ($F(2,162) = 133.57, p < .001$). Adjusted post-hoc comparisons between each mean pair showed that AQ scores for Medium Male and Medium Female groups did not differ from each other, but that they both differed significantly from the High AQ Group (by 9.9 and 10.4 points respectively, both $p < .001$). A one-way ANOVA of the pooled accuracy scores with AQ group as the independent variable revealed no main effect of Group ($F < 1$); control trial accuracy was therefore comparable across groups. Independent samples t -tests were also carried out to ensure that there were no differences between accuracy scores on either of the unambiguous control trial conditions between the sexes; this test revealed that gender groups were comparable in this respect ($t_{\text{miss}}(163) = 0.16, t_{\text{crash}}(163) = 1.19$, both $p > .05$).

Experiment 5a: Cross-modal differences in crash reports and latencies by Gender and AQ group

Analysis 1: Crash Reports by Gender

Group	n	Trial Type	Mean Crash Reports	Std. Deviations	Range
<i>Male</i>	<i>61</i>	- 250 ms	.31	.29	.00 – 1.00
		0 ms (Simultaneous)	.36	.29	.00 – 1.00
		+250 ms	.23	.27	.00 – 1.00
<i>Female</i>	<i>104</i>	- 250 ms	.35	.32	.00 – 1.00
		0 ms (Simultaneous)	.46	.32	.00 – 1.00
		+250 ms	.26	.29	.00 – 1.00
<i>Total</i>	<i>165</i>	- 250 ms	.34	.31	.00 – 1.00
		0 ms (Simultaneous)	.42	.31	.00 – 1.00
		+250 ms	.25	.28	.00 – 1.00

Table 3.16: CoMG crash report proportions by Trial Type and Gender (Experiment 5a).

The means for each of the three experimental trial types (-250ms, 0ms and +250ms, relative to occlusion) for each gender subgroup are provided in Table 3.16. The associated standard deviations indicate that there is considerable variation within both gender groups. There is some suggestion of an interaction between trial type and gender, as indicated by the difference in female and male mean for the 0 ms (simultaneous) condition. A mixed 2 x 3 ANOVA was therefore conducted to test for gender differences on this task, with Gender as the between factor and the auditory timing conditions providing three levels of the within factor, Trial. A main effect of Trial was obtained ($F(2, 326) = 48.83, p <.001$). No main effect of gender was found ($F(1, 163) = 1.82, p >.05$). A trend towards significance was seen for the interaction between gender and auditory timing ($F(2, 326) = 2.64, p = .07$).

Given the apparent different in means for the simultaneous condition between sexes (Table 3.20 above), an independent samples *t*-test was conducted to

consider whether the trend towards a significant interaction was in part due to a gender difference for this trial type. The analysis confirmed that, when the auditory signal was timed to correspond with the point of occlusion, women reported more crashes than men ($\mu(\text{male}) = .36$, $\mu(\text{female}) = .46$; $t(163) = -2.09$, $p < .05$).

Trial Type 1	Trial Type 2	Mean Difference	Std. Error
<i>-250ms</i>	0 ms	-.08*	.02
	+250 ms	.09*	.02
<i>0ms</i>	+250 ms	.16*	.02

* The mean difference is significant at the .001 level.

Table 3.17: Post-hoc tests (Bonferroni-adjusted) of mean differences in Crash Report Proportions by Trial Type (Experiment 5a).

For the main effect of Trial (the within-group factor), post-hoc test of differences between marginal means verified that crash report proportion scores differed significantly between each pair of trial types (Table 3.17), with the simultaneous and -250ms trial types eliciting significantly more crash reports than the -250ms condition.

Analysis 2: Response Latencies by Gender

Gender analyses were performed for the response time measure. Collapsed response times representing the two unambiguous control conditions (crash and miss) were highly correlated ($r = .82$), and so a general Unambiguous response time condition was generated, increasing the levels of the within-group variable (Trial) to four. Standardised values of the Unambiguous control variable identified six individuals for whom average response times across all unambiguous trials were

two standard deviations above the mean obtained from the entire data set. These outliers (four male and two female; three high AQ scorers and three medium AQ scorers) were removed to avoid their inclusion masking any between-group effects, reducing the sample size to 159 participants.

Group	n	Trial Type	Mean Response Times (ms)	Std. Deviations	Range
<i>Male</i>	<i>57</i>	- 250 ms	579.8	450.5	13.10 - 2198.9
		0 ms (Simultaneous)	515.6	348.5	47.10 - 1566.3
		+250 ms	482.6	384.3	35.80 - 2015.8
		Unambiguous	360.2	205.1	9.84 - 910.9
<i>Female</i>	<i>102</i>	- 250 ms	577.9	408.8	27.80 - 2107.4
		0 ms (Simultaneous)	591.9	519.1	15.00 - 3586.1
		+250 ms	570.7	373.3	6.10 - 1804.7
		Unambiguous	395.2	213.1	60.74 - 906.9
Total	159	- 250 ms	578.6	422.8	13.10 - 2198.9
		0 ms (Simultaneous)	564.6	465.5	15.00 - 3586.1
		+250 ms	539.1	378.4	6.10 - 2015.8
		Unambiguous	382.7	210.2	9.84 - 910.9

Table 3.18: Descriptive Statistics of CoMG response latencies (ms) by Trial Type and Gender (Experiment 5a)

The descriptive statistics obtained from the final data set (without response time outliers) are given in Table 3.18. It can be seen that response to the collapsed Unambiguous condition was generally faster than was found for the experimental ambiguous conditions. Outside of this observation, latency means across the auditory timing conditions do not appear to vary greatly.

A 2 x 4 mixed ANOVA was undertaken to determine the effect of Gender (the between-group factor) on latencies for each trial type (the within-group factor). The analysis confirmed that there is a main effect of Trial ($F(3, 471) = 23.41, p < .001$). No main effect of Gender ($F < 1$), or significant interaction between Gender

and Trial ($F(3, 471) = 1.21, p > .05$) were identified, agreeing with the observation that latencies are generally equivalent across gender subgroups.

Trial Type 1	Trial Type 2	Mean Difference	Std. Error
<i>-250ms</i>	0 ms	25.1	27.8
	+250 ms	52.2	24.4
	Unambiguous	201.1*	25.8
<i>0ms</i>	+250 ms	27.1	27.0
	Unambiguous	176.1*	30.4
<i>+250ms</i>	Unambiguous	148.9*	22.0

* The mean difference is significant at the .001 level.

Table 3.19: Post-hoc tests (Bonferroni-adjusted) of mean differences in Response Times by Trial Type (Experiment 5a).

Significant mean differences were found between latencies obtained for the pooled Unambiguous condition and for each of the experimental trial types, but these were not found to differ from each other (Table 3.19), indicating that introduction of the auditory signal generally lengthens response times.

Analysis 3: Crash Reports by AQ Group

Prior to consideration of the experimental data, accuracy data were analysed to ensure that all AQ groups performed the task according to the instructions. A mixed 3 x 2 ANOVA, with the AQ group as the between factor was performed. The collapsed unambiguous control trial conditions (Unambiguous crashes and Unambiguous misses) were used to provide the within factor, Trial. No main effect of AQ Group or trial (both $F < 1$) was obtained, nor a significant interaction found

between Group and Trial ($F(2, 162) = 1.39$). Thus no AQ group was less accurate with respect to either control variable more than the others.

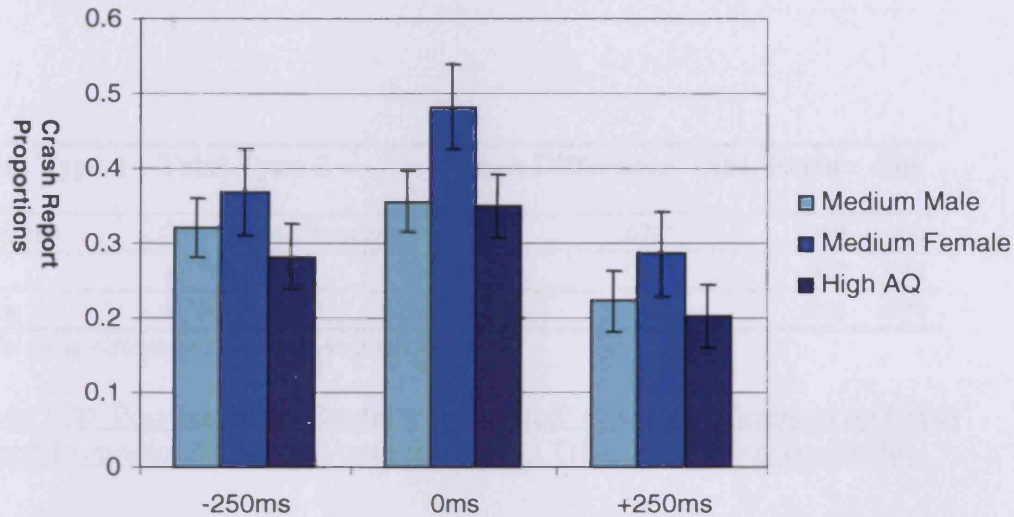


Figure 3.4: Crash Reports by Auditory Signal Timing and AQ Group (Experiment 5a).

Figure 3.4 presents the means and standard errors for each level of auditory timing condition by AQ group. All groups show the same pattern across timing conditions, with auditory signal presentation prior to occlusion generating fewer crash reports than induced by simultaneous presentation, and presentation after occlusion producing the lowest crash reports. However, in the Medium Male and High AQ groups, the facilitatory ‘peak’ produced in the 0 ms condition is not as pronounced as it appears to be in the Medium Female group, for which an elevation in number of crashes reported is generally apparent. Medium Male and High AQ groups’ responses appear equivalent across all conditions.

To analyse the affect of varying auditory timing on the number of crashes reported, a mixed 3 x 3 ANOVA was performed with AQ group (Group) as the between-groups factor, and the three auditory timing trial types as the within-group factor (Trial). No main effect of Group ($F(2,162) = 2.29, p = .10$) nor interaction

between Group and Trial ($F(4,324) = 1.32, p >.05$) were obtained. A main effect of auditory timing condition (the within-group factor) was apparent ($F(2,324) = 45.06, p <.001$).

Trial Type 1	Trial Type 2	Mean Difference	Std. Error	Sig.
-250 ms	<i>0 ms (Simultaneous)</i>	-.072*	.018	.000
	<i>+250 ms</i>	.087*	.017	.000
0 ms	<i>+250 ms</i>	.159*	.016	.000

* The mean difference is significant at the .001 level.

Table 3.20: Post-hoc tests (Bonferroni-adjusted) of mean differences on Crash Report Proportions between Auditory Timing Trial Types (Experiment 5a).

As presented in Table 3.20, adjusted post-hoc comparisons confirmed that each timing condition differed significantly from all other timing conditions in terms of crash report scores, confirming the observation that the highest crash report scores are associated with the simultaneous condition, and the lowest scores are produced in response to the +250ms condition.

From Figure 3.4, it appears that the Medium Female group may differ from the other two groups in terms of crashes reported for the simultaneous auditory timing trials. For this condition, the AQ groups were therefore compared using a one-way ANOVA in which AQ group was the between-group factor (Group), and a significant main effect of Group was found; $F(2, 164) = 3.74, p <.05$.

AQ Group 1	AQ Group 2	Mean Difference	Std. Error	Sig.
Medium Male	<i>Medium Female</i>	-.13	.10	.10
	<i>High AQ</i>	.01	.10	1.00
Medium Female	<i>High AQ</i>	.13	.10	.08

Table 3.21: Post-hoc tests (Bonferroni-adjusted) of mean differences on Crash Report Proportions for the Simultaneous Trial Type between AQ Groups (Experiment 5a).

Using Scheffe pair-wise comparisons (Table 3.21), post-hoc analysis found that no group significantly differed from any other with respect to the number of crashes experienced in the simultaneous auditory timing condition, although trends were seen for a difference between the Medium Female group with both the High AQ ($p = .08$), and Medium Male ($p = .10$) groups.

The trend between the typical female and High AQ group warranted further analysis, as inclusion of High AQ females may have distorted the result. Testing gender subgroups within the High AQ group by independent samples t -test demonstrated, however, that the number of crashes reported in the simultaneous auditory timing condition did not differ between men and women in this category ($\mu_{\text{male}} = .35, \mu_{\text{female}} = .35; t(38) = 0.05, p > .05$).

Analysis 4: Response Latencies by AQ group

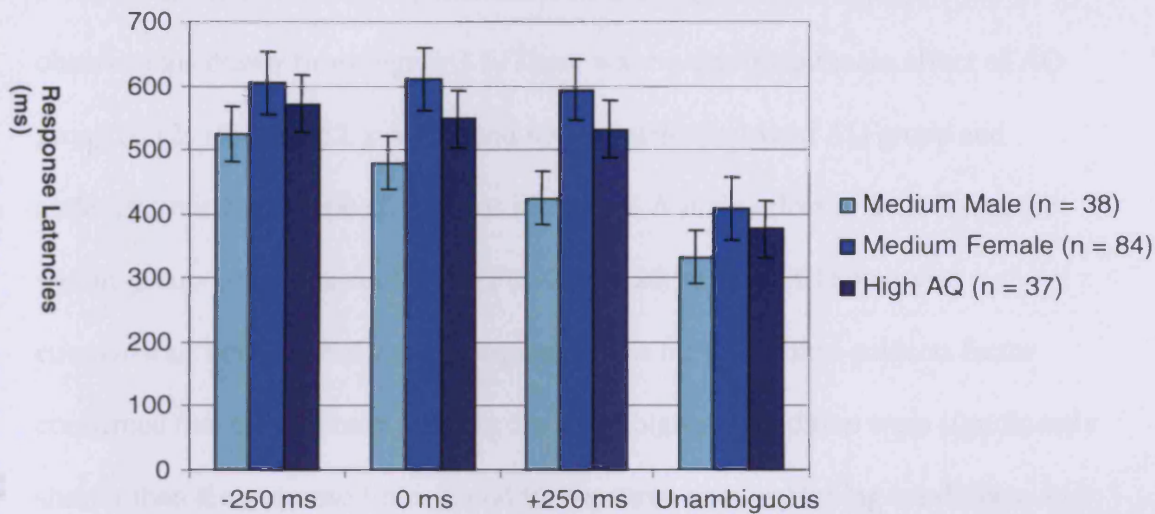


Figure 3.5: Response Times (ms) by Auditory Signal Timing and AQ Group.

As for the gender analysis, the collapsed data for both unambiguous control trial types was included in analysis of the response latencies associated with each auditory timing condition¹⁴. The six outliers identified from the control data were removed prior to analysis. Figure 3.5 shows that the Medium Female and High AQ groups vary very little in response times across experimental trial types. The Medium Male group produced the fastest times for each condition, and this group does appear to vary in terms of response speeds across auditory signal timings. The shortest response times are seen for the Unambiguous control condition, irrespective of group.

A 3 x 4 mixed ANOVA, with the three AQ groups as the between factor, and Trial (three levels of auditory timing conditions plus the collapsed control trial

¹⁴ Average response times for all unambiguous control trials (crashes and misses) were found to correlate highly and significantly with each other, justifying use of a single collapsed variable for control trial response times.

condition) as the within-group factor, was performed. This analysis provided no evidence of differences in response times across AQ groups, contrary to the observations drawn from Figure 3.5. There was no significant main effect of AQ group ($F(2, 156) = 1.62, p > .05$), and no interaction between AQ group and auditory timing trial type ($F < 1$) was identified. A main effect of Trial Type, the within-group factor, was obtained ($F(3,468) = 20.90, p < .001$). Pairwise comparisons between estimated marginal means for this within-subjects factor confirmed that the response times in the Unambiguous condition were significantly shorter than the response times found for the three auditory timing conditions, and latencies between experimental trial types did not differ (corresponding to the same analysis in relation to gender, above).

Experiment 5b: EFT task performance by Gender and AQ Group

Performance on the EFT was measured by accuracy and response times. The data sample used was the same as that used for Experiment 5a, with the outliers on CoMG control trial accuracy and response times excluded prior to this analysis (in preparation for Experiment 5c, where CoMG variables are correlated with EFT measures). Outliers on the EFT accuracy scores (i.e., those with scores two standard deviations below the mean for the entire sample) were identified. Identification led to the further removal of three men and three women, all from the Medium AQ groups, except for one high AQ scoring male. Outlier exclusion therefore reduced the sample size from Experiment 5a by c.4% to 153 participants.

Analysis 1: EFT Accuracy and Response Times by Gender

EFT Measure	Group	n	Mean	Std. Deviation	Range
<i>Accuracy (/10)</i>	Male	54	8.69	1.21	5 - 10
	Female	99	8.15	1.33	4 - 10
	Total	153	8.34	1.31	4 - 10
<i>Response Time (Sec.s)</i>	Male	55	10.88	4.66	3.35 – 23.51
	Female	99	12.46	4.38	2.50 – 22.74
	Total	153	11.90	4.53	2.50 – 22.74

Table 3.22: Descriptive Statistics of EFT Accuracy and Response Times (seconds) by Gender (Experiment 5b)

Table 3.22 provides the means and standard deviations for both EFT measures (accuracy and response times) by gender. It can be seen that men are both generally more accurate and take less time to respond than women, although the ranges and standard deviations are similar. These observations were confirmed by performing independent samples *t*-tests adjusted for unequal cell sizes ($t_{Acc.}(151) = 2.51, p < .05$; $t_{Time}(151) = -2.04, p < .05$), with men showing significantly higher accuracy scores and lower response times.

Analysis 2: EFT Accuracy and Response Times by AQ Group

Measure	AQ Group	n	Mean	Std. Deviation	Range
Accuracy (/10)	<i>Medium Male</i>	36	8.58	1.36	5 – 10
	<i>Medium Female</i>	81	8.12	1.34	4 – 10
	<i>High</i>	36	8.58	1.13	6 – 10
	Total	153	8.34	1.31	4 – 10
Response Time (Sec.s)	<i>Medium Male</i>	36	11.32	4.67	4.32 – 19.62
	<i>Medium Female</i>	81	12.58	4.15	5.21 – 22.74
	<i>High</i>	36	10.97	5.06	2.50 – 22.51
	Total	153	11.90	4.53	2.50 – 22.74

Table 3.23: Mean EFT Accuracy Scores and Response Times (seconds) by AQ Group (Experiment 5b).

Considering AQ groups, the means (Table 3.23) for both measures generally followed the patterns predicted; women were slower and less accurate than men, who in turn were slower than the high AQ participants (although equally accurate). Taking each measure independently, one-way ANOVA analyses were run using AQ group as the independent variable (between-group factor). Scores obtained were found not to differ by AQ group in either analysis, although a trend was found for EFT accuracy scores to differ by AQ group ($F(2,150) = 2.40, p = .09$). With respect to response times, no effect of AQ Group was observed; $F(2, 150) = 2.00, p >.05$.

To investigate the trend in accuracy score differences, independent samples *t*-tests were conducted between both Medium Male and High AQ group scores with Medium Female group scores, but again only trends were obtained after correcting for unequal cell sizes ($t_{\text{Med. Male}}(115) = -1.71, p = .09$, and $t_{\text{High AQ}}(115) = -1.80, p = .08$, and so the observation that women performed the task less accurately than typical men and High AQ scorers was only partially supported.

Measure	Gender	n	Mean	Std. Deviation	Range
Accuracy (/10)	Male	18	8.89	.83	7 – 10
	Female	18	8.28	1.32	6 – 10
	Total	36	8.58	1.13	6 – 10
Response Time (Sec.s)	Male	18	10.02	4.68	4.91 – 22.51
	Female	18	11.92	5.38	2.50 – 21.03
	Total	36	10.97	5.06	2.50 – 22.51

Table 3.24: Mean EFT Accuracy Scores and Response Times (seconds) by High AQ Gender Subgroup (Experiment 5b).

Table 3.24 shows that EFT mean scores and response times appear similar between male and females with high AQ scores. A gender comparison was

undertaken to ensure that conflation of high AQ scoring males and females had not distorted the AQ group analyses. Scores on both measures between high AQ subgroups were not significantly different ($t_{Acc.(34)} = 1.66, p = .11$, and $t_{Time(34)} = -1.13, p >.05$). Female High AQ individuals were also less accurate and slower than Medium group male participants, but not significantly so ($t_{Acc.(54)} = 0.79, p >.05$, and $t_{Time(54)} = -0.43, p >.05$). The high AQ group responses were therefore not affected by combining data from males and females with high total scores, although high AQ men are significantly faster and more accurate regarding EFT performance than medium-scoring females ($t_{Acc.(97)} = 3.11, p < .05$, and $t_{Time(97)} = -2.31, p <.05$) when these data are compared independently.

Experiment 5c: Relationships between perceptual integration and EFT performance

Measure 1	Measure 2	<i>r</i>	<i>p</i>
EFT Accuracy (/10)	<i>EFT Response Times (Sec.s)</i>	-.78*	.00
	<i>Crash reports</i>	-.13	.10
EFT Response Times (Sec.s)	<i>Crash reports</i>	.14	.08

* Correlation is significant at the 0.001 level (2-tailed).

Table 3.25: PPMC Correlations between EFT measures and Crash Report Proportions from the Simultaneous (0 ms) CoMG condition (Experiment 5c).

The simultaneous (0ms) condition was selected to determine whether perceptual integration was related to performance on the Embedded Figures Task; this timing condition produced the maximum number of crash reports for each AQ group. Correlations between this variable and the EFT variables were computed for the complete data set (153 participants). These results are presented in Table 3.25. Accuracy and response time data from the EFT were found to be inversely related (r

= -.78, $p < .001$); as accuracy scores increased, average response times decreased.

The crash report measure was found not to correlate significantly with either EFT measure, although trends were found for accuracy to decrease and response times to increase as more crashes were reported ($r_{\text{Acc.}} = -.13, p = .10$; $r_{\text{Time}} = .14, p = .08$).

The magnitudes of these correlation values represent small effect sizes.

Measure 1	Measure 2	Gender	<i>r</i>
EFT Accuracy	<i>EFT Response Times</i>	Male	-.78*
		Female	-.78*
	<i>Crash report</i>	Male	.07
		Female	-.19
EFT Response Times	<i>Crash reports</i>	Male	.09
		Female	.14

* Correlation is significant at the 0.001 level (2-tailed).

Table 3.26: PPMC Correlations between EFT measures and Crash Report Proportions from the Simultaneous (0 ms) CoMG condition by Gender (Experiment 5c).

As shown in Table 3.26, female ($n = 99$) and male ($n = 54$) data produced significant correlations between the two EFT measures of equal magnitude ($r = -.78$ and $r = -.78$, respectively; $p < .001$). The relationship between EFT accuracy and crashes reported bordered on significance for women ($r = -.19, p = .06$), but not for men; the relative values of r do not significantly differ (Fisher's r -to- $z = -1.51, p > .05$).

AQ Group	N	Crashes vs. EFT accuracy	Crashes vs. EFT response time	EFT accuracy vs. response time
Medium Male	36	.03	.21	-.75**
Medium Female	81	-.25*	.25*	-.75**
High AQ	36	.13	-.21	-.90**
Total	153	.14	-.13	-.78**

** Correlation is significant at the 0.001 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

Table 3.27: PPMC Correlations between Crash Proportions from the Simultaneous (0 ms) CoMG condition and EFT measures, by AQ Group (Experiment 5c).

Correlation results for the same relationships investigated for each of the AQ groups are summarised in Table 3.27. A significant inverse relationship was produced between EFT accuracy and response times for all groups. Two further relationships were also derived for the Medium Female group. The number of crashes reported increased as EFT accuracy decreased, and as EFT average response times lengthened. These relationships were of identical magnitude (both $r = .25$, $p < .05$), representing small-to-medium effect sizes.

Fisher's r -to- z transformations between the Medium Female group and each of the Medium Male and High AQ groups were performed. For the Medium Male comparison, the value of r obtained for the Medium Female group was not found to be significantly different for EFT accuracy ($z_{Acc.} = -1.37$, $p > .05$, two-tailed) or EFT response times ($z_{Time} = .2$, $p > .05$). In comparison with the High AQ group, however, the z value obtained for accuracy correlations is close to significance ($z_{Acc.} = -1.86$, $p = .06$, two-tailed), and is significant for response times ($z_{Time} = 2.26$, p

<.05); these results indicate that the typical female and High AQ groups are dissociated in terms of EFT performance.

A separate analysis of the High AQ group was undertaken for the female participants only ($n = 18$). The correlations between EFT measures and crashes reported in the simultaneous condition of the CoMG were $r_{Acc.} = .08$, and $r_{Time} = -.25$; neither of these values is significant, and they are both of opposite valence to those obtained for the Medium Female group. A Fisher's r -to- z transformation comparing the respective correlation values for the relationship between EFT time and crash reports for High AQ and Medium AQ females revealed a trend towards significance ($z = -1.81, p = .07$).

3.4.4 Results summary and Discussion

Experiment 5a

Generally, results from this experiment indicate that no evidence was found to support the idea that the broader autism phenotype is substantially different from the typical phenotype with respect to cross-modal integration. However, there was evidence that typical men and women differ in terms of sensitivity to simultaneous cross-modal stimuli, although men and women expressing the broader phenotypes are equivalent in this respect.

The main hypothesis for Experiment 5a was that integration across the senses would be compromised in high AQ scoring individuals; hence fewer crash reports were predicted for this group in response to audio-visual perceptual causality

stimuli. There was no support for this prediction from Experiment 5a; no evidence of a main effect of group was discernible when crash report proportions were compared between AQ groups across all auditory timing conditions. Furthermore, lack of a significant interaction suggests that none of the groups responded differently from the others under the varying auditory timing conditions. All groups perceived more crashes when the auditory signal was presented as the moving disk occluded the stationary disk, but fewer crashes were seen when the signal occurred 250 milliseconds before or after this point. Given that the pattern of response across conditions ran in parallel across Medium Male and High AQ groups, the hypothesis that temporal encoding of audio-visual integration is atypical in relation to the BAP received no support, as a 'flat' response level was no more apparent for the High AQ group than for the Medium Male group.

Only the Medium Female group showed any tendency towards a true 'peaked' response. The absence of a significant interaction between group and auditory timing condition is difficult to interpret, in that none of the patterns in the data are as exaggerated as was expected, given the high crash report proportion (0.70) obtained across groups in Experiment 4 (see Figure 3.2), which followed the data originally reported by Sekuler et al., 1997 (simultaneity generating a mean percentage of bounces exceeding 60% from ten naïve participants).

The disparity between studies in relation to power of the simultaneity effect may reflect sampling biases, as the overall AQ score mean for the first study was almost four points lower than found for the sample here (13.7 vs. 17.5); people with fewer autistic traits are predicted to be *better* perceptual integrators than people with

relatively more traits (the logical extrapolation from the hypothesis that high AQ scores are associated with poorer integration). However, this cannot be the sole explanation, as the High AQ group in Experiment 4 experienced more crashes than the typical female group in Experiment 5, despite having a considerably higher mean AQ score at group level.

It would appear then that methodological differences between studies are also involved in producing these conflicting results. The most obvious difference between studies is that the control trials in Experiment 5 were all presented with auditory signals at timings equivalent to those for the experimental trials. This aspect of the design was purposeful. The relative salience of experimental trials was reduced so that no rule-based response strategies could be adopted by participants (such that hearing a click generated an automatic crash response). The introduction of audio-visual control trials may have caused the categorisation boundaries defining the crash percept to be less distinct in Experiment 5 relative to Experiment 4. The finding that no significant differences exist in terms of differences in latencies at group level across trial types may also be explained on this basis (no interaction was obtained between Group and Trial in the latency analysis in Experiment 5a).

When genders were compared, women were seen to experience more crashes in the simultaneous condition of the CoMG (although this difference only produced a trend towards an interaction when all three timing conditions were included in the analysis). Enhanced female susceptibility to this specific audio-visual phenomenon is unexpected for two reasons: The stimuli are object-based, not

social in nature, and no such disparity in crash report proportions was found between sexes in the equivalent simultaneous audio-visual condition in Experiment 4a. As men tend to show enhanced processing of objects and reduced social stimuli processing, and women show the reverse pattern (Baron-Cohen & Hammer, 1997) this result initially appears anomalous.

However, it could be argued that object-based processing in men (and social stimuli preference in women) is due to attentional (and hence cognitive) biases; when attention is directed solely towards basic perceptual stimuli, sex differences in perception may reflect different patterns. For instance, perceptual speed indexes have shown female advantages (Hedges & Nowell, 1995; Kimura, 1999). Although these tasks (such as object-based pair matching) are generally uni-modal, the enhanced ability to process sensory information efficiently and quickly may generalise to include more effective cross-modal processing in women.

When both Experiments 4 and 5 are considered together, there exists a conflict in terms of heightened typical female crash responses over typical male crash reports in the simultaneous condition of Experiment 5a (which was not found for the identical condition in Experiment 4a). The inconsistency may relate to the fact that the mean for the Medium AQ group in Experiment 4 was relatively low. The normative mean for typical (i.e., non-BAP) student males originally provided (Baron-Cohen et al., 2001) was 18.6, whereas the male student AQ mean for the sample in Experiment 4 was 13.5 (versus 15.4 in Experiment 5). This five point discrepancy suggests that the conflict in results is caused by sampling differences, with the typical male sample in Experiment 4 showing far fewer autistic traits than

would generally be expected. In EMB terms, it would be expected that fewer traits in the typical males would be related to more 'female-type' processing for the Medium AQ group overall, which in turn would account for the lack of male/female differences found in Experiment 4a for the perceptual causality task. The conclusion, therefore, is that the sex difference in Experiment 5a is a valid result.

Experiments 5b

The adapted version of the adult Embedded Figures Task was specifically designed to assess the perceptual processing component of participant performance. Participants did not have to hold the simple target shape in mind whilst examining the complex figure in which it is embedded, and hence the visuo-spatial working memory aspect of the task was removed. Enhanced perceptual processing of single features has been argued to be the root of autistic superiority on this task (Jarrold et al., 2005; Pellicano et al., 2005) , and so it was anticipated that this amended embedded figures task would provide evidence of an ability advantage in association with the broader autism phenotype. If the BAP is an extreme manifestation of the male brain, then typical men should also show superiority over typical women. Additionally, women with the broader phenotype were predicted to show the same advantages as men with BAP on this task.

This altered EFT methodology produced gender differences in which men were found to be generally more accurate and took less time on average to respond than women. The significantly faster response latencies corroborate a wealth of evidence of male advantage on this task (e.g., Miller, 2001; Voyer, Voyer, & Bryden, 1995). In a review of visuo-spatial versus verbal sex differences, Halpern

(2004) concluded that memory tasks in which spatial transformations (such as mental rotations) are required favour men, suggesting that such information is better encoded by men than women. It was reasonable to predict therefore, taking response times for accurate trials as representative of processing efficiency, latency differences between the sexes to be maintained even though the visuo-spatial memory component was removed in the new EFT methodology. Results indicating male superiority supported this expectation, and are interpreted here to suggest that perceptual processing drives this advantage in men.

The results from the AQ group analysis are more complex. Neither accuracy nor speed of response advantages could be found for the High AQ scoring group over typical males and females using this EFT methodology. This study therefore does not support the findings from recent research that BAP is associated with superior ability on tests of weak central coherence. Happé, Briskman and Frith (2001) and Bolte and Poustka (2006) report enhanced speed for correct responses in parents with ASD children, but Baron-Cohen et al. (2006) and de Jonge, Kemner and van Engeland (2006) found no such difference between BAP parents and comparison parents.

Given the fact that EFT accuracy is also inconsistent in autism research (even within ASD studies; Brian & Bryson, 1996, Ozonoff, Pennington & Rogers, 1991), the results reported here are not unusual. It is likely that the altered methodology and changes in data adjustment have contributed to the results observed for Experiment 5b. The amendments made to standard EFT procedure for Experiment 5 were specifically designed to aid understanding whether *perceptual*

processes between groups defined by AQ scores differed. In most other studies, as de Jonge et al. (2006) state, response times for inaccurate responses are adjusted to 180 seconds, which means that slight differences between participants in accuracy lead to disproportionately inflated differences in their mean response times. This flawed method may have generated false latency results in prior studies, but this is not the case here as the mean time for inaccurate scores across all participants was substituted for every inaccurate response and every response that exceeded 30 seconds¹⁵. Also, side-by-side target shape/complex figure presentation removed the cognitive element involved in other studies, which was important because this prevented confounds based on individual variation in visuo-spatial working memory.

On this basis, from this study it appears that there is little difference between BAP individuals and non-BAP individuals on EFT performance when perceptual processing alone is considered. It may be then, that the BAP and ASD studies in which superiorities are found when testing participants with embedded figures represent a cognitive (i.e., memory) difference, in which (visual) detail encoding and retention is enhanced in working memory.

It may also be that the range of EFT accuracy and latency scores across the entire sample is constrained due to the distorted AQ score distribution in Experiment 5. In particular, there was only one participant who scored under ten in the female sub-sample. Furthermore, the female group mean in Experiment 5 ($\mu =$

¹⁵ The alternative approach was to analyse data relating to correct responses only. This option would have led to people who only responded accurately to the easiest trials appearing to have very fast average latencies.

16.7) is comparatively high, relative to that found for females from Experiment 4 ($\mu = 11.3$); the AQ scores for the female participants in Experiments 4 and Experiment 5 are significantly different ($t(155) = -4.22, p < .001$). In terms of the AQ group analyses, complete lack of 'extreme female brain' participants in the typical female group may have prevented a significant effect of group being found in Experiment 5b.

The last points to note regarding Experiment 5b are that the women included in the broader phenotype group exhibited mean EFT scores on both measures that fell between those associated with typical men and women, and that the high AQ scoring men were seen to be significantly faster and more accurate than typical women once the BAP females were removed. In this respect, the results presented here parallel those found by Happé, Briskman & Frith (2001), who reported that fathers, but not mothers, of children with ASD were faster and more accurate than controls on the Embedded Figures Task.

Experiment 5c

When the relationship between EFT performance and cross-modal integration is considered, more information regarding the role of gender in EFT performance is discovered. The expected result for Experiment 5c was that poor perceptual integration would be related to enhanced EFT performance in men and BAP individuals. No such relationships were found, and instead *inverse* correlations were obtained between heightened perceptual integration and poorer EFT performance for both measures in typical women *only*. There are two interesting conclusions to draw from this male/female difference. The first is that, in line with

the finding that women appear better perceptual integrators than men generally (Experiment 5a), female and male perceptual phenotypes show distinctions in terms of how the same visual stimuli are processed. The second is that atypical women (those with a relatively high number of autism traits) are comparable to men (irrespective of BAP presence or absence) in that they do not display this negative perceptual integration/visual disembedding relationship.

To understand the neural processes responsible for this dissociation between typical females and typical males/BAP individuals, one candidate brain region warranting discussion is the extrastriate visual cortex. Activity within this site may be the common factor that accounts for enhanced cross-modal integration (as inferred from elevated number of crashes seen in the simultaneous condition of the CoMG in Experiment 5a), and its correlation with visual disembedding performance in Experiment 5c, in typical women. The extrastriate visual cortices function to integrate visual information and resolve competition between types of visual information (Beck & Kastner, 2005; Kastner, De Weerd, Pinsk, Elizondo, Desimone & Ungerleider, 2001; Miller, Gochin & Gross, 1993; Pack, Gartland & Born, 2004). This cortical region also includes area MT/V5, the neural base for motion information processing (Braddick, Atkinson & Wattam-Bell, 2003). Enhanced responsivity to complex dynamic audio-visual stimuli may be related to increased feature integration, as both processes involve activation of areas within the extrastriate visual region. Therefore, at neural level, results from Experiment 5 taken together suggest women and men may differ in terms of the neural areas that respond to the cross-modal perceptual causality and EFT stimuli.

Evidence from a recent brain imaging study does support the suggestion of differential neural recruitment between genders in response to complex stimuli. Although deemed a pilot study due to low group numbers, Baron-Cohen et al. (2006) has reported fMRI research study in which activation of neural regions in response to EFT stimuli varied by gender. Their results indicated significantly heightened levels in extrastriate activity in typical females as compared to typical males and BAP adults (parents of ASD probands). In this study, mothers of children with ASD generally responded at the neural level in the same way as did fathers and male controls. In the left-hemisphere primary visual cortices, mothers also showed *less* activity than typical males, suggesting that they have an extreme male pattern of neural response (as well as the fathers). The argument of equivalence between the BAP in men and women in terms of a particularly male perception/cognition relationship is therefore empirically supported by response to stimuli testing weak central coherence, as reported both in Experiment 5c and in the fMRI study by Baron-Cohen et al. (2006).

It would therefore appear that differential encoding of embedded figures is gender-based, with women expressing the broader phenotype possibly showing a 'male brain' pattern of response. In typical women, the extrastriate visual cortex may play a role in EFT resolution that is specific to their sex. Elevated levels of extrastriate activity may also account for the heightened sensitivity shown by typical women in this study to cross-modal perceptual causality, as the stimuli used are dynamic in nature. This explanation extends to the inverse relationship found between elevated levels of crash reports and EFT performance between individuals within the typical female group. No such relationships were found for women

expressing a high number of autistic traits, who, like typical men and BAP men, exhibit correlations between perceptual integration and EFT measures that verge on being significantly different from those of typical women.

It is therefore concluded that Experiment 5c provides partial support for the Extreme Male Brain theory of autism, in that the BAP appears to represent male brain functioning, whether such individuals are male or female, with respect to relationships between perceptual integration and EFT performance.

3.5 General Discussion and Conclusions

The general aims of this chapter were to investigate whether there was any initial experimental evidence for compromised cross-modal integration in ASD, using the Broader Autism Phenotype as an analogue model. Secondly, the studies were designed to consider whether the BAP in the general population showed the same cognitive superiorities as have been found in relations of ASD probands. As Extreme Male Brain theory equates the BAP to an exaggeratedly male brain type, gender differences within BAP and non-BAP groups were also analysed.

Results from these investigations are summarised below. However, there are many factors that could have influenced results generated by using Autism-Spectrum Quotient questionnaire scores as the basis for categorising groups. The AQ is a self-report instrument and behavioural questionnaires are known to be methodologically flawed in this respect. Participants may distort data by resorting to socially desirable responding. In other words, they may “stretch the truth in an effort

to make a good impression” (Martin & Nagao, 1989, p. 72). Distortion of self-report behavioural data on this basis has been acknowledged as challenge to psychological research for over five decades (e.g. Edwards, 1953); questionnaire-based study results must therefore be treated cautiously. The argument here, though, is that a few BAP individuals may have been included in the Medium AQ group in both studies. Given that this group contains many more individuals than the experimental BAP groups, their data is unlikely be disproportionately influential, although in the experiments 4b and 4c the marginal superiority of Medium AQ group males over BAP males on average Intuitive Physics scores (means 12.64 vs. 12.13) may reflect an impression management effect.

Notwithstanding potential confounds generated by using the AQ, the studies did produce some interesting findings. In terms of cross-modal integration, compromise in association with BAP was only apparent when audio-visual stimuli were compared with visual stimuli (Experiment 4a) within this group. Extended response times in both the audio-visual and ambiguous conditions suggest that processing ambiguity is hard for BAP participants, and that the auditory signal is not as effective as the visual capture cue in terms of relative disambiguation strength. This finding was interpreted as meaning that the causal percept generated by cross-modal integration is less clear than the percept created by viewing the visual capture stimuli, given that these unimodal stimuli were processed as quickly as unambiguous control stimuli. Results from comparing categorical responses (i.e., crashes reported) between AQ groups showed that the BAP group is similar to other groups in terms of responding to disambiguating cues, irrespective of cue type (cross-modal or unimodal). However a trend was found in the hypothesised

direction when crash reports in the key audio-visual CoMG condition were compared between High and Low AQ groups, with the BAP latencies being significantly longer.

The results relating to the low AQ group suggested that task performance by these participants in Experiment 4a differed distinctly from that of the BAP group. The uniformly rapid responses across trial types suggested that percepts generated by all stimuli facilitated easy judgements, and the response to disambiguating cues indicated a greater sensitivity to these signals than the other groups (although not significantly so). Hence this group potentially represents the opposite end of the autistic dimensional continuum (Wakabayashi et al., 2006). If this is the case, it is interesting to note that the continuum may have a perceptual aspect, and that absence of autistic traits may be related to heightened perceptual integration (both within and across modes). The low AQ group was predominantly female, hence the low AQ/high AQ distinctions found in Experiment 4a provide support for EMB theory, rather than for the main hypothesis of compromised perceptual integration.

The results of Experiment 5a cannot add to this conclusion, as no participant could be categorised as exhibiting this 'anti-BAP' profile (none reported fewer than 7 autistic traits). Lack of low AQ scorers may therefore have influenced results; in this study, High AQ responses showed no differences in either latencies or crash reports with respect to the auditory signal irrespective of its presentation timing. However, in this version of the main task, typical women and men differed again in that women integrated the auditory signal more effectively in the critical (simultaneous) auditory timing condition and consequently perceived significantly

more crashes, whereas within the BAP group no such gender distinction was found, and responses produced a pattern equivalent to that of typical men. The broader phenotype therefore does not appear to be associated with compromised cross-modal integration, but the fact that BAP women are similar to BAP men although typical women are dissimilar to typical men does partially support EMB theory (Baron-Cohen, 2002), and suggests the inclusion of perceptual integration behaviour as a marker for the BAP/anti-BAP continuum.

Broader autism phenotype was not found to be linked to autistic superiority in either physics or visual disembedding ability. Where difference was found to exist, it occurred between typical men and high AQ scorers with typical women. Typical females were found to be weaker at physics, to integrate audio-visual stimuli more effectively than men, and to be comparable to men with respect to the EFT, yet process stimuli differently from men (in that variation in EFT performance is correlated at the individual level with cross-modal integration sensitivity for women with normal range autistic trait expression). Unlike typical women, female participants deemed to represent the BAP are similar to men, especially with respect to the lack of perception/cognition relationship inferred from the crash report/EFT accuracy data (although they were not found to be superior to typical women on EFT measures, unlike High AQ men). Again, this dissociation in male/female performance differences between BAP and typical groups is predicted by EMB theory (Baron-Cohen, 2002).

On most cognitive functions, gender distributions are broadly similar and only produce small mean disparities (Hedges & Nowell, 1995). It has been

concluded that gender ratio biases at the extreme tails of these distributions are the source of such small effect sizes (Halpern et al., 2007). There is support from the studies here that some individuals represent exaggeratedly female and male brain types, which are associated with low or high presence of autistic traits. Has the BAP and its hypothetical antithesis contributed to sex differences findings in the cognitive literature?

Broader phenotype investigation presents research method issues that may not be easy to resolve. This point notwithstanding, the main finding from this chapter regarding the *perceptual* broader autism phenotype is that it appears similar to the typical male perceptual phenotype, which shows differences from the typical female phenotype in some respects. Hence the BAP shows signs of ‘extremity’ only when its counterfoil (the exaggerated female brain type) is present. This conclusion generates a problem for further research into perceptual integration in ASD, in that subtle perceptual differences based on male vs. female brain differences may not be found (as target and control groups are gender matched).

Generally, no inferences regarding autism as the manifestation of **extreme** male brain function can be made from these studies. It could be argued, though, that to produce the severity of atypical behaviour sufficient to warrant diagnosis of an autism spectrum disorder, the brain function of an affected individual is likely to be very different from that of a typical peer. If perceptual integration is causal to the autistic condition, then exaggerated differences in response to cross-modal stimuli should be detectable. The following chapter therefore investigates cross-modal integration with respect to a group of children and adolescents with ASD.

Chapter 4: Cross-modal integration in ASD

4.1 Overview

The previous chapter provided some indication that cross-modal integration is compromised in the Broader Autism Phenotype. The general conclusions drawn were that individuals expressing the BAP, irrespective of their gender, are largely comparable to non-BAP males, and that they differ from typical females and individuals with few autistic traits in some respects. For instance, individuals with the BAP of both genders and typical men tended to report fewer crashes than typical females when the auditory signal coincided with occlusion of the disks in Experiment 5a. Also, EFT performance in typical women is inversely related to the number of causal events experienced, suggesting that perceptual integration within the visual extrastriate region competes with single feature processing; this relationship is not apparent in men or, more interestingly, in association with expression of the BAP in individuals of either sex (Experiment 5c).

These findings, although consistent with Extreme Male Brain theory, do not constitute evidence that difficulties in multisensory processing at the perceptual level exist in ASD, as responses to the cross-modal perceptual causality stimuli associated with the broader autism phenotype are broadly comparable to levels of response for typical men expressing an average number of traits (as measured by the AQ). However, the BAP groups in Experiments 4 and 5 display AQ means that equate to 'intermediate level' scores (as defined by Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001), therefore the slight (non-significant) reductions

in causal percepts generated in association to the BAP relative to typical male results may be more pronounced when testing individuals with diagnoses of ASD.

In this chapter Experiment 6 considers cross-modal integration in ASD by comparing boys with and without diagnoses matched for age and non-verbal IQ or verbal IQ in terms of CoMG performance. This study also includes data from the children's intuitive physics test (the What Happens Next? Task, as described in Chapter 2). Comparative analyses using these data explore whether any relationships exist between perception and cognition within ASD. Given recent evidence of perceptual differences between autism and Asperger Syndrome (Mazefsky & Oswald, 2006; Tsermentseli, O'Brien & Spencer, 2007), a final analysis is presented in Experiment 6 in which cross-modal integration and intuitive physics scores are contrasted between age and non-verbal IQ-matched ASD diagnosis subgroups.

4.2 Introduction

4.2.1 Multisensory processing in ASD

Myriad reports of abnormal visual perception in relation to ASD, and growing evidence of auditory differences in autism, led Iarocci and Macdonald (2006) to call for a specific and systematic investigation of multisensory processing from a cognitive neuroscience perspective. They point out that no single historical psychological or neuroscientific account of ASD has comprehensively explained both the cognitive phenotype and characteristic behaviours of autism. The co-

existence of abnormal sensory patterns with cognitive differences in ASD has been portrayed as coincidental rather than potentially causal. The fundamental cause for all autistic behaviours has therefore been suggested to be the atypical neurodevelopment of multisensory integration systems, and its subsequent impact on establishing the neural architecture required to support socio-cognitive functions dependent on multimodal signals (Iarocci & McDonald, 2006).

Within the visual mode, Bertone has in part justified the validity of viewing perceptual integration issues in autism as a problem arising at primarily the perceptual rather than the cognitive level. His 'complexity-specific' hypothesis (Bertone & Faubert, 2006) predicts that perception in autism reflects 'diffuse or non-specific neural dysfunction of neuro-integrative mechanisms affecting complex perceptual processing in autism in general'. The resulting Signal Integration Theory (Bertone & Faubert, 2006) is supported by evidence that response to first and second order sinusoidal gratings, in which the visual 'noise' variable between stimuli recruit either visual area V1 alone or multiple visual areas, is *specifically* associated with autism (see Chapter 1, section 1.3.2 for a more comprehensive description of this theory).

Signal Integration Theory has not as yet been extended to abnormal multisensory processing of poorly integrated unimodal information. Little has been established to date with regard to multisensory processing differences in autism. Seemingly similar studies have produced conflicting results. For instance, de Gelder and Vroomen (1991) found that children with autism experience a diminished facilitatory effect of simultaneous visual speech to aid decoding of unclear auditory

speech in comparison to controls, and concluded that cross-modal integration is deficient in autism.

However, Williams, Massaro, Peel, Bosseler and Suddendorf (2004) more recently reported that it is not cross-modal integration *per se* that is affected in autism. Although Williams et al. (2004) found evidence of a reduced McGurk effect in a group of children with ASD, they also demonstrated that differences in visual speech-reading ability (unimodal) were largely responsible for this difference. With the McGurk effect, mouthed presentation of a syllable such as /ga/ distorts the auditory perception of /ba/ so that /da/ is heard; such perceptual blending dramatically reduces the overall accuracy of auditory syllable detection, whereas congruent presentation of the syllable in both auditory and visual modes greatly facilitates accuracy. In this study, once speech-reading ability was accounted for, no bi-modal facilitation of accuracy was discernible in the target group in the congruent condition, suggesting that the lack of perceptual blending in the McGurk condition was being driven by weaknesses in visual processing alone.

In the emotional domain, Hall, Szechtman and Nahmias (2003) found that adults with HFA/AS did not experience a facilitatory effect of auditory emotional congruence when viewing emotional face stimuli, unlike their peers. Irrespective of congruence or otherwise of the emotional content of the face/voice pairings, simultaneous presentation produced abnormal cerebral blood flow patterns in the target participants that were suggestive of attentional conflict (i.e., over-activation of 'gating' regions such as the thalamus). It could be argued that stable integration of multisensory signals would lead to prioritised processing over unimodal signals

so that this conflict in recruiting attentional resources would not occur; attentional conflict therefore points to a pre-attentional perceptual integration failure in the target group.

However, examining cross-modal effects on high-order processes such as speech or emotional recognition in autism cause interpretative difficulties, in that this approach necessitates the involvement of both perceptual and cognitive systems, and so performance might not directly reflect perceptual activity (because top-down influences cannot be discounted). For instance, Williams et al. (2004) found that auditory speech accuracy of a small sample of target participants improved after computer-mediated speech-reading training in which *directed attention* to lip movements was promoted. This amelioration of an apparent perceptual integration deficit associated with ASD through increasing attendance to the visual component of speech argues against any perceptual integration basis for multisensory deficits.

Conversely, Smith and Bennetto (2007) considered this evidence against a perception system involvement for the multisensory incoherence reported by individuals with ASD to be insufficient. Their careful investigation of the degree to which visual information aids comprehension when listening to speech embedded in noise showed that autistic participants did not benefit from intersensory redundancy in the stimuli to the same extent as typical controls. Furthermore, when group differences were re-analysed at the individual level by hierarchical regression, a unique factor distinct from lip-reading ability was found to be significant within the model produced from the ASD data. The researchers concluded that this separate

factor may represent a pre-attentive audio-visual integration abnormality associated with autism diagnosis that contributes to early and ongoing speech development.

The search for a pre-attentive perceptual integration deficit has also been attempted using purely audio-visual non-speech stimuli. For example, the Shams (or fission) illusion refers to the influence of a series of beeps on the perception of a series of flashes presented in the visual periphery (Shams, Kamitani, Thompson & Shimojo, 2002). In typical subjects, when more beeps than flashes are presented they evoke additional illusory flickers. In a recent autism study based on this illusion (Van der Smagt, van Engeland & Kemner, 2007) fifteen adult participants meeting DSM-IV criteria for autism, and fifteen controls matched for age and IQ produced patterns of reported numbers of flashes in relation to the number of beeps presented that did not differ significantly between groups. Van der Smagt et al. (2007) concluded that any multisensory integration difficulties discovered in association with Autism Spectrum Disorder must therefore originate in processing stages beyond low-level perception in high-functioning adults with autism.

The authors are careful not to over-generalise the conclusion drawn to apply to autistic individuals with below-normal IQ, but the difficulty is that this study's target group is actually superior to the average normal population in terms of general intelligence. In fact the IQ profile obtained, in which standardised verbal scores exceeded performance scores by 7 points (with comparative standard deviations between IQ tasks), suggests that the target group included more individuals with a diagnosis of Asperger Syndrome than with high-functioning

autism, as Asperger Syndrome has been found to relate to high verbal functioning (Ehlers et al., 1997).

The distinction between diagnoses of autism and AS is relevant as it has been suggested that the two diagnoses are differentiable in terms of response to auditory cue intensity. In one recent study (Mazefsky & Oswald, 2006) comparison showed that an HFA group performed significantly worse than an AS group in terms of accuracy of emotional comprehension conveyed by tone of voice, but only when the stimuli's signal intensity was low, suggesting that signal processing efficiency is compromised in autism more so than in Asperger Syndrome. With respect to the Shams ASD study (Van der Smagt et al., 2007), the intensity of the auditory signal (75dB) may have been super-threshold for the sample group; without threshold testing the modulating effect of auditory cue intensity on sensitivity to the Shams phenomenon, any fine-grained differences between target and control groups may have been lost, and any overall differences at this high intensity clouded through conflation of AS and HFA diagnoses within the target sample.

Another consideration of the wider applicability of the study by Van der Smagt et al. (2007) to ASD as a whole is the particular pattern of neural activity evoked by the Shams illusion stimuli, which may actually play on a relative perceptual 'strength' associated with ASD. It is thought that the combination of the auditory and visual stimuli in the Shams task functions to increase activity early on in visual processing, within the primary cortex, V1 (Arden, Wolf & Messiter, 2003). The subjective perception of the illusion has also been shown to be associated with

enhanced V1 activity (Watkins, Shams, Tanaka, Haynes & Rees, 2006). The autism-specific visual signature proposed by Bertone and Faubert (2006) includes an amplification of signalling efficiency of this area in comparison to other visual regions.

The disparity across the existing cross-modal literature may reflect testing audio-visual integration at different processing levels; the Shams illusion is low-level and perceptual in nature, but the speech stimuli used in the lip-reading and McGurk tasks evoke several cognitive, as well as perceptual, processes although Smith and Bennetto (2007) concluded that 'pre-attentive' perceptual integration is deficient in ASD using speech-in-noise stimuli. It is therefore essential to investigate multimodal processing at an early level in ASD using paradigms other than the Shams task.

4.2.2 Cross-modal integration mechanisms in perceptual causality

Selection of the cross-modal perceptual causality phenomenon (Sekuler et al., 1997) as the basis for the studies in this thesis was designed to facilitate assessment of audio-visual integration at the perceptual level in ASD. In the cross-modal experience of perceptual causality, the auditory information provided distorts perception of the ambiguous dynamic visual event in order to generate a percept that has inherent higher-order meaning (i.e., causality). The neural mechanics of this phenomenon have been investigated by Bushara, Hanakawa, Immisch, Toma, Kansaku and Hallet (2003) using similar stimuli to those used by Sekuler et al. (1997) and presented within the Crash or Miss Game.

Bushara et al. (2003) were specifically interested in the neural processes within the perceptual system that support cross-modal binding in order to afford a high level of meaning, rather than those recruited simply when congruent auditory and visual information is provided. In their fMRI task, the ambiguous stimuli used comprised two bars converging with a collision sound presented at the point of occlusion. The differences between the activation patterns associated with reports of causal and non-causal percepts generated in response to these stimuli were contrasted. Activation only associated with the experience of causality was taken to represent neural areas involved in cross-modal binding, rather than simple processing of the separate auditory and visual stimuli components (a result verified by repeating the process using identical stimuli with the sound removed, to ensure that these regions were not simply related to causal perception *per se*).

The results reported by Bushara et al. (2003) concurred with prior cross-modal studies using audio-visual stimuli that were congruent in space and time, in that the multimodal network found in association with 'causal' responses was widely distributed across cortical and sub-cortical regions. However, the important result from this study was that the experience of causality is related to exaggerated activity within multimodal areas such as the superior colliculus, coupled with decreased activity in both visual and auditory modality-specific areas. The authors interpreted the finding of decreased activation in both visual and auditory cortex as evidence against top-down attentional modulation, arguing that an attentional shift or bias to either the auditory or visual signals generated would create heightened activation in one cortex relative to the other. As both unimodal cortices' activity was suppressed whenever a causal percept was experienced, Bushara et al. (2003)

concluded that this activation pattern evidences a ‘reciprocal and competitive interaction between multimodal and predominantly unimodal processing networks’. They further propose that the operation of multimodal networks occurs in parallel with modality-specific areas, i.e., as equivalent sites for early sensory processing and cross-modal interaction, rather than serving at a later stage within a hierarchical, unimodal-to-multimodal sensory processing model.

The conclusion from the study by Bushara et al. (2003) is of considerable interest as it accommodates the proposal that enhanced perceptual functioning within one modality (as suggested by Mottron et al., 2006) may exist alongside cross-modal integration deficits at the individual level. Evidence of neural path dissociation between unimodal and cross-modal processing in relation to audio-visual perceptual causality stimuli therefore aids interpretation of results on Experiment 6.

4.2.3 *Intuitive Physics in ASD*

This final study (Experiment 6) includes the WHN?T in order to determine whether prior evidence of an ‘innate’ physics superiority can be replicated using IQ- and gender-matched children. Baron-Cohen, Wheelwright, Scahill, Lawson and Spong (2001) reported the finding that children with AS achieved higher scores on an Intuitive Physics task than their overall mental age (MA) scores predicted (although their scores on a test of non-verbal IQ were in line with mental ages), and significantly better than a large group of age-matched control males of normal

intelligence. However, it should be noted that the control children were not matched on IQ measures in this study.

Binnie and Williams (2002) have also demonstrated that children with autism show preserved abilities in the domain of physical causal cognition, in conjunction with impaired intuitive psychology and intuitive biology. In a later related study (Binnie & Williams, 2003) comparing intuitive physics and intuitive psychology, the target group (mean age 6 years, 3 months) showed a superior ability to reason about physical phenomena. Despite the autistic children having the lowest mean standardised PIQ score, the physics scores for this group were significantly higher than those of chronologically matched TD controls, and of three other comparison groups of TD children (preschoolers, 7-year olds and 10-year olds), suggesting that the children in this sample were displaying an 'islet of ability' as their physics scores exceeded predictions from their general intellectual functioning.

The finding that superior physics ability applies to autism as well as to AS is important, as autism is more frequently associated with below normal IQ, and so this result strengthens the argument of preserved/superior innate physics aptitude outside of general intellectual abilities; according to the Binnie and Williams study (Binnie & Williams, 2003) this domain-specific specialism appears to generalise across autism spectrum subgroups. The final analyses in Experiment 6 therefore include comparison of intuitive physics measures between matched autism and AS groups.

4.2.4 Summary of hypotheses

The current conflict in findings between studies investigating the hypothesis that perceptual incoherence and multisensory processing difficulties in ASD are related to disrupted early integrative processing is re-examined in Experiment 6, in which cross-modal perceptual causality data obtained from children with and without ASD are contrasted. As the causal phenomenon generated by the CoMG reflects early integrative processing, it is predicted that children with ASD will report fewer crashes than their control peers across all timing conditions of the task, in line with Signal Integration Theory (Bertone & Faubert, 2006). The second part of this study considers whether ASD is related to superior intuitive physics in comparison to matched controls, as has been previously reported, and whether there is any evidence of an intact correlation between cross-modal processing and intuitive physics skill in these boys, as was found in the non-diagnosed (and therefore deemed ‘typically developing’) sample of science-orientated boys (Experiment 3).

To date no distinguishing markers have been identified that reliably differentiate between Aspergers Syndrome and Autism (Ritvo, Ritvo, Guthrie & Ritvo, 2008), although multiple studies have provided evidence of AS-specific cognitive, attentional, behavioural, genetic and sensory atypicalities (Baron-Cohen & Klin, 2006). Specific stimulus-intensity differences in interpretation of emotion information suggests that there may exist perceptual differences between autism and Asperger Syndrome (Mazefsky & Oswald, 2006). Also, Tsermentseli, O’Brien and Spencer (2007) have recently reported that autism differs from AS in terms of compromised coherent visual form detection. Therefore the final analyses in this

chapter presents comparisons using a subset of the data from Experiment 6 in order to evaluate whether these two diagnoses might be separable in terms of cross-modal integration, and intuitive physics.

4.3: Experiment 6: Cross-modal integration in children with ASD

4.3.1 Introduction

The aim of this study was to investigate whether or not children and adolescents with ASD differed from matched controls in terms of their response to cross-modal perceptual causality, their relative intuitive physics abilities and the relationships between them.

Using audio-visual perceptual causality stimuli, cross-modal integration may be shown to be compromised in three respects: The consequence of integration (i.e. the perception of causality) may be less frequently experienced in ASD; the processing speed may be slower (as indicated by longer response times), and the temporal window across which the auditory information can influence visual processing may be extended (generating a flat response pattern when auditory presentation timings are varied). If any or all of these factors are found to differ significantly between target groups and controls, the hypothesis that cross-modal perceptual integration is atypical in ASD would be supported.

In Experiment 3, a significant developmental effect was found in that the number of causal percepts (crashes) reported by participants systematically increased as their ages increased, and therefore participants in this study were

matched closely for chronological age between ASD and control groups. As gender effects were found in adults (Experiment 5) with typical women experiencing crashes more often than men or participants with the BAP, this study examines cross-modal integration in ASD boys only. The reasoning behind this decision is that if atypical perceptual integration is related to behavioural aspects of ASD (Mottron et al., 2006) then it should be demonstrably different between boys with and without diagnoses; inclusion of ASD girls, who are conjectured to have integration processing more akin to that of boys than to that of their own gender (after Experiments 4 and 5), may produce a false result as female controls may have higher crash reports than males.

It is not known how dimensions of intelligence affect perceptual causality processing, but it is feasible that functions of 'general intelligence' may interact with perceptual development to influence results. To avoid potential confounds of this nature, matching was extended beyond chronological age to produce two control groups on the basis of either verbal or non-verbal intelligence, using the British Picture Vocabulary Scale (BPVS) and the Naglieri Nonverbal Assessment Task (NNAT) respectively. Age effects were again controlled across target and control groups through close chronological matching, and so raw rather than standardised task scores were used to ensure that vocabulary and non-verbal reasoning abilities were evenly matched between groups. Any differences found could then be ascribed to ASD, rather than to any differences in intelligence between groups.

4.3.2 *Method*

Participants

Twenty- three boys and male adolescents with diagnoses of either autism (ten), Asperger Syndrome (eleven) or Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS; two) were recruited via mainstream schools with special needs units and special needs schools across South Wales and Somerset. Parents contacted by letters distributed by the participating schools provided full informed consent. Potential control participants were recruited as in the same way from mainstream schools across South Wales. Parents were asked not to respond if their children had been diagnosed with dyslexia, ADHD, colour-blindness, visual or hearing difficulties in order to avoid confounds introduced by these conditions. Ninety-one boys recruited were assessed for verbal and non-verbal IQ abilities using the BPVS and NNAT were tested on IQ measures. Of these, 85 also completed the experimental tasks.

Families of the target children provided details of diagnosis and the clinicians or educational psychologists who had diagnosed their children, in order to confirm that each participant met with current DSM-IV criteria for an ASD condition. Parents of twenty out of these twenty-three participants also completed the Social Communication Questionnaire (SCQ¹⁶; Rutter, Bailey & Lord, 2003). From these parental report data, suitability for inclusion in the study was verified for twenty participants (Appendix G). Testing with the two standardised intelligence scales showed that four target participants fell below the lower normal/near-normal

¹⁶ The SCQ was previously called the Autism Screening Questionnaire (Berument, Rutter, Lord, Pickles & Bailey, 1999). It provides a categorical cut-off for diagnosis of ASD of 12 points from a possible 40, and uses an algorithm designed for diagnosis according to DSM-IV and ICD-10 criteria.

IQ range (i.e., below 80 points) on the BBPVS, and a further three scored below 80 standardised points on the NNAT. One additional participant scored below this cut-off level on both IQ tasks.

Apparatus/Task Stimuli

The apparatus and task stimuli used were identical to those used in Experiment 3, for the experimental tasks. Participants' verbal and non-verbal intelligence quota scores were obtained using the British Picture Vocabulary Scales (BPVS) and Naglieri Non-Verbal Assessment Task (NNAT) respectively, according to published procedures (Dunn, Dunn, Whetton & Burley, 1997; Naglieri, 1997).

Procedure

Participants were tested in quiet, isolated rooms under normal lighting conditions during their normal daytime school routine. As far as possible, similar environments were created across all participating schools. The BPVS and NNAT (in that order) were administered on the first testing day, and the experimental test day was conducted within two weeks for all bar three cases¹⁷. The experimental tasks were presented in the same order, with the CoMG preceding the WHN?T in all cases.

¹⁷ BPVS and NNAT testing is advised to be repeated only after 6 months, and so the data from few individuals with extended periods between test days is unlikely to have influenced results.

4.3.3 Results

Outlier and exclusion analysis

Three potential participants from the control reserve were excluded on the basis that their control trial accuracy measures exceeded 2 standard deviations of the mean for the entire group data on either or both of the control trial accuracy measures. In addition, three potential participants' data were excluded because their responses to the feedback sheet (Appendix C) indicated that they had generated response rules, producing a total control group of 79 participants. Three participants with ASD were excluded as their control data exceeded two standard deviations of the control means for the entire data set, and one data set was removed as the participant refused to complete the CoMG task. The final group size for target participants was therefore nineteen; seventeen of whom had SCQ scores provided by parents that reaffirmed their diagnosis of ASD (Appendix M).

Group allocation according to age and IQ matching

Allocation of typically-developing boys to control groups was made on the basis of their raw scores and chronological age after completion of all study tasks¹⁸; matching was completed 'blind' to experimental data to avoid selection bias.

¹⁸ As recruitment of ASD participants extended across a long period of time, potential control participants completed the experimental tasks to generate a reserve of potential matches.

Group	N	Mean age (years;months)	Age range	BPVS (mean raw scores; range in brackets)	NNAT (mean raw scores; range in brackets)
ASD	19	12;5	9;11 – 15;1	103.5 (60 – 147)	36.4 (12 – 56)
VIQ-match (control 1)	19	11;9	5;2 – 17;1	104.5 (79 – 148)	-
NVIQ – match (control 2)	19	12;1	6;9 – 17;6	-	36 (17 – 61)
Total	57	12;1	5;2 – 17;6	-	-

Table 4.1: Group means and ranges for age and IQ scores (Experiment 6)

Descriptive statistics of the age and IQ match dimensions for each group are provided in Table 4.1. For non-verbal IQ matching, raw scores generally matched within 3 points, but inclusion of ASD participants with below normal and high IQ caused three match pairs to be highly discrepant in age (>30 months); for two of these match pairs, the control children were younger than targets, but the reverse was true for the final pair. An independent *t*-test revealed the age difference between groups to be non-significant ($t(36) = 0.47, p = .64$).

Matching on verbal IQ was comparatively more difficult; poor performance of target participants with autism led to problems identifying same-age individuals with the same difficulties; six of the pairs matched on this dimension have widely discrepant chronological ages between participants. However, at the group level, these age differences did not produce a significant difference between control and ASD chronological age means ($t(36) = 0.91, p = .37$). Two one way ANOVAs with group as the between-factor and accuracy as the dependent variable were performed to determine whether the ASD target group performed the CoMG task comparably to both the control groups on control trials. Both analyses indicated that there were

no significant differences between average accuracy scores for either the unambiguous miss or crash conditions ($F < 1$, $p > .05$ for all analyses).

Experiment 6a: Comparison of cross-modal integration across groups (the Crash or Miss Game)

Analysis 1: Crash reports

Group	N	-250ms	0ms (Simultaneous)	+250ms
ASD	19	.34 (.29)	.40 (.31)	.22 (.24)
VIQ-match (control 1)	19	.38 (.24)	.48 (.28)	.25 (.24)
NVIQ-match (control 2)	19	.45 (.27)	.56 (.27)	.36 (.27)
Total	57	.39 (.26)	.47 (.29)	.28 (.25)

Table 4.2: Crash report proportion means (with standard deviations in parentheses) by auditory stimulus timing condition across groups (Experiment 6a).

As can be seen from Table 4.2, there was a tendency for mean crash reports for the target group to be consistently low across all auditory stimulus timing conditions relative to the control groups (especially in contrast with the non-verbal control group means). However, the pattern obtained across conditions was found to be similar (with highest crashes reported for the simultaneous condition in all groups).

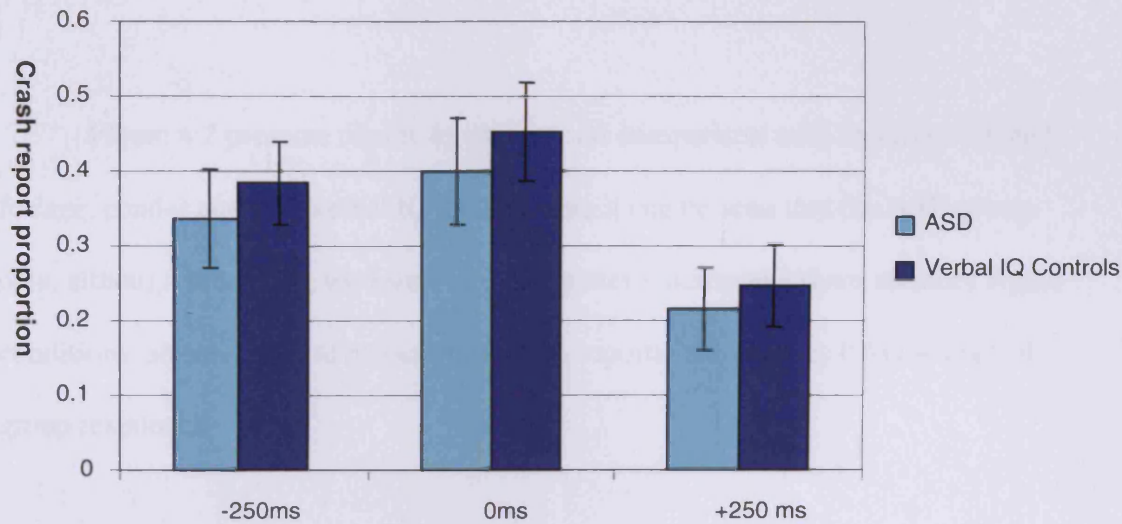


Figure 4.1: Crash Reports by Auditory Signal Timing and Group (Verbal IQ matching; Experiment 6a).

For the verbally-matched comparison, a mixed 2 x 3 ANOVA analysis, with Group as the between-factor and auditory signal timing as the within-factor (Trial Type) revealed no main effect of Group or significant interaction between Group and Trial Type was obtained ($F < 1$ in both cases), and so the number of crashes reported by the ASD group did not significantly differ from the control group. There was, as usual, a main effect of Trial Type; $F(2,72) = 17.23, p < .005$. The post-hoc analyses are presented in Table 4.3, below.

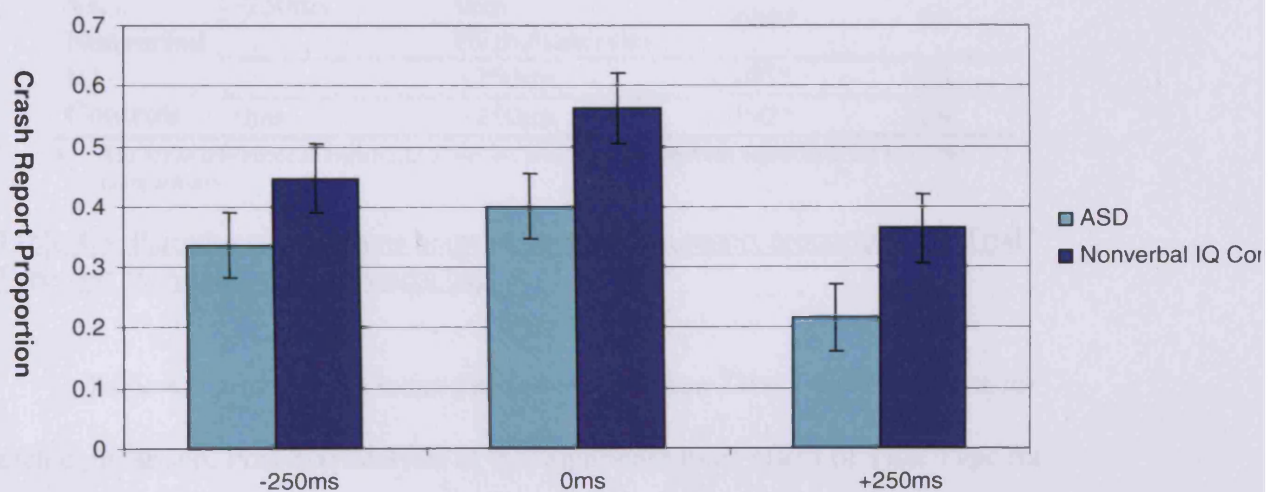


Figure 4.2: Crash Reports by Auditory Signal Timing and Group (Nonverbal IQ matching; Experiment 6a).

Figure 4.2 presents results for the second comparison with controls matched for age, gender and non-verbal IQ ability. Here it can be seen that the ASD group data, although producing the usual ‘peaked’ pattern across the three auditory signal conditions, show a general reduction in crash reports in comparison to the control group responses.

The mixed 2 x 3 ANOVA undertaken for this comparison revealed, however, no significant main effect of the between factor, Group; $F(1,36) = 2.96, p = .09$, although the trend seen is in the hypothesised direction. The interaction between Group and Trial Type was also not found to be significant ($F < 1$). Again, the main effect of Trial Type was significant; $F(2,72) = 18.54, p < .005$. The post-hoc analyses are presented below in Table 4.3.

Analysis	Trial type 1	Trial type 2	Mean Difference	Std. Error
Vs. Verbal IQ Controls	-250ms	0ms (Simultaneous)	.07	.04
		+250ms	-.20*	.03
	0ms	+250ms	-.13*	.04
Vs. Nonverbal IQ Controls	-250ms	0ms (Simultaneous)	-.089*	.03
		+250ms	.103*	.03
	0ms	+250ms	.192*	.04

- The mean difference is significant at the .01 level after Bonferroni adjustment for multiple comparisons.

Table 4.3: Pairwise comparisons between mean crash report proportions by Trial Type and by Analysis (Experiment 6a).

Table 4.3 provides the mean differences between Trial Type conditions for each comparison. Post-hoc analysis of the significant main effect of Trial Type for the verbal IQ comparison revealed that the -250 ms and simultaneous auditory signal timings did not produce crash report proportions that differed significantly

from each other, but crash report scores for both conditions were significantly different from those of the +250 ms timing condition. For the nonverbal IQ comparison, means obtained from all three timing conditions differed significantly from each other.

Analysis 2: Response Latencies

Testing the latencies for both unambiguous crash and miss control trials indicated that they were not significantly different but were highly correlated within each group. Therefore the data from these two control conditions were pooled to produce a single latency variable (Unambiguous), against which the three experimental conditions could be compared.

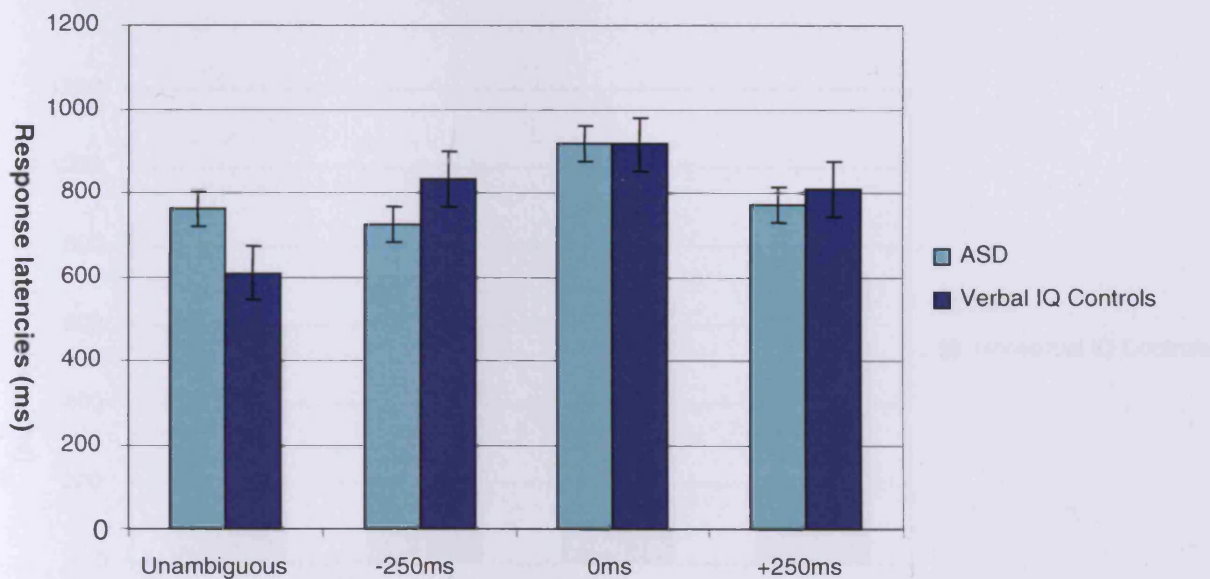


Figure 4.3: Response Latencies (milliseconds) by Auditory Signal Timing Condition and Group (Verbal IQ matching; Experiment 6a).

Figure 4.3 presents the pattern of response latencies across ASD and verbal IQ matched groups. The Unambiguous pooled condition produced lower latencies in the verbally matched group, but in general responses look comparable across the

three experimental trial conditions. Using a 2 x 4 mixed ANOVA analysis with Group as the between-group factor and auditory signal timing as the within factor, Trial Type, it was found that a main effect of Trial Type was produced ($F(3,108) = 5.00, p < .001$ after Huynh-Feldt adjustment). No main effect of Group, or significant interaction between Group and Trial Type ($F < 1$ in both cases) were obtained, supporting the observation that the two groups look comparable across auditory signal timing conditions.

Adjusting for multiple comparisons, post-hoc analysis indicated that the main effect for the within factor (Trial Type) was the result of a significant difference between the pooled Unambiguous condition latencies and the response times for the Simultaneous (0 ms) experimental condition.

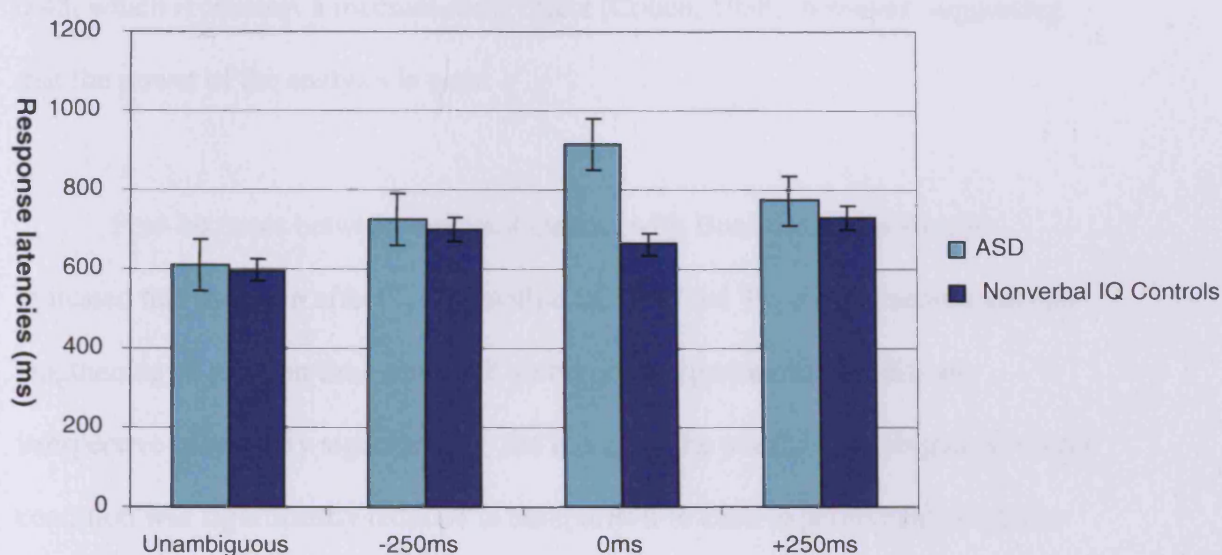


Figure 4.4: Response Latencies (ms) by Auditory Signal Timing Condition and Group (Nonverbal IQ matching, Experiment 6a).

In Figure 4.4 the latencies for each auditory signal timing condition are presented by group for the ASD comparison with non-verbal IQ matched controls.

The latencies for ASD group responses appear large in comparison to the nonverbal group response times in the simultaneous condition. An analysis of response latencies, using a 2 x 4 mixed ANOVA with Group as the between factor and Trial Type as the within factor, was therefore performed. Results indicated that there was a main effect of Trial Type ($F(3, 108) = 3.84, p < .05$), but no main effect of Group ($F < 1$). The interaction term between Group and Trial Type was also not found to be significant ($F(3, 108) = 1.92, p > .05$).

Although the ASD target group responded to the Simultaneous condition more than 250ms, on average, slower than the nonverbal IQ matched controls, this difference was not found to be significant when tested independently ($t(36) = 1.36, p > .05$). Effect size analysis of this mean difference produced a Cohen's d value of 0.45, which represents a medium-sized effect (Cohen, 1988), however, suggesting that the power of the analysis is poor.

Post-hoc tests between marginal means (with Bonferroni adjustment) indicated that the main effect for the within factor (Trial Type) represents a general lengthening of reaction time across all ambiguous experimental conditions, irrespective of auditory signal timing; the mean for the pooled Unambiguous control condition was significantly reduced in comparison to each experimental condition mean.

Experiment 6b: Comparisons of intuitive physics scores across groups (the What Happens Next? Task)

Group	n	WHN?T score (/24)	Standard Deviation	Range
ASD	18	14.4	7.2	4 – 23
VIQ-match (control 1)	18	14.6	6.8	1 – 22
NVIQ – match (control 2)	18	14.9	6.2	1 – 22
Total	54	14.6	6.6	1 – 23

Table 4.4: Means and standard deviations for WHN?T scores by Group (Experiment 6b).

One participant with ASD refused to complete the What Happens Next? Task; removal of his data and that of his matched controls reduced the cell size for analysis of WHN?T scores to eighteen. As can be seen from Table 4.4 mean values for WHN?T scores were found to be very similar across all groups. A one-way ANOVA with Group as the between factor verified that there is no significant difference between the scores obtained across all groups ($F(2, 55) = .03, p > .05$).

Experiment 6c: Relationships between cross-modal integration and intuitive physics

Group	n	Comparison	PPMC (<i>r</i>)	<i>p</i>
ASD	18	Age vs. CoMG	.14	.58
		Age vs. WHN?T	.58*	.01
		CoMG vs. WHN?T	.24	.34
VIQ-match (control 1)	18	Age vs. CoMG	.15	.55
		Age vs. WHN?T	.58*	.01
		CoMG vs. WHN?T	.25	.31
NVIQ-match (control 2)	18	Age vs. CoMG	-.32	.20
		Age vs. WHN?T	.81*	.00
		CoMG vs. WHN?T	.03	.91
Total	54	Age vs. CoMG	-.04	.78
		Age vs. WHN?T	.62*	.00
		CoMG vs. WHN?T	.19	.18

* Correlation is significant at the 0.01 level (2-tailed).

Table 4.5: PPMC values for correlations between age, CoMG crash report proportions and WHN?T scores by Group (Experiment 6c).

Table 4.5 presents correlational analyses undertaken between age, cross-modal integration (using the CoMG simultaneous condition responses) and intuitive physics (WHN?T) variables. Only one significant relationship was observed; age was found to be positively correlated to WHN?T scores across the total 5 to 17 year old sample ($r = .63, p < .001$). Repeat analyses undertaken separately for each group generated the same pattern of results. Analysing relationships between raw scores for vIQ and nVIQ with intuitive physics scores for each group produced high and similar r values across and within groups (ranging from .70 to .85).

Experiment 6d: Comparison of cross-modal integration between autism and Asperger Syndrome

Group	Age (months)		Verbal IQ		Nonverbal IQ	
	Mean (SD)	Range	Mean (S.D.)	Range	Mean (S.D.)	Range
AS (8)	153 (19.7)	123 - 181	117(26.4)	61 - 147	38.4 (13.8)	12 - 56
Autism (8)	151 (10.2)	138 - 169	98.6 (18.9)	60 - 121	37.4 (8.0)	29 - 49
Total (16)	152.1 (15.4)	123 - 181	107.8 (25.1)	60 - 147	37.9 (11.5)	12 - 56

Table 4.6: Mean Age and IQ raw scores for Diagnostic Subgroups (Experiment 6d).

Table 4.6 provides descriptive statistics for two diagnostic subgroups to facilitate comparison between autism and Asperger Syndrome/PDD-NOS¹⁹. The AS participants have superior verbal scores to the Autism participants, although these groups are comparable in terms of both non-verbal IQ ability and age. The standardised scores on each measure indicate that the AS group shows equivalence in terms of non-verbal and verbal abilities (102.0 vs. 107.5, respectively), whereas the Autism subgroup exhibits a 15-point differences between the two (with non-verbal ability superior to verbal ability; 102.8 vs. 87.4, respectively). These two subgroups therefore appear to differ only in terms of verbal ability; an independent *t*-test of standardised verbal scores confirms this observation ($t(14) = 2.36, p < .05$).

Independent *t*-tests on accuracy scores for both unambiguous crash and miss trials between autism and AS subgroups were found not to be significant ($t_{\text{Crash}}(14) = 1.08, t_{\text{Miss}}(14) = -0.92, p > .05$ in both cases), and so these groups did not differ in terms of following the task rules.

¹⁹ Only one participant with PDD-NOS is included in this group.

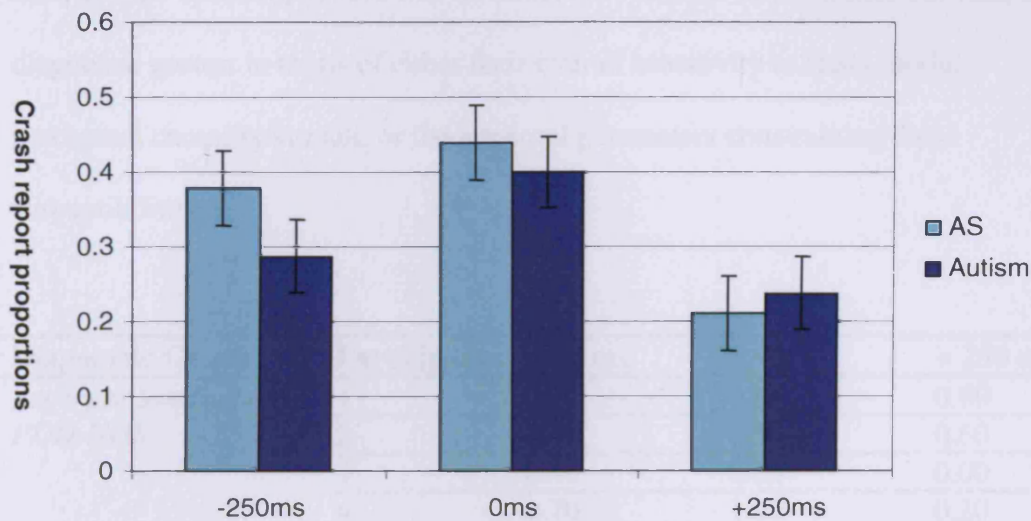


Figure 4.5: Crash Reports by Auditory Signal Timing and Diagnostic Group (Experiment 6d).

Figure 4.5 provides the crash report proportions by diagnostic subgroup. In general, the pattern across auditory timing conditions looks similar between groups in that a peak in responses is associated with the 0 ms timing condition. From this figure, however, the AS group appear to produce a ‘flatter’ response across time, as the facilitation effect of simultaneous auditory signal presentation is seen to be minimal, in contrast to the Autism group, for which an uplift in crash responses between the 0 ms and -250 ms conditions can be seen.

A 2 x 3 mixed ANOVA analysis was performed to test these observations, with diagnostic subgroup as the between-factor, Group, and the auditory timing levels as the within-factor, Trial. This analysis produced a significant main effect of Trial ($F(2, 28) = 6.45, p < .05$), but no main effect of Group or significant interaction between Group and Trial (both $F < 1$). Adjusted post-hoc tests of the main effect of Trial resulted in findings of significant differences in marginal means between both the -250ms and 0ms auditory timing conditions in comparison with

the +250 ms condition. There was therefore no evidence of difference between these diagnostic groups in terms of either their overall sensitivity to cross-modal perceptual causality stimuli, or the temporal parameters constraining these susceptibilities.

Diagnostic Group	Participant	-250 ms	0 ms	+ 250 ms
<i>Asperger Syndrome/ PDD-NOS</i>	1	0.00	0.00	0.00
	2	0.60	0.50	0.60
	3	0.40	0.55	0.00
	4	0.70	1.00	0.20
	5	0.00	0.00	0.00
	6	0.60	0.45	0.50
	7	0.40	0.25	0.20
	8	0.40	0.80	0.10
	<i>Means</i>	0.39	0.44	0.21
<i>Autism</i>	1	0.60	0.70	0.50
	2	0.10	0.20	0.00
	3	0.00	0.50	0.10
	4	0.60	0.65	0.70
	5	0.10	0.15	0.00
	6	0.20	0.35	0.40
	7	0.10	0.10	0.00
	8	0.60	0.55	0.20
	<i>Means</i>	0.29	0.40	0.24
Total	16	.34	.42	.22

Table 4.7: Individual Participants' Crash Reports by Auditory Signal Timing and Diagnostic Subgroup (Experiment 6d).

Table 4.7 provides subgroup crash report data at the individual level, from which it can be seen that the AS and Autism groups have comparable numbers of participants with relatively high and low crash reports.

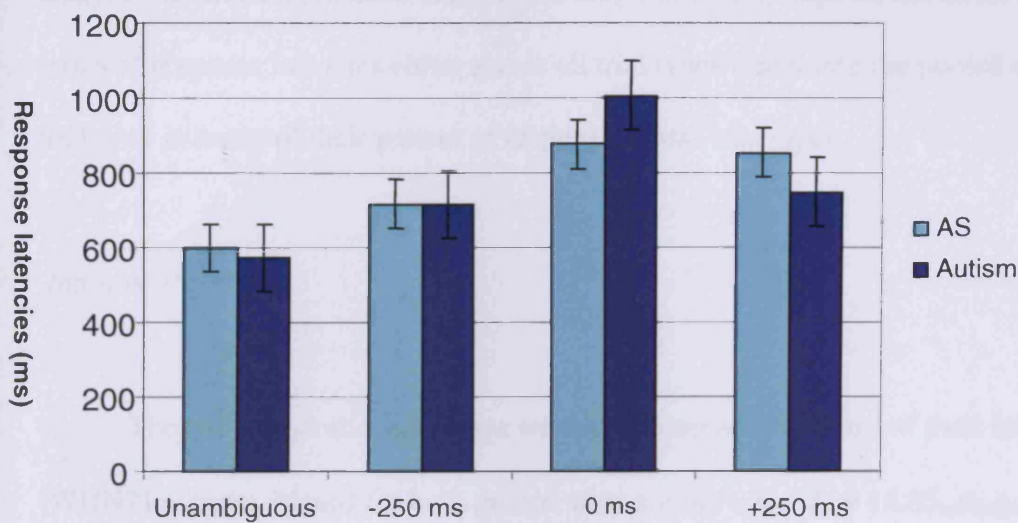


Figure 4.6: Response Latencies by Auditory Signal Timing and Diagnostic Group (Experiment 6d).

As can be seen from Figure 4.6, response latencies for the pooled Unambiguous control variable and across the three levels of the auditory timing factor are broadly comparable between diagnostic subgroups. Both groups generate the same pattern of responses, with lengthened response times seen in association with the experimental trial types relative to those found for the Unambiguous condition, with the longest times reported for the simultaneous (0 ms) auditory timing condition.

Performance of 2 x 4 mixed ANOVA analysis, with diagnostic subgroup as the between-factor, Group, and the auditory timing levels as the within-factor, Trial was conducted. This analysis confirmed the observations derived from Figure 4.6; no main effect of Group or significant interaction between Group and Trial (both $F < 1$). A main effect of Trial was obtained ($F(3, 42) = 2.80, p = .05$). Adjusted post-hoc tests of the main effect of Trial produced no significant differences in marginal means between any pair of auditory signal timing or control conditions. From these

analyses, it can be concluded that the two diagnostic subgroups do not differ in terms of response latencies either across all trial types (including the pooled control trials), or in terms of their pattern of response across trial types.

Intuitive Physics

The two diagnostic subgroups were also compared in terms of their intuitive (WHN?T) scores. Means for both groups were similar ($\mu_{ASD} (8) = 14.85$, $\mu_{Autism} (8) = 14.00$), and an independent samples *t*-test verified that the two groups did not differ in terms of their intuitive physics abilities ($t(16) = 0.21$, $p > .05$).

4.3.4 Results Summary and Discussion

In recent research into autism, focus has been on integration of perceptual information across disparate brain regions (Bertone, Mottron, Jelenic & Faubert, 2003). In this study, a hypothesised deficit in cross-modal integration associated with ASD was investigated utilising an audio-visual perceptual causality phenomenon, similar to that reported by Sekuler et al. (1997). In this phenomenon, presentation of an auditory cue induces the perception of causality in an otherwise ambiguous dynamic visual event. By matching children with and without diagnoses of ASD according to gender, age *and* measures of general intelligence, cross-modal perceptual integration was assessed in terms of both sensitivity to the phenomenon (number of causal events perceived) and its temporal constraints, using a computerised test called the Crash or Miss Game (CoMG).

Contrary to the hypothesis, both target and control participants were found to experience cross-modal perceptual causality to the same extent. Furthermore, no difference in overall sensitivity to the phenomenon between groups was discernible whether the children with ASD were matched to peers on the basis of verbal IQ or non-verbal IQ functioning, although a trend towards significance was identified when total crash reports were compared in the non-verbal IQ analysis. In terms of spatio-temporal constraints, the pattern of responses shown by children with ASD as the timing of the auditory cue was varied relative to the point of occlusion was also comparable to both control groups, with peak levels of response associated with the simultaneous condition of the task. In this last respect, the perception of causality generated in participants by the launch/pass stimuli in the CoMG task were comparable to those originally reported using similar bouncing/streaming stimuli in typical adults (Sekuler et al., 1997).

The interpretation of these results is that, with respect to this sample of individuals with ASD, cross-modal integration is not compromised to any significant extent, and the impression of causality derived from audio-visual events is governed by the same temporal parameters in ASD that constrain causal perception in typically developing children. The second conclusion to be drawn is that cross-modal integration at the *perceptual* level is intact, given the findings of the fMRI study by Bushara et al. (2003) that cross-modal perceptual causality is, in part, generated by pre-attentive activity in multimodal regions such as the superior colliculus.

The distinction between multisensory processing at the cognitive and perceptual levels is important, as it is the level of processing that differentiates between studies investigating the role multisensory processing plays in ASD. The stimuli used in the CoMG task here and in the study published by Van der Smagt et al. (2007) are said to be primarily perceptual in nature. The speech-based stimuli in other ASD studies (e.g. Smith & Bennetto, 2007) recruit both perceptual and cognitive subsystems, and are therefore more complex; difficulties dissociating the relative contributions of cross-modal perception and cognitive processes to speech-processing ability make any deficits found hard to locate the locus of any deficit identified.

Assessment of audiovisual integration of speech stimuli at early pre-phonological and late phonological stages using an ERP method has recently allowed identification of the locality of integrative difficulties within the autistic brain (Magnee, de Gelder, van Engeland & Kemner, 2008). The results of this recent study support the crux of the main finding from Experiment 6. Pre-phonological audiovisual interactions were found to be intact in terms of the timing and pattern of the electroencephalographic responses (EEG) obtained from a target group of adult males diagnosed with PDD. The audiovisual interactions corresponding to later phonologically driven integration, however, indicated impairments relative to matched controls.

The conclusion to draw from both the perceptual causality results and this ERP study is therefore that relative sparing of early audio-visual processing may be dissociated from complex audio-visual integration at a higher processing level. This

argument also corresponds with the interpretation provided by Van der Smagt et al. (2007) that early perceptual integration is intact in high-functioning individuals with autism, as their null findings of resistance to Shams illusion stimuli indicated.

Given that a trend in the hypothesised direction was found between target and nvIQ control groups' relative sensitivities to cross-modal perceptual causality stimuli, the converse interpretation of these results could be made; proponents of perceptual integration as a primary deficit in ASD might argue this case. However, I would suggest that, if cross-modal integration is of wide-ranging developmental significance, better evidence of a deficit should be obtainable especially as age, gender and absolute non-verbal ability (raw scores) were matched on a one-to-one basis for the majority of participants in the nvIQ comparison.

Additionally, I would look to within-mode explanations for the marginal difference found, through consideration of the neural regions involved in the experience of perceptual causality. The findings from the fMRI study reported by Bushara et al. (2003) that audio-visual causality is a perceptually-driven phenomenon (rather than the consequence of an explicit inference) have recently been supported by Dufour, Touzaine, Moessinger, Brochard, and Després (2007), who found that subliminal presentation of the auditory signal suffices to induce the effect. Dufour et al. (2007) concluded from the breadth of the temporal window across which sound could be made to induce perceptual causality in their subliminal study that the superior colliculus was the neural site involved, because the optimal functioning of multisensory neurons in this subcortical structure is associated with an interactive temporal window of several hundreds of milliseconds (Meredith,

Nemitz, & Stein, 1987). No abnormality was found in relation to the ASD group in Experiment 6a in terms of the temporal constraints determining response levels across the three auditory timing conditions; no significant interaction between Trial and Group was obtained in either comparative analysis. It would therefore appear that the integrative function of the superior colliculus is generally intact for these participants.

In addition to superior colliculus (SC) operation, however, perceptual causality phenomena also recruit considerable visual extrastriate region resources. Using fMRI, Blakemore et al. (2001) have demonstrated that the dynamic visual component of unambiguous visual causal events generates heightened levels of activity bilaterally in V5/MT/MST, the motion processing system within extrastriate cortex, concomitant with elevated SC operation. It is proposed that visually-generated perceptual causality signalling may have augmented superior colliculus activity in the typical children in the nvIQ analysis but not in the target participants, as several studies exist in which motion processing has been found to be deficient in ASD (see Milne, Swettenham & Campbell (2005) for a review).

Milne et al. (2005) concluded that motion processing deficits are not present in *all* children with ASD. For the first analysis, children with diagnoses of AS, autism and PDD-NOS were included within one group to ensure statistical power, but to ensure that this conflation across the range of autism spectrum diagnoses had not masked a bivariate distribution within the first analysis (Experiment 6a), a comparison of crash report scores between groups categorised as AS/PDD-NOS versus autism was undertaken. Although cell size was low ($n = 8$ per subgroup), the

analysis reported in Experiment 6d provides no evidence from crash reports or response latencies of a diagnostic dissociation in terms of cross-modal perceptual integration.

At the individual level (Table 4.7) the numbers of individuals per subgroup showing little or no sensitivity to cross-modal perceptual causality appear comparable; in total, five out of 16 individuals with ASD can be categorised as 'poor integrators' for whom neither superior colliculus or visual extrastriate signalling suffices to induce the percept of causality. It would be interesting to analyse the relative proportions of such individuals within clinical and control groups. A significant difference in frequencies of unsusceptible individuals between groups would be informative for future research, particularly because superior colliculus malfunction has been associated with poor connectivity with the dorsolateral prefrontal cortex and frontal eye fields in HFA, which together may account for eye gaze problems found in many individuals with ASD (e.g., Goldberg, Lasker, Zee, Garth, Tien & Landa, 2002).

At the cognitive level, the ASD group showed intact, but not superior, intuitive physics abilities; scores on the WHN?T were similar across all groups (Experiment 6b) , and between diagnostic subgroups matched for nvIQ (Experiment 6d). These results could be interpreted to mean that individual performance of the WHN?T may reflect general intelligence, rather than, domain-specific function (especially as results from the vIQ match group were equivalent to those of the nvIQ group). In Experiment 6c, the only significant correlations found in relation to WHN?T scores were with age, and with vIQ or nvIQ raw scores (which in

themselves are highly correlated with age), across all groups. No evidence of a privileged relationship between the experience of causality and physical causal reasoning was therefore obtained, suggesting that even for the ASD group, general maturation and education are likely to account for intuitive physics ability in this study. Does this finding suggest that the 'innate' superiority of individuals with ASD in terms of intuitive physics previously suggested does not exist? Binnie and Williams (2003) have reported precocious physics superiority in children with ASD over control groups of both older and more able TD children, but here the target group children were substantially younger than the participants in Experiment 6, and so it may be that any innate advantage, or islet of ability, in children with autism is expressed in terms of precocity, rather than absolute superiority across development into adulthood (by which stage general intellectual functioning may compensate for mediocre domain-specific operation in typical individuals). Indeed, in many studies investigating intuitive physics, intra-individual dissociations between intuitive physics and intuitive psychology have been reported (e.g., Baron-Cohen, Wheelwright, Scahill, Lawson & Spong, 2001), whereas some studies have failed to find differences in physics skill between adult males with and without AS (e.g., Lawson et al., 2004). These points will be discussed further in Chapter 5.

In summary, the results of the study presented in this chapter are that, generally, individuals with any of a range of autism spectrum conditions show no signs of atypical cross-modal integration at the perceptual level in response to audio-visual stimuli established to induce causal percepts. In addition to intact sensitivity to such stimuli, the participants in this study showed a pattern of response to varying timing of the auditory component of these stimuli that is

broadly similar to that found for closely-matched peers. Together these results have been interpreted to mean that multisensory processing at the perceptual level in relation to superior colliculus activity is generally intact in ASD, although some individuals within the cohort do appear to show broad insensitivity to these stimuli. It is unlikely, therefore, that this particular aspect of *perceptual* integration is of causal relevance to ASD as a developmental condition, at least in individuals with near- to above-normal IQ with ASD, a conclusion supported by similar results from other studies using perceptual cross-modal phenomena.

4.4 General Discussion and Conclusions

In Chapter 3, evidence of male/female differences in cross-modal perceptual integration were interpreted as partial support from Extreme Male Brain theory, particularly in the light of apparent dissociations between women with high autistic trait expression and individuals with low or medium levels of trait expression. However, it was stated at the start of this chapter that, for cross-modal perceptual integration to be of fundamental importance to development in ASD, clear evidence was required of a deficit in this respect between boys with and without diagnoses. Using cross-modal perceptual causality to stimulate cross-modal integration failed to provide unequivocal evidence, although some individuals in the target group were uniformly resistant to this phenomenon, irrespective of the timing of the auditory signal. It is therefore suggested that some individuals with ASD may exhibit signs of multisensory processing failure within superior colliculus, but that this neural challenge is not ubiquitous. Signal integration theory (Bertone &

Faubert, 2006) was therefore not found to extend to cross-modal perceptual integration.

It was also conjectured that extrastriate visual functioning may contribute over and above cross-modal integration in the superior colliculus to the experience of causality, as motion processing is predominantly a function of the V5/MT visual area which has been shown to be highly activated by causal visual events. This extrapolation reflects, in part, findings from Chapter 3 (Experiment 5c) that women with poor EFT performance (presumably as a result of strong feature integration in the visual extrastriate) also show heightened sensitivity to cross-modal perceptual causality stimuli. Again, women expressing the BAP showed a non-significant relationship in this respect, with a correlation value significantly different from that of typical women.

Given that the ASD participants here also showed no distinct advantage in either a child's intuitive physics task or a perception-based variant of the EFT, the results presented in Chapter 4 are taken to mean that ASD represents normal male brain function in terms of perceptual integration.

Chapter 5: Cross-modal Integration as a Complexity/Simplicity Gender Difference

5.1 Introduction

The integration of sound and vision is important for humans to interact efficiently with their environment. Co-occurrence of sensory inputs in space and time orients our attention (Spence & McDonald, 2004), helps us to understand causal relationships between events (Blakemore et al., 2001), and putatively enhances our formation of specific forms of representations, such as emotion or quantity, from early infancy (Jordan et al., 2006). Dysfunction within the neural mechanisms supporting multisensory processing would therefore have widespread consequences, particularly with respect to social interaction as emotion, speech and non-verbal communication are heavily reliant on processing stimuli that are feature-rich and multimodal by nature.

People with autism spectrum disorders are diagnosed mainly by the presence of atypical behaviours relating to social interaction. Language development and social communication, along with restricted imagination and interests and/or repetitive stereotypies, form the 'autistic triad'. The sensory threshold hypo- and hyper-sensitivities also frequently associated with this behavioural triad have long been catalogued (Kern et al., 2006), but their relevance to the development differences seen in ASD has yet to be understood. Iarocci and McDonald (2006) consider that the many autobiographical accounts of subjective perceptual incoherence provided by individuals with HFA and AS should be empirically investigated, in order to evaluate the potential contribution disjointed multisensory processing may make to the development of autistic cognition and behaviour.

Considerable evidence of superior within-mode perceptual processing in ASD has been reported in the last decade, leading to theories that enhanced perceptual functioning (EPF) is an important part of the autism phenotype (Mottron et al., 2006). Bertone and Faubert (2006) propose that, in addition to elevated functioning in relation to single features of sensory stimuli, perceptual integration within a single modality may be compromised (and in fact, that simple stimulus feature processing may be a compensatory result). Their Signal Integration Theory (SIT) therefore represents a perceptual interpretation of the Complexity Hypothesis (Minshew, Goldstein & Siegel, 1997), in which underconnectivity between distal brain regions is thought to account for 'negative' aspects of autism in terms of complex representational failure; Signal Integration Theory is attractive, in that it also accommodates findings of superiorities ('positive' signs) linked to ASD cognition. For instance, enhanced primary cortex activity could explain faster and more accurate visual disembedding performance, which until recently was considered to reflect failure to generate integrated representations at the cognitive level in ASD (Weak Central Coherence theory; Happé & Frith, 2006).

Attempts at extrapolating the ideas within EPF and SIT to the multisensory framework proposed by Iarocci and McDonald (2006) have produced conflicting results to date. At the perceptual level, cross-modal (taken here to mean audio-visual) processing has been found to be intact by Van der Smagt et al. (2006). In terms of speech processing, Magnée et al. (2008), using ERP methodology, have found early intact cross-modal potentials coupled with atypical late signalling, and hence conclude also that perceptual integration is not abnormal in ASD. Bennetto

and Smith (2006), conversely, suggest that a pre-attentive cross-modal component of speech processing is compromised in children with autism.

To be relevant to the debate regarding ASD as a perceptual development disorder, a cross-modal phenomenon was selected as the basis of examination of multisensory processing in typical children, adults with autistic traits and children with ASD diagnoses. Cross-modal perceptual stimuli (Sekuler et al., 1997) are of value to research in this area because they have been shown to be the consequence of perceptual system functioning (Bushara et al., 2003), generate large effect sizes in adults (Zhou et al., 2007), and are theoretically related to the development of intuitive physics (Michotte, 1963). Intuitive physics is a specific aspect of cognition that is thought to be spared/superior in ASD (Baron-Cohen, Wheelwright, Scahill, Lawson & Spong, 2001).

Visual disembedding and intuitive physics are tasks that show gender differences; males are known to exhibit advantage over females in these respects (Halpern et al., 2007). Such differentiation in cognitive abilities between the sexes has led Baron-Cohen (2002) to propose the Extreme Male Brain (EMB) theory of Autism, in which the ‘hypersystemising’ of individuals with ASD (i.e., their tendency to process all environmental stimuli in terms of systems and rules) occurs at the expense of ‘empathising’ (i.e., failure to process social information, resulting in mindblindness; Baron-Cohen, 1995). As men’s cognitive phenotype can be broadly described as a systemising bias, and women’s cognitive style as an emphasis on socio-cognition, ASD is said to be the product of an extremely male-type brain.

Baron-Cohen (2008) has also suggested that autistic ‘traits’ (personality characteristics producing behaviours similar to those associated with autism) are expressed in everyone to a greater or lesser extent, such that ASD is not a category of difference but one end of a continuum (with individuals representing extreme female-type brains at the other end).

Hence, through research using adapted cross-modal perceptual stimuli, the studies in this thesis were designed to evaluate whether perceptual integration of sound and vision is compromised both in individuals with a high number of autistic traits, and in children with ASD. The theoretical idea informing these studies is that development in ASD is biased towards a male perceptual phenotype in which simple stimuli are processed over complex stimuli. This concept conjoins the principles within Extreme Male Brain, Signal Integration and Complexity theories (Baron-Cohen, 2002; Bertone & Faubert, 2006; Minshew, Goldstein & Siegel, 1997). In addition, a developmental study was included to determine whether perceptual developmental differences exist between typical boys and girls in terms of inter-relationships with a cognitive ability known to be superior in ASD (intuitive physics), in order to consider whether ASD might, in future, be remodelled in terms of extreme male perceptual development.

5.2 Summary of findings

5.2.1 Task development (Experiments 1 and 2)

In order to address the questions raised regarding the role of multisensory processing at the perceptual level may play in the development of the autistic mind, two tasks were designed and piloted: The first of these, the Crash or Miss Game, is based on the phenomenon of cross-modal perceptual causality induction, originally reported by Sekuler et al. (1997); the second is a novel task that facilitates assessment of the development of intuitive physics across a wide range of ages and abilities (called the What Happens Next? Task, or WHN?T).

Experiment 1 was a pilot of the CoMG, in which adult participants' responses to varying the timing of auditory signal presentation relative to the point at which a dynamic disk occludes a stationary disk onscreen were assessed. In the original task (Sekuler et al., 1997) the two disks moved towards each other, occluded, and passed on; presentation of an auditory signal at the point of occlusion was found to influence the impression made by this ambiguous event such that the two disks were seen to collide and reverse direction on occlusion. Simultaneous presentation of the auditory signal with occlusion in the CoMG (Experiment 1) was also shown to generate percepts of causality in adult observers although trials comprised one static and one dynamic visual element. Presentation of the auditory signal 250 ms prior to and after occlusion also generated causal 'crash' reports, but to a lesser extent than seen for the simultaneous (0 ms) condition.

The results from Experiment 1 are equivalent to the findings reported by Sekuler et al. (1997) that the spatio-temporal parameters constraining the induction of cross-modal perceptual causality generate a peak in response associated with simultaneous audio-visual presentation. However, rather than generating the impression of two disks bouncing, the auditory stimulus in my task serves to create the causal impression of one disk launching the other. It can therefore be concluded that the CoMG stimuli elicit the cross-modal perceptual causality in a way that is similar to the original paradigm investigating this phenomenon, making the task suitable for testing perceptual processing aspects of this phenomenon in various populations.

Intuitive physics tasks assess the cognitive ability to reason about the action of forces on objects, or the operation of physical systems. Many tests exist that assess aspects of intuitive physics (e.g, the Intuitive Physics test designed by Baron-Cohen et al., 2001), but these were deemed unsuitable for use in developmental research in that they were either too complex (in terms of verbal ability demanded of participants) or insufficient in trial number and scope of difficulty to look for cross-sequential developmental effects. The What Happens Next? Task was therefore specifically designed to be biased towards non-verbal processing (through use of simple instructions and graphics), and to cover a range of levels of difficulty in which trial content drew on several different physical concepts. In Experiment 2, it was shown that the WHN?T effectively assesses the development of conceptual physical reasoning in children from 5 to 11 years old, producing correlations of moderate-to-high effect size ($r = .62$) between intuitive physics scores and child age in both genders.

5.2.2 *Perceptual causality and intuitive physics during development (Experiment 3)*

In Experiment 3, the inter-relationships between the perception of causality and intuitive physics ability during development were investigated. There were three objectives for the study: The first was to assess sensitivity of the CoMG task to development of cross-modal perceptual causality experience in typical children; the second was to investigate the neuroconstructivist idea that cognitive ability is predicated by perceptual development on a domain-specific basis (Karmiloff-Smith, 1991; 2007), and the last aim was to consider whether gender differences are discernible during typical development. This third objective was related to the hypothesis that the development at the neurobiological system level of processing biases might differentiate between male and female cognitive phenotypes, which in turn might contribute to the association between male cognition and science aptitude (Baron-Cohen, 2002; Halpern et al., 2007).

The key result from Experiment 3 is that sensitivity to cross-modal perceptual causality stimuli was found to develop in typically developing children aged from 5 to 13 years old; crash (launch) percepts in the simultaneous condition of the CoMG increase as age increases ($r = .33$). The pattern of results across auditory timing conditions produced the same 'peaked' pattern as found in the adult pilot (Experiment 1), but also indicated that the temporal window for experiencing causality was wider for children than adults (as pre-occlusion auditory signal presentation generated causality to a greater extent in this sample). Hence it was concluded that the CoMG is an effective method of assessing differences in cross-modal perceptual causality across ages, and also that varying auditory presentation

timing may allow for temporal contingencies important to the phenomenon to be investigated.

The finding that the What Happens Next? Task is sensitive to age effects was replicated in Experiment 3, demonstrating that the age range that can be tested by this task extends to older children (to age 13 years; $r = .64$). No gender differences in this age/cognition relationship was discernible, as a Fisher's r -to- z comparison failed to reach significance, and the slight superiority of girls over boys in terms of WHN?T scores was also not found to be significant.

Given that both tasks effectively measure developmental effects, the relationship between the perception of causality and intuitive physics ability could be investigated. For the TD group as a whole, a small-to-moderate correlation was found between these two measures ($r = .38$). The interpretation of this result is ambiguous. Although the perceptual and cognitive tasks are theoretically related (Michotte, 1963), evidence that both sensitivity to perceptual causality and physical causal cognition increase with age could simply represent general brain maturation, a reasonable conclusion that does not address the idea of privileged perception/cognition relationships that facilitate domain-specific neural maturation (as proposed by Karmiloff-Smith, 1991). For such an idea to be supported, evidence of differences in developmental perception/cognition relationships between groups known to function differentially at the cognitive level is required.

Experiment 3 provides partial support for the concept that privileged perception/cognition relationships drive domain differentiation. When the TD

sample was sub-divided on the basis of gender, a dichotomy was apparent between groups in terms of the inter-relationships between age, perceptual causality and intuitive physics. For the girls, partialing out the variance in both perception and cognition measures reduces their correlation to one that is not significant, yet for the boys' data, this relationship remains significant. In terms of multiple regression analysis, age was found to be the only significant factor predicting intuitive physics ability in girls, whereas in boys the only significant predictor entered for the stepwise regression model was CoMG crash scores. It can be argued from these results that intuitive physics develops differently in the sexes; for the girls, general development (and education) are probably the most likely contributors to physics understanding, but the individual difference effect found for the boys indicates that the more perceptual causality is perceived during development, the better the child's physical causal cognition.

A true dissociation between genders is not claimed from the findings from Experiment 3c, as comparison of the relative r values for partial correlations between perception and correlation measures between the sexes is not significant. However, the difference in regression models produced from these data when subdivided by gender is taken here to be partial support for neuroconstructivist theory (Karmiloff-Smith, 1991). However, Experiment 3 reiterates that both the CoMG and WHN?T are sufficiently sensitive to be useful in the investigation of both individual differences and development effects.

5.2.3 The Broader Autism Phenotype and gender differences in cross-modal integration, and perception/cognition relationships (Experiments 4 and 5)

Having verified that the CoMG task is sensitive to age differences, the next two experiments investigated individual difference effects in cross-modal perceptual causality, in relation to Autism Spectrum Disorder. Expression of personality traits relating to characteristics of ASD has been shown to normally distributed across non-clinical populations as measured by the Autism-Spectrum Quotient (Baron-Cohen, 2008). Wakabayashi et al. (2006) have also shown that total AQ scores load onto a single personality dimension that is independent of the 'Big Five', which suggests that 'autistic-ness' exists in all individuals to varying extent. In Experiments 4 and 5, the responses of individuals with a relatively high number of autistic traits (as measured by the AQ) were contrasted with low- and medium AQ scoring groups on two versions of the CoMG task. The first of these was a variant of the original in which the relative strength of the auditory cue to generate causal percepts was measured against that of a visual 'causal capture' cue (Scholl & Nakayama, 2002). The second study utilised the original CoMG task in which the timing of auditory cue presentation varied between trial conditions. As it has been proposed that multisensory processing is both atypical in, and of causal importance to, ASD (Iarocci & McDonald, 2006), it was hypothesised that cross-modal perceptual causality effects would be reduced in association with a sample of participants displaying autistic traits, and may also show temporal contingency differences in this group.

In both these studies, secondary tasks for which people expressing the Broader Autism Phenotype (Bailey et al., 1998) have been shown to be superior

were included, namely the Intuitive Physics Task (Baron-Cohen et al., 2001) and the Embedded Figures Task (Shah & Frith, 1983). Their inclusion was designed to examine a) whether individuals with high AQ scores drawn from a general, non-clinical population exhibit similar advantages, and b) the relationships between gender and these task advantages. Testing physics and visual disembedding abilities therefore allowed the population-level interpretation of the BAP, and its relationship to Extreme Male Brain Theory of Autism (Baron-Cohen, 2002), to be examined.

The final aim of the studies presented in Chapter 3 was to investigate, in each of Experiments 4 and 5, whether gender differences exist in terms perception/cognition relationships. The rationale behind this aim was that perceptual theories of autism as a developmental disorder (e.g., Enhanced Perceptual Functioning; Mottron et al., 2006) propose that atypicalities in processing environmental stimuli are causal to both the aetiology of ASD and the outcome at the individual level of children with this diagnosis. If perceptual differences reflect exaggeration of the male phenotype (cf. EMB theory), and if intuitive physics/EFT task performance is associated with superiorities in the BAP (Happé et al., 2001), then individuals with high numbers of autistic traits should show ‘exaggeratedly male’ response patterns on both the CoMG and the cognitive tasks. Furthermore, perceptual and cognitive measures should be inter-related.

Findings from Experiment 4: The BAP, Cross-modal Perceptual Causality and Relationships with Intuitive Physics

Experiment 4 showed that the high AQ group perceived crashes when viewing ambiguous stimuli *more* often than low- and medium-scoring groups in the absence of perceptual causality cues. However, this group also reported fewer

crashes when the auditory cue was present in relation to the low AQ group (trend only; $t(23) = 1.87, p = .07$). Gender was not found to produce significantly different general levels of response, or differing patterns of response across trial types, and therefore the interaction found between AQ group and trial condition is not the consequence of gender biases within the high and low AQ groups.

The low AQ group generally responded faster and the high AQ group slower than the medium (control) group. The medium group was found to display a 'cue-cost', in that response times lengthened in response to trials in which either of the perceptual causality cues (auditory or visual capture) were present. This cue-cost was also found for the high AQ group, but significantly more so in relation to the audio-visual condition than the visual capture condition. Furthermore, latencies recorded in response to ambiguous (no cue) trials were significantly longer in this group than found for the unambiguous control trials and visual capture trials. Between groups, response times for ambiguous trials differed between the high AQ group and both other groups, and between high and low AQ groups for the audio-visual condition. Again, no differences between genders were found in terms of general response times or patterns of latencies across experimental conditions.

A male advantage was found in the Intuitive Physics Task data in Experiment 4b, but no evidence of superiority associated with high AQ scores was found. Contrasting scores by gender within each AQ category, it was found that a gender difference was only apparent within the medium range control group.

Correlations between intuitive physics scores and the number of causal percepts experienced in the audio-visual CoMG condition were found not be

significant when the data were analysed at either the AQ group level or between genders. This result was also found when crash reports and physics scores were correlated in relation to the visual capture and ambiguous conditions of this CoMG adaptation. When latencies were analysed, significant negative correlations were found between response speed for ambiguous trials and physics scores in the low AQ group (i.e. faster responses were associated with higher scores), and, in the high AQ group, between response speed on the unambiguous miss control trials and physics scores.

Results from Experiment 5: The BAP, Cross-modal Perceptual Causality and the Embedded Figures Task

In Experiment 5, no low scoring individuals were identified within the sample, and targeted recruitment of participants produced a significantly higher group mean for AQ scores than was found for the sample in Experiment 4. The categorisation criteria for AQ groups was therefore amended to produced three groups: A medium AQ scoring female group; medium AQ scoring male group, and high scoring (BAP) group, comprising male and female participants with total AQ scores exceeding 20 points. The CoMG in this study was the original version, in which audio-visual trials were categorised according to stimulus onset asynchronies between auditory timing and the point of occlusion (-250 ms, 0 ms and +250 ms), which allowed the effect of varying auditory presentation timing on the numbers of crashes reported to be assessed.

Prior to AQ group analysis, gender sub-groups were found not to differ in terms of the total crashes seen when the number of causal percepts were

analysed, but a trend towards significance was seen for the interaction between gender and auditory timing ($F(2, 326) = 2.64, p = .07$). When the simultaneous condition was analysed independently, a significant difference was obtained between genders; women were shown to be more sensitive to the cross-modal perceptual phenomenon than men. No differences in latencies were found.

When the AQ group analyses on crash scores were undertaken, the influence of gender was also apparent, although only a borderline trend ($p = .10$) for a main effect of AQ group was found, and no interaction across the three timing conditions (- 250 ms, 0 ms and +250 ms) between AQ group and trial type was obtained.

When, however, the simultaneous (0 ms) condition was analysed in isolation, a main effect was found; at post-hoc stage, the Medium Female group showed a trend towards experiencing a greater numbers of crashes than either the Medium Male or the High AQ groups. Moreover, within-group analysis of the high AQ group showed that women and men with a high number of autistic traits did not differ in this respect, with mean crash scores being identical. Again, no significant differences in latencies were obtained from any AQ group analysis.

Gender was also implicated when EFT accuracy and response time measures between gender groups were assessed, replicating many findings of male superiorities on this task (originating with its development by Witkin, 1950). Only one trend was obtained when the AQ group analysis was undertaken, with the Medium Female group accuracy scores tending to be lower than both those from the Medium Male and high AQ groups (trends only). The high AQ female participants

were shown to be slightly less accurate in terms of EFT performance than medium-scoring men; comparison between accuracy scores of high AQ males and medium-scoring females produced a significant result, however.

The EFT was amended in this study so that rapid, accurate responses determined scores and latencies; any inaccurate responses were given a fixed latency value, and any overlong accurate responses (or time-outs during the response verification) were recoded as inaccurate trials. Also, targets and complex figures were provided together. On this basis, results can be interpreted as representing perceptual, rather than cognitive, processing. This scoring system means that, at the individual level, reaction times and accuracy scores are highly correlated. However, trends were also seen in the correlations between sensitivity to cross-modal perceptual causality (simultaneous condition crash reports) and EFT measures, with accuracy decreasing and latencies increasing as more crashes are perceived.

Further investigation of these relationships showed that these relationships were significant within the Medium Female group alone. Comparisons of the relative r values using the Fisher's r -to- z method indicated a near-significant difference in the variance in EFT accuracy related to the variance in crashes reported between the Medium Female and the High AQ groups. The difference in relative correlational values found for this relationship between medium-scoring and high-scoring women was also found to approach significance ($z = -1.81, p = .07$).

Results Interpretation

From these results, the conclusion regarding whether the Broader Autism Phenotype is associated with compromised cross-modal perception, cognitive superiorities or relationships between perception and cognition is equivocal; differences, where apparent, are mainly marginal and exist only in the context of gender or low level of expression of autistic traits.

If ASD represents an 'extreme male brain' then the BAP should exhibit exaggeratedly male response patterns across all the tasks involved in Experiments 4 and 5. However, high AQ scorers performed each task at levels that were broadly equivalent to male participants with medium-range trait expression. A notable exception to this statement relates to processing perceptual causality stimuli. In Experiment 5a, for high AQ scorers, relatively high crash report scores with elongated response times were found to significantly differ from those of the medium- and low-scoring groups when no cues were present, but a trend towards a reduction in crashes perceived was obtained when the auditory cue was present (relative to low AQ scorers). These differences suggest that cross-modal processing is atypical in association with the BAP, but only in comparison with individuals with low autistic trait expression. Therefore only partial evidence for the hypothesis that multisensory processing is challenged at the perceptual level in relation to autism can be claimed from these studies.

Men and individuals expressing the broader phenotype are similar, yet from these two experiments it was demonstrated that women are different; significantly worse than men on intuitive physics and EFT tasks (Experiments 4b and 5b), more

sensitive to cross-modal stimulation (Experiment 5a) and, at the individual level, showing a trend towards an inverse relationship between propensity to perceive cross-modal causality and EFT accuracy ($p = .06$). Women with high autistic trait expression, however, show none of these differences when scores are compared with either those of typical men or those of men with high AQ scores, indicating that the female broader autism phenotype most closely resembles ‘male brain’ functioning in terms of both perceptual and cognitive processing. The significant dissociation between women with high and average autistic trait expression in terms of the relationship between EFT accuracy and cross-modal perceptual causality is therefore relevant to Extreme Male Brain theory (Baron-Cohen, 2002), in that women with autistic characteristics appear to perceive (and think) like men in this respect.

5.2.4 Cross-modal integration in ASD (Experiment 6)

The evidence from Experiments 4 and 5 mainly indicated that the female perceptual phenotype differs from the male, and provided partial evidence of compromised audio-visual processing in relation to the BAP. Experiment 6 was designed to examine cross-modal integration specifically in relation to ASD by using the original CoMG task to test boys and adolescents with diagnoses for autism, PDD-NOS or Asperger Syndrome. The CoMG version used allowed auditory signal timing to be varied between trial types. Given that a developmental effect had been established in a comparable sample of boys (Experiment 3), and heightened cross-modal perceptual causality was found in typical women (Experiment 5), the control children in Experiment 6 were matched by gender and

age, as well as on one of two standard measures of general intellectual function (verbal/non-verbal IQ). In this sample, children with ASD diagnoses ranged in IQ from near normal to above normal on both measures.

The number of causal percepts reported did not differ overall between groups in the vIQ comparison. In the nvIQ (in which age matching was less compromised) a trend was found in the hypothesised direction; across all three timing conditions, the ASD group crash scores were reduced, and a marginal main effect was seen. In terms of interactions, the pattern of response across auditory timings was invariant across all three groups, with the normal simultaneous 'peak' response apparent in ASD as well as vIQ and nvIQ control group data. Similarly all analyses of latencies showed no between-group differences, nor interactions between group and auditory timing factors.

Testing intuitive physics using the What Happens Next? Task revealed that no one group's scores were superior (and means across target and control groups were very similar). Therefore performance by the ASD participants in this study did not display any natural domain-specific physics ability above and beyond the level seen for children with comparable general intellectual function, as measured by their verbal or non-verbal attainment. This conclusion was verified by the fact that the only significant correlations produced within each group between age, crash reports, physics scores and these IQ measures indicated developmental and general intelligence effects that were comparable in magnitude across participant groups.

As both Mazefzky and Oswald (2007) and Tsermentseli et al. (2007) have recently reported perceptual differences between HFA and AS, a comparison was undertaken between subgroups of participants with ASD categorised according to diagnosis. It was hypothesised that this comparison would indicate a general reduction in cross-modal perceptual causality sensitivity in between participants with autism and AS in Experiment 6. Individuals with HFA have been shown to have lower emotional perception accuracy than those with AS (Mazefsky & Oswald, 2007), and they also appear to exhibit both form and motion processing deficits (whereas comparison participants with AS were shown to have intact motion processing; Tsermentseli et al., 2007). However, the hypothesis here was not supported, as no such difference was discernible between groups at the perceptual level. Furthermore, there were no differences between groups apparent in relation to their physical causal reasoning, as WHN?T scores were of similar magnitude.

5.3 Overall interpretation of empirical results

5.3.1 *Cross-modal and Visual Integration in ASD*

Only marginal evidence of compromise was found when comparing children with and without diagnoses on their sensitivity to cross-modal perceptual causality, and therefore it has been concluded that, in terms of this phenomenon, cross-modal integration is intact. This conclusion concords with that made by Van der Smagt et al. (2007).

The phenomenon of cross-modal perceptual causality has been related to function of a specific sub-cortical region, the superior colliculus. It is inferred from

the results of Experiment 6 that the operation of the SC is intact in the majority of participants with ASD in this study. The marginal finding of a slight reduction in susceptibility might relate to inclusion of a few resistant individuals in the ASD group, which in turn may be associated with either superior colliculus failure. Alternatively, these individuals' performance may arise from poor SC function *and* reduced augmentation of cross-modal signalling by motion processing signals (as a consequence of poor visual processing within extrastriate areas V5/MT/MST; Milne et al., 2005), given that visual causality is a function of collaborative SC and extrastriate operation (Blakemore et al., 2001).

This interpretation appears to be reasonable given extant research on vision processing in ASD. Bushara et al. (2003) have proposed that multisensory processing of perceptual stimuli in the SC occurs in parallel with serial processing, with SC activation inhibiting the function of unitary sensory cortices through feedback inhibition. It would be predicted therefore that the enhanced simple feature processing in ASD stated to reflect V1 functioning with associated reduced visual feature integration across visual system regions outside of V1 (Bertone & Faubert, 2006) could co-exist with intact cross-modal integration in superior colliculus.

However, lack of augmentation of cross-modal signalling in SC as a consequence of dysfunctional signal integration would have developmental consequences for the developing brain in individuals with autism. The superior colliculus plays a role in emotion comprehension (de Gelder, Morris & Dolan, 2005); reduction in complex visual signal integration due to weak extrastriate visual cortex function would prejudice the development of neural architecture supporting

emotion processing, whilst leaving simplistic cross-modal integration operation intact. The issue for neurodevelopment would then be one of underconnectivity from the SC onwards. This extrapolation is based by recent advances in brain imaging research in ASD that has led to the Underconnectivity Hypothesis (Just, Cherkassky, Keller & Minshew, 2004; Just, Cherkassky, Keller, Kana & Minshew, 2006), in which distal neural region connectivity is posited to be the basis for negative symptomatology in ASD.

5.3.2 The Broader Autism Phenotype and Gender Differences in Perceptual Integration

The general conclusion drawn from studies relating the broader phenotype is that high expression of traits associated with characteristic ASD behaviours shows a trend towards lower cross-modal perceptual integration. As women with average trait expression appear to experience cross-modal causality more than men, then it is surmised that SC supplementation of cross-modal integration by extrastriate function (specifically with regards to motion processing) may account for this gender effect. If this is the case, then the finding that women with high trait expression show a male-like tendency to be less susceptible to the cross-modal phenomenon might mean that their extrastriate function shows signs of compromise that their gender would not predict. The finding that 'typical' women experience cross-modal causality significantly more in the simultaneous condition of the CoMG only supports this interpretation, as the multisensory function of the SC extends across hundreds of milliseconds (Merideth, Nemitz & Stein, 1987).

The interpretation of this conclusion is that the studies in this thesis provide partial support for Extreme Male Brain theory (Baron-Cohen, 2002) in terms of perceptual processing. It is not the case that Experiments 4 and 5 unequivocally demonstrate cross-modal disadvantage in relation to a broader perceptual phenotype in ASD, as comparison of high AQ scorers' performance on the CoMG on both versions of the task were broadly comparable to medium-ranging AQ scorers and men. However, the proposed existence of differential gender-based perceptual causality processing styles is supported by evidence from CoMG scores correlated with EFT performance, in which women (not men or high AQ scorers) alone show a trend towards inverse relationship between cross-modal perceptual causality sensitivity and EFT performance (i.e. better perceptual integration response is coupled with poorer visual disembedding at the individual level).

In neuro-imaging studies Blakemore et al. (2001) showed visual causality is associated specifically with V5/MT/MST activation in extrastriate cortex that was not apparent when similar, non-causal dynamic events were presented, and Baron-Cohen et al. (2003) found that response to EFT stimuli involved exaggerated extrastriate activity in typical women, but not in men or in parents of either gender of ASD probands (although this paper reported pilot data only). In Experiment 5c, the correlations between cross-modal perceptual causality versus EFT performance relationship between women with and without high autistic trait expression were of opposite valences, and comparison of the effect sizes found for each of these groups by Fisher's r to z transformation suggested a trend towards dissociation ($p = .07$). Taken together, one interpretation of the findings from Experiment 5 is that perceptual processing in women is biased to 'complex integration' (cross-modal

sensitivity boosted by complex visual integration signalling). Conversely, men (and individuals of both sexes with high numbers of autistic-like traits) could be regarded as favouring simplistic perceptual processing.

In broad terms, this conjectured general model of gender differences in perceptual processing biases inter-relates EMB theory with ‘weak perceptual coherence’, an alternative to Weak Central Coherence theory that accommodates findings of both superior visual disembedding performance in connection with ASD and the BAP (Shah & Frith, 1983; Happé, Briskman & Frith, 2001) and inferior performance by women (Witkin, 1950).

5.3.3 Perceptual Causality and Intuitive Physics

On the basis of the interpretation of results provided to this point, the results from Experiment 3, in which an individual differences effect between the experience of cross-modal perceptual causality was related to intuitive physics across a wide-age range of TD boys, could be also be reframed in terms of gender – based perceptual biases during development; ‘simplistic’ object-based causality, as a function of SC activity, may facilitate representational formation regarding causal physical relations.

It has been shown that infants’ representation of number is enhanced by multisensory redundancy (Jordan et al., 2008); the idea here is that SC activity facilitates the same amelioration of physical causal representations, but that this is more a feature of ‘male-type’ than ‘female-type’ brain development. Spelke (2005) avers that innate knowledge and privileged perception/cognition domain-specific

relationships are equivalent in male and female infants. However, connectivity and neuronal maturation in infant visual systems is rapid, and differential processing biases encoded in male and female genotypes might produce dissociated neurodevelopmental trajectories in the first few years of life. Potentially, social stimulus versus non-social stimulus gender preferences (Connellan et al., 2000) in infancy might reflect such perceptual developmental tendencies.

It has been argued, on the basis that gender differences do not show large effects, that male and female brains function to a large extent on a similar basis (Hyde, 2005); therefore, any biases in perception/cognition during development may be masked by general intellectual development in the majority of children. At the extreme tails of gender distributions of psychological variables it may be possible to see such effects. The visitor population of the science museum may have included a high frequency of children with a 'gift' for science, hence results from Experiment 3 have not been replicated to date in general school populations, or in Experiment 6 participants. If science-giftedness is the consequence of an innate neurodevelopmental relationship between object-based causality perception and physical reasoning, then students with precocious talents in this direction should evidence the same relationship as obtained in Experiment 3.

5.4 The Complexity/Simplicity Model in Development

On the basis of the research I have undertaken I propose that the crucial phenotypic difference between the genders during development reflects separate perceptual processing biases towards complex feature-rich environmental stimuli in women, and simple object-based stimuli in men. If a female drive to complexity at

the perceptual level is a feature of early neurodevelopment, then the relative salience of social (complex) over object (simple) stimuli in the environment could conceivably train attention towards one stimulation source over another from infancy. This idea is an adaptation of the Intersensory Redundancy Hypothesis proposed by Bahrick and Lickliter (2000), who suggest that multisensory processing serves to direct attention and enhance perceptual discrimination during development, but here their idea is extrapolated to suggest a mechanism for the development of sex differences.

The complexity/simplicity developmental model, although conjecture, reconciles conflict between findings from Experiment 3 and Experiment 4a. Ultimately, extreme bias towards processing simple features within vision, combined with reduced augmentation of cross-modal causality processing through complex feature integration, would lead to intact/superior object-based cognition and reduced socio-cognitive functioning. Simplistic perceptual processing (whether cross-modal or unimodal) in the absence of complex perceptual processing would bias neurodevelopment in an extreme male brain direction.

5.5 Limitations of the thesis and future directions

The studies in this thesis, though novel, generate more questions than are answered by the findings. There are also some concerns regarding design and analysis that constrain their interpretation.

With the BAP studies (Experiments 4 and 5), the high AQ scoring groups are treated as if they represent a homogeneous sample, yet there is considerable heterogeneity between individuals in terms of subscale scores. It may be that there are particular endophenotypic relationships (Losh & Piven, 2007) that cannot be detected within the studies which would be theoretically informative to analyse, but small sample sizes make such an approach difficult. Although Wakabayashi et al. (2006) consider that an 'autistic' personality dimension exists in which every individual displays traits relating to ASD to varying degrees, aggregations of such traits do not necessarily map onto subscales, or subscale combinations, within the Autism-Spectrum Quotient.

The potential existence of a population-level autism continuum also highlights a difficulty when matching children with and without diagnoses, and it may be that the nvIQ control group in Experiment 6 includes some individuals (particularly those displaying precociously high nvIQ raw scores) may also express aspects of the BAP; this possibility could in future be controlled through using the adolescent version of the AQ to screen potential participants (Baron-Cohen, Hoeckstra, Knickermeier & Wheelwright, 2006), although doing so might raise some interesting questions about co-relationships between extreme nvIQ and ASD in itself.

Experiment 6 is also limited in that it does not allow for inter-group contrast between visually-induced and cross-modal perceptual causality. The reason for this is that an initial attempt to do so failed because the children with ASD strove for 'truth' and regularity in the CoMG (Baron-Cohen, 2008a); when trials with and without auditory cue trials were inter-mingled, most of the six pilot participants

responded consistently to audio-visual trials by reporting crashes. Feedback suggested that they formed an explicit inference whenever they heard a noise to the effect that the objects must have collided.

As is the case with many studies in ASD and the broader phenotype, all the analyses here would have benefited from increased power through larger group sizes. Small cell numbers in particular constrained within-group gender comparisons that would have made inferential statistics obtained in the BAP studies easier to interpret.

In addition to redesigning tasks to address the issues described above, proposal of male/female perceptual developmental phenotype differences generates several novel avenues for further research. In adults, differences in extrastriate function (using global dot matrix stimuli contrasted with EFT presentation, for instance) would be particularly interesting in conjunction with neuro-imaging and AQ group categories; this study would extend the pilot study reported by Baron-Cohen et al. (2006) outside of proband families into the general population.

Similarly, on a larger scale, the relationships between the Broader Autism Phenotype and perceptual processing atypicalities such as motion processing need to be better understood, especially as recent research suggests the presence within the BAP of endophenotypes described as ‘aloof’ and ‘rigid’ (Losh & Piven, 2007).

One of the predictions made in this thesis is that superior colliculus functioning will be found to be intact with respect to multisensory processing in

ASD. New static stimuli have already been programmed as a first step towards testing this hypothesis; the Which Ball is Beeping? Game is a psychophysical staircase in which the offset/onset duration between an audio-visually synchronous event and a vision-only event is incrementally decreased until the chance threshold is reached. It is expected that performance on this task will be improved in girls, but not boys, when the visual complexity of the cross-modal stimulus is increased, with the reverse pattern seen when the visual distractor's complexity is increased.

If the superior colliculus has a role to play in the development of emotional processing, then the complexity/simplicity developmental hypothesis could be tested using the CoMG task again with typically developing children, but this time with the second cognitive measure being a social task, such as 'Reading the Mind in Film' (Golan, Baron-Cohen & Golan, 2008). A dissociation should be apparent between genders in this study, with girls' crash report scores significantly predicting socio-emotional task scores.

Finally, the idea that extreme sensitivity to object-based causality generates superior physical causal reasoning that is most apparent at the extreme tails of IQ distribution can be tested out through recruitment of children of both genders with precocious intellectual abilities. Such a 'gifted child' study would incorporate a suitable measure of ASD trait expression (such as the AQ-Adolescent version; Baron-Cohen, Hoekstra et al., 2006) so that relationships between IQ, gender and autistic superiorities could be explored.

5.5 Concluding Comments

The seminal and influential cognitive theories of ASD, especially Weak Central Coherence (Frith & Happé, 1994; Happé & Frith, 2006) and Mindblindness (Baron-Cohen, 1995) have provided massive insights into autism and its related conditions. Though these theories are still highly relevant, the criticisms that no single cognitive account suffices to explain all behaviours characteristic of this mysterious way of being, or provides a truly developmental explanation for the processes described, have moved the debate on to focus on other issues. Of typical note are the advances being made in understanding the perceptual autism phenotype, inspiring new theories, such as Enhanced Perceptual Functioning (Mottron et al., 2006) and Signal Integration Theory (Bertone & Faubert, 2006), which have the potential to shed light on the developmental course of ASD.

The idea that perception may drive development through stimulating brain maturation has been proposed by researchers of great merit such as Karmiloff-Smith, who has posited that privileged perception/cognition relationships produce both domain-specific differentiation at the cognitive level and increasingly complex neural architectures (1992). More recently, Karmiloff-Smith (2007) has proposed that atypical epigenesis, such as that seen in the course of ASD development at the individual level, reflects small neural challenges and processing abnormalities present from birth that cascade over time to generate widespread effects. Innate perceptual atypicalities represent a possible candidate for such snowballing effects.

Bertone and Faubert (2006) draw on the concept that complexity is the core issue in ASD (Minshew, Goldstein & Siegel, 1997) by considering its application to perceptual processing in autism. They propose that neurobiological interaction (i.e., co-operation and competition) between areas of the visual system is atypical in autism, in that feedback signalling from integrative areas fails to modulate inhibitory processes within primary cortex V1. The consequence of this failure is an 'autistic perceptual signature' in which feature processing is enhanced and feature integration is compromised. A particularly attractive aspect of their Signal Integration Theory is that it can account for positive aspects of ASD such as attention-to-detail and enhanced visual disembedding, as well as implying that processes relying on complex perceptual integration may be challenged.

This thesis began by considering perceptual integration across modalities to be potentially a source of cascading neurodevelopmental differences that would push the autistic brain along a highly specific maturation path. However, in the light of evidence obtained through these studies that cross-modal integration at the perceptual level is possibly intact, it has been concluded that the combination of 'simple' visual processing with low-level multisensory processing may promote the development of a brain that is geared to attend and respond to, and think about objects rather than people. Conversely, brains that process complex, highly-integrated information might orientate their owners towards social attention and cognition.

As a dichotomy is apparent in aspects of female versus male perception and cognition, I have proposed in the conclusion of this thesis that autism during

development represents the operation of an extreme male perceptual brain, an idea based on Extreme Male Brain Theory (Baron-Cohen, 2002). Autism as an exaggeration of differing developmental trajectories based on gender differences at the perceptual level would predict the pattern of spared versus under-developed neural connectivity between distal brain regions that is now being uncovered through imaging techniques (e.g. Just et al., 2006). Multisensory perceptual processing may prove to be important in understanding the developmental course of ASD, but not in itself *per se* but in terms of developmental interactions with the single senses of sound and vision.

References

- Alcántara, J.I., Weisblatt, E.J., Moore, B.C., & Bolton, P.F. (2004). Speech-in-noise perception in high-functioning individuals with autism or Asperger's syndrome. *Journal of Child Psychology and Psychiatry*, 45(6), 1107 – 1114.
- Allen, J.S., Damasio, H., Grabowski, T.J., Bruss, J., & Zhang, W. (2003). Sexual dimorphism and asymmetries in the gray–white composition of the human cerebrum. *NeuroImage*, 18(4), 880 – 894.
- Andersen, T.S., Tiippana, K., & Sams, M. (2004). Factors influencing audio-visual fission and fusion illusions. *Cognitive Brain Research*, 2, 301–308.
- American Psychiatric Association (1994). *Diagnostic and Statistical Manual of Mental Disorders*, (DSM-IV) (4th ed.). Washington, DC: APA.
- Asperger, H. (1944). Die "autistischen Psychopathen" im Kindersalter. *Archive fur psychiatrie und Nervenkrankheiten*, 117, 76 - 136. (Reprinted in *Autism and Asperger syndrome*, by U. Frith, Ed., 1991, Cambridge, UK: Cambridge University Press).
- Arden, G.B., Wolf, J.E., & Messiter, C. (2003). Electrical activity in visual cortex associated with combined auditory and visual stimulation in temporal sequences known to be associated with a visual illusion. *Vision Research*, 43(23), 2469 – 2478.
- Austin, E.J. (2005). Personality correlates of the broader autism phenotype as assessed by the Autism Spectrum Quotient (AQ). *Personality And Individual Differences*, 38(2), 451 – 460.
- Back, E., Ropar, D., & Mitchell, P. (2007). Do the eyes have it? Inferring mental states from animated faces in autism. *Child Development.*, 78(2), 397 – 411.
- Bahrack, L.E., & Lickliter, R. (2000). Intersensory Redundancy Guides Attentional Selectivity and Perceptual Learning in Infancy. *Developmental Psychology*, 36(2), 190 – 201.
- Bahrack, L. E., Lickliter, R., & Flom, R. (2004). Intersensory redundancy guides the development of selective attention, perception, and cognition in infancy. *Current Directions In Psychological Science*, 13(3), 99 – 102.
- Bailey, A., Le Couter, A., Gottesman, I., Bolton, P., Simenoff, E. Yuzda, E., & Rutter, M. (1995). Autism as a strongly genetic disorder: Evidence from a British Twin Study. *Psychological Medicine*, 25(1), 63 – 78.
- Bailey, A., Palferman, S., Heavey, L., & Le Couteur, A. (1998). Autism: The Phenotype in Relatives. *Journal of Autism and Developmental Disorders*, 28(5), 369 – 362.

- Bailey, A., & Parr, J. (2003). Implications of the broader phenotype for concepts of autism. *Autism: Neural Basis And Treatment Possibilities*, 251, 26 – 47.
- Baillargeon, R. (2004). Infants' physical world. *Current Directions in Psychological Science*, 13(3), 89 – 94.
- Baillargeon, R. (2008). For a Principle of Persistence in Infants' Physical Reasoning. *Perspectives on Psychological Science*, 3(1), 2 – 13.
- Baron-Cohen, S. (1995). *Mindblindness: An Essay on Autism and Theory of Mind*. Boston, U.S.:MIT Press.
- Baron-Cohen, S. (1999). The extreme male brain theory of autism. In H. Tager-Flusberg (Ed.), *Neurodevelopmental disorders*. Boston: MIT Press/Bradford Books.
- Baron-Cohen, S. (2002). The extreme male brain theory of autism. *Trends in Cognitive Science*, 6, 248 – 254.
- Baron-Cohen, S. (2003). *The Essential Difference*. Penguin: London.
- Baron-Cohen, S. (2008a). Autism, hypersystemizing and truth. *The Quarterly Journal of Experimental Psychology*, 61(1), 64 – 75.
- Baron-Cohen, S. (2008b). Theories of the autistic mind. *The Psychologist*, 21(2), 112 – 116.
- Baron-Cohen, S., Bolton, P., Wheelwright, S., Short, L., Mead, G., Smith, A., & Scahill, V. (1998). Autism occurs more often in families of physicists, engineers, and mathematicians. *Autism*, 2, 296- 301.
- Baron-Cohen, S., & Hammer, J. (1997). Is autism an extreme form of the male brain? *Advances in Infancy Research*, 11, 193–217.
- Baron-Cohen, S., Hoeckstra, R.A., Knickermeyer, R. & Wheelwright, S. (2006). The Autism-Spectrum Quotient (AQ)—Adolescent Version. *Journal of Autism and Developmental Disorders*, 36(3), 297 – 439.
- Baron-Cohen, S., & Klin, A. (2006). What's so special about Asperger syndrome? *Brain And Cognition*, 61(1), 1 – 4.
- Baron-Cohen, S., Knickermeyer, R.C., & Belmonte, M.K. (2005). Sex differences in the brain: Implications for Explaining Autism. *Science*, 310 (5749), 819 – 823.
- Baron-Cohen, S., Leslie, A.M., & Frith, U. (1985). Does the autistic child have a 'theory of mind'?. *Cognition*, 21, 37– 46.
- Baron-Cohen, S., Ring, H., Chitnis, X., Wheelwright, S., Gregory, L., Williams, S., Brammer, M., & Bullmore, E. (2006). fMRI of parents with children with Asperger Syndrome: A pilot study. *Brain and Cognition*, 61(1), 122 – 130.

- Baron-Cohen, S., Wheelwright, S., Burtenshaw, A., & Hobson, E. (2007). Mathematical Talent is Linked to Autism. *Human Nature*, 18(2), 125 – 131.
- Baron-Cohen, S., Wheelwright, S., Hill, J., Raste Y., & Plumb. I. (2001). The “Reading the Mind in the Eyes” Test Revised Version: A Study with Normal Adults, and Adults with Asperger Syndrome or High-functioning Autism. *The Journal of Child Psychology and Psychiatry and Allied Disciplines*, 42, 241 – 251.
- Baron-Cohen, S., Wheelwright, S., Scahill, V., Lawson, J., & Spong, A. (2001). Are intuitive physics and intuitive psychology independent? A test with children with Asperger Syndrome *Journal of Developmental and Learning Disorders*, 5, 47-78.
- Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-Functioning Autism, Males and Females, Scientists and Mathematicians. *Journal of Autism and Developmental Disorders*, 31(1), 5 – 16.
- Baron-Cohen, S., Wheelwright, S., Stone, V., & Rutherford, M. (1999). A mathematician, a physicist, and a computer scientist with Asperger Syndrome: Performance on folk psychology and folk physics tests. *Neurocase*, 5(6), 475 – 483.
- Baron-Cohen, S., Wheelwright, S., Stott, C., Bolton, P., & Goodyer, I. (1997). Is there a link between engineering and autism? *Autism: An International Journal of Research and Practice*, 1, 153 – 163.
- Bayliss, A.P., di Pellegrino, G., & Tipper, S.T. (2005). Sex differences in eye gaze and symbolic cueing of attention. *The Quarterly Journal of Experimental Psychology Section A*, 58(4), 631 – 650.
- Beaudet, A.L. (2007). Autism: highly heritable but not inherited. *Nature Medicine*, 13, 534 – 536.
- Beck, D.M. & Kastner, S. (2005). Stimulus context modulates competition in human extrastriate cortex. *Nature Neuroscience*, 8 (8), 1110 – 1116.
- Bertamini, M., Spooner, A. & Hecht, H. (2004). The representation of naïve knowledge about physics. In Malcolm, G. (Ed.). *Multidisciplinary Approaches to Visual Representations and Interpretations*. New York: Elsevier.
- Bertone, A., & Faubert, J. (2006). Demonstrations of Decreased Sensitivity to Complex Motion Information Not Enough to Propose an Autism-Specific Neural Etiology. *Journal of Autism and Developmental Disorders*, 36(1), 55 – 64.
- Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2003). Motion perception in autism: A “complex” issue. *Journal of Cognitive Neuroscience*, 15, 218 – 225.
- Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2005). Enhanced and diminished visuo-spatial information processing in autism depends on stimulus complexity. *Brain*, 128, 2430–2441.

Bettelheim, B. (1967). *The Empty Fortress: Infantile Autism and the Birth of the Self*. New York: The Free Press.

Binnie, L., & Williams, J. (2002). Intuitive psychological, physical and biological knowledge in typically developing preschoolers, children with autism and children with Down's syndrome. *British Journal of Development Psychology*, 20(3), 343-359.

Binnie, L., and Williams, J. (2003). Intuitive Psychology and Physics amongst Children with Autism and Typically Developing Children. *Autism*, 7(2), 173 – 193.

Bishop, D., Maybery, M., Maley, A., Wong, D., Hill, W., & Hallmayer, J. (2004). Using self-report to identify the broad phenotype in parents of children with autistic spectrum disorders: a study using the Autism-Spectrum Quotient. *Journal of Child Psychology and Psychiatry*, 45(8), 1431 – 1436.

Blakemore, S.J., Fonlupt, P., Pachot-Clouard, M., Darmon, C., Boyer, P., Meltzoff, A.N., Segebarth, C., & Decety, J. (2001). How the brain perceives causality: an event-related fMRI study. *NeuroReport*, 12(17), 3741 – 3746.

Bleuler, E. (1951). *Textbook of psychiatry* (A. A. Brill, Trans.). New York: Dover (Original work published 1916).

Bloom, P., & German, T.P. (2000). Two reasons to abandon the false belief task as a test of theory of mind. *Cognition*, 77(1), B25 – B31.

Bogdashina, O. (2003). *Sensory Perceptual Issues in Autism and Asperger Syndrome – Different Sensory Experiences – Different Perceptual Worlds*. London: Jessica Kingsley.

Bolte, S., & Poutska, F. (2006). The broader cognitive phenotype of autism in parents: How specific is the tendency for local processing and executive dysfunction? *Journal of Child Psychology and Psychiatry*, 47(6), 639 -645.

Bolton, P., Macdonald, H., Pickles, A., Rios, P., Goode, S., Crowson, M., Bailey, A., & Rutter, M. (1994). A case-control family history study of autism. *Journal of Child Psychology and Psychiatry*, 35, 877-900.

Bonnel, A. C., Mottron, L., Peretz, I., Trudel, M., Gallun, E., & Bonnel, A. M. (2003). Enhanced sensitivity for pitch in individuals with autism: A signal detection analysis. *Journal of Cognitive Neuroscience*, 15, 226-235.

Booth-Kewley, S., Larson, G.E., & Miyoshi, D. K. (2007). Social desirability effects on computerized and paper-and-pencil questionnaires. *Computers in Human Behavior*, 23(1), 463-477.

Bowler, D. M. (1992). "Theory of mind" In Asperger syndrome. *Journal of Child Psychology and Psychiatry*, 33, 877-893.

Boyd, B.A., Conroy, M.A., Mancil, G.R., Nakao, T., & Alter, P.J. (2007). Effects of Circumscribed Interests on the Social Behaviors of Children with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, 37(8), 1550 – 1561.

Braddick, O., Atkinson, J., & Wattam-Bell, J. (2003). Normal and anomalous development of visual motion processing: motion coherence and 'dorsal-stream vulnerability', *Neuropsychologia*, 41, 1769–1784.

Briskman, J., Happé, F., & Frith, U. (2001). Exploring the cognitive phenotype of autism: Weak 'central coherence' in parents and siblings of children with autism. II. Real-life skills and preferences. *Journal of Child Psychology and Psychiatry*, 42, 309–316.

Brian, J. A., & Bryson, S.E. (1996). Disembedding performance and recognition memory in autism/PDD. *Journal of Child Psychology and Psychiatry*, 37, 865 – 872.

Brody, L.R., & Hall, J. A. (2008). Gender and emotion in context. In Lewis, M., Haviland-Jones, J.M., & Barrett, L. F.(Ed.s). *Handbook of Emotion*. Guildford, UK: Guildford Press.

Bushara, K.O., Hanakawa, T., Immisch, I., Toma, K., Kansaku, K., & Hallett, M. (2003). Neural correlates of cross-modal binding. *Nature Neuroscience*, 6(2), 190 – 195.

Castelli, F., Frith, C., Happe, F., & Frith, U. (2002). Autism, Asperger syndrome and brain mechanisms for the attribution of mental states to animated shapes. *Brain*, 125(8), 1839 – 1849.

Champoux, F., Tremblay, C., Mercier, C., Lassonde, M., Lepore, F., et al. (2006). A role for the inferior colliculus in multisensory integration. *Neuroreport*, 17, 1607–1610.

Cherkassky, V.L., Kana, R.K., Keller, T.A., & Just, M.A. (2006). Functional connectivity in a baseline resting-state network in autism. *Neuroreport*, 17(16), 1687 – 1690.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.)*. Hillsdale, NJ: Erlbaum.

Cohen, L.B., Amsel, G., Redford, M.A., & Casasola, M. (1998). The development of infant causal perception. In A. Slater (Ed.) *Perceptual Development: Visual, Auditory and Speech Perception in Infancy*. Psychology Press.

Cohen, L.B., & Amsel, G. (1998). Precursors to infants' perception of the causality of a simple event. *Infant Behavior*, 21(4), 713 – 731.

Colvert, E., Custance, D., & Swettenham, J. (2002). Rule-based reasoning and theory of mind in autism: a commentary on the work of Zelazo, Jacques, Burack and Frye. *Infant and Child Development*, 11 (2), 197 – 200.

Connellan, J., Baron-Cohen, S., Wheelwright, S., Batki, A., & Ahluwalia, J. (2000). Sex differences in human neonatal social perception. *Infant Behaviour and Development*, 23(1), 113 – 118.

Costa, P.T., & McCrae, R.R. (1992). Normal Personality Assessment in Clinical Practice: The NEO Personality Inventory. *Psychological Assessment*, 4(1) 5 – 13.

Dakin, S., & Frith, U. (2006). Vagaries of Visual Perception in Autism. *Neuron*, 48(3), 497 – 507.

Dalton, K., Nacewicz, B., Alexander, A., & Davidson, R. (2006). Gaze-Fixation, Brain Activation and Amygdala Volume in Unaffected Siblings of Individuals with Autism. *Biological Psychiatry*, 61(4), 512 – 520.

Deary, I.J., Thorpe, G., Wilson, V., Starr, J.M., & Whalley, L.J. (2003). Population sex differences in IQ at age 11: The Scottish Mental Survey 1932. *Intelligence*, 31, 533 –542.

De Gelder, B., Morris, J.S., & Dolan, R.J. (2005). Unconscious fear influences emotional awareness of faces and voices. *PNAS*, 102(51), 18682 – 18687.

De Gelder, B., & Vroomen, J. (1991). Phonological deficits: Beneath the surface of reading-acquisition problems. *Psychological Research*, 53(1), 88 – 97.

DeLong, R. (2004). Autism and familial major mood disorder: Are they related? *Journal of Neuropsychiatry and Clinical Neurosciences*, 16, 199 – 213.

De Jonge, M.C., Kemner, C., & van Engeland, H. (2006). Superior Disembedding Performance of High-Functioning Individuals with Autism Spectrum Disorders and Their Parents: The Need for Subtle Measures. *Journal of Autism and Developmental Disorders*, 36(5), 677-683.

Demetriou, A., & Raftopoulos, A. (2004). *Cognitive Developmental Change: Theories, Models and Measurement*. Cambridge, UK: Cambridge University Press.

Dufour, A., Touzalin, P., Moessinger, M., Brochard, R., & Després, O. (2007). Visual motion disambiguation by a subliminal sound. *Consciousness and Cognition*, 17, 790 – 797.

Dunn, W. (1999). *Sensory profile*. San Antonio, TX: The Psychological Corporation.

Dunn, L., Dunn, L., Whetton, C., & Burley, J. (1997). *British Picture Vocabulary Scales* (2nd ed.). NFER-Nelson Publishing Company Ltd.

Edwards, A. L. (1953). The relationship between the judged desirability of a trait and the probability that the trait will be endorsed. *Journal of Applied Psychology*, 37, 90 – 93.

Ehlers, S., Nyden, A., Gillberg, C., Sandberg, A.D., Dahlgren, S.O., Hjelmquist, E., & Oden, A. (1997). Asperger syndrome, autism and attention disorders: A comparative study of the cognitive profiles of 120 children. *Journal Of Child Psychology And Psychiatry And Allied Disciplines*, 38(2), 207 – 217.

Eskes, G. A., Bryson, S. E., & McCormick, T. A. (1990). Comprehension of concrete and abstract words in autistic children. *Journal of Autism and Developmental Disorders*, 20, 61–73.

Fayol, M., Barrouillet, P., & Marinthe, C. (1998). Predicting arithmetical achievement from neuro-psychological performance: a longitudinal study, *Cognition*, 68(2), B63 – B70.

Flom, R., & Bahrick, L.E. (2007). The development of infant discrimination of affect in multimodal and unimodal stimulation: The role of intersensory redundancy. *Developmental Psychology*, 43(1), 238 – 252.

Fodor, J.A. (1983). *The Modularity of Mind*. Cambridge, MA: MIT Press.

Fombonne, E., Bolton, P., Prior, J., Jordan, H., & Rutter, M. (1997). A family study of autism: cognitive patterns and levels in parents and siblings. *Journal of Child Psychology and Psychiatry*, 38(6), 667 – 683.

Freitag, C.M. (2007). The genetics of autistic disorders and its clinical relevance: a review of the literature. *Molecular Psychiatry*, 12, 2 – 22.

Frith, U. (1996). Cognitive explanations of autism. *Acta Pædiatrica*, 85, s416, 63 – 68.

Frith, U. (2003). *Autism: Explaining the Enigma* (2nd Ed.). Oxford: Blackwell.

Frith, U., & Happé, F. (1994). Autism: beyond 'theory of mind'. *Cognition*, 50, 115 – 132.

Frith, U., & Snowling, M. (1983). Reading for meaning and reading for sound in autistic and dyslexic children. *British Journal of Developmental Psychology*, 1(4), 329 – 342.

Golan, O., Baron-Cohen, S. & Golan, Y. (2008). The 'Reading the Mind in Films' Task [child version]: complex emotion and mental state recognition in children with and without autism spectrum conditions. *Journal of Autism and Developmental Disorders*, 38(8), 1534 – 1541.

Goldberg, M.C., Lasker, A.G., Zee, D.S., Garth, E., Tien, A. & Landa, R.J. (2002). Deficits in the initiation of eye movements in the absence of a visual target in adolescents with high functioning autism. *Neuropsychologia*, 40, 2039 – 2049.

Grandin, T. (1992). An inside view of autism. In E. Schopler, & G. B. Mesibov (Eds.), *High-functioning individuals with autism* (pp. 105-126). New York: Plenum Press.

- Guski, R., & Troje, N.F. (2003). Audiovisual perceptual causality. *Perception and Psychophysics*, 65(5), 789 – 800.
- Hale, S. (1990). A global developmental trend in cognitive processing speed. *Child Development*, 61, 653 – 663.
- Hall, G.B., Szechtman, H., & Nahmias, C. (2003). Enhanced Salience and Emotion Recognition in Autism: A PET Study. *American Journal of Psychiatry*, 160, 1439 – 1441.
- Halpern, D. F. (2000). *Sex differences in cognitive abilities* (3rd ed.). Mahwah, NJ: Erlbaum.
- Halpern, D.F. (2004). A cognitive-process taxonomy for sex differences in cognitive abilities. *Current Directions In Psychological Science*, 13(4), 135 – 139.
- Halpern, D.F., Benbow, C.P., Geary, D.C., Gur, R.C., Hyde J.S., & Gernsbacher, M.A. (2007). The Science of Sex Differences in Science and Mathematics. *Psychological Science in the Public Interest*, 8(1), 1 – 51.
- Happé, F. (1997). Central coherence and theory of mind in autism: Reading homographs in context. *British Journal of Developmental Psychology*, 15, 1 – 12.
- Happé, F. (2006). Understanding autism: From basic neuroscience to treatment. *Nature*, 442, 632 – 633.
- Happé, F. G. E., & Booth, R. D. L. (2008). The power of the positive: Revisiting weak coherence in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, 61(1), 50 – 63.
- Happé, F., Briskman, J., & Frith, U. (2001). Exploring the cognitive phenotype of autism: Weak ‘central coherence’ in parents and siblings of children with autism. I. Experimental tests. *Journal of Child Psychology and Psychiatry*, 42, 299–307.
- Happé, F., & Frith, U. (2006). The Weak Coherence Account: Detail-focused Cognitive Style in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, 36(1), 5 – 25.
- Happé, F., Ronald, A., & Plomin, R. (2006). Time to give up on a single explanation for autism. *Nature Neuroscience*, 9(10), 1218 – 1220.
- Hedges, L.V., & Nowell, A. (1995). Sex differences in mental test scores, variability, and numbers of high-scoring individuals. *Science*, 269(5220), 41 – 45.
- Hermelin, B. (2002). *Bright splinters of the mind: a personal story of research with autistic savants*. London: Jessica Kingsley.
- Hill, E. L. (2004a). Executive dysfunction in autism. *Trends in Cognitive Sciences*, 8(1), 26 – 32.

- Hill, E. L. (2004b). Evaluating the theory of executive dysfunction in autism. *Developmental Review, 24*(2) 189 – 233.
- Hyde, J.S. (2005). The Gender Similarities Hypothesis. *American Psychologist, 60*(6), 581 – 592.
- Iarocci, G., & McDonald, J. (2006). Sensory Integration and the Perceptual Experience of Persons with Autism. *Journal of Autism and Developmental Disorders, 36*(1), 77 – 90.
- Jackson, D.N., & Rushton, J.P. (2006). Males have greater g: Sex differences in general mental ability from 100,000 17- to 18-year-olds on the Scholastic Assessment Test. *Intelligence, 34*(5), 479-486.
- Jarrold, C., Gilchrist, I.D. & Bender, A. (2005). Embedded figures detection in autism and typical development: preliminary evidence of a double dissociation in relationships with visual search. *Developmental Science, 8*(4), 344 – 351.
- Järvinen-Pasley, A., & Heaton, P. (2007). Evidence for reduced domain-specificity in auditory processing in autism. *Developmental Science, 10*(6), 786 – 793.
- Jolliffe, T. & Baron-Cohen, S. (1997). Are people with autism and Asperger Syndrome faster than normal on the Embedded Figures Test? *Journal of Child Psychology and Psychiatry, 38*, 527-534.
- Jordan, K.E., Suanda, S.H. & Brandon, E.M. (2008). Intersensory redundancy accelerates preverbal numerical competence. *Cognition, 108*(1), 210 – 221.
- Just, M.A., Cherkassky, V.L., Keller, T.A., & Minshew, N.J. (2004). Cortical activation and synchronization during sentence comprehension in high-functioning autism: Evidence of underconnectivity. *Brain, 127*(8), 1811 – 1821.
- Just, M.A., Cherkassky, V.L., Keller, T.A., Kana R.K., & Minshew, N.J. (2006). Functional and anatomical cortical underconnectivity in autism: Evidence from an fMRI study of an executive function task and corpus callosum morphometry. *Cerebral Cortex, 17*(4), 951 – 961.
- Kail, R. (1991). Developmental change in speed of processing in childhood and adolescence. *Psychological Bulletin, 109*, 490 – 501.
- Kanner, L. (1943). Autistic disturbances of affective contact. *Nervous Child, 2*, 217 – 250.
- Karmiloff-Smith, A. (1991). Beyond modularity: Innate constraints and developmental change. In S. Carey & R. Gelman (Eds.), *The Epigenesis of Mind; Essays on Biology and Cognition* (pp. 171 – 197). Hillsdale, NJ: Erlbaum.
- Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science*. Cambridge, MA: MIT Press.

- Karmiloff-Smith, A. (1998). Development itself is the key to understanding developmental disorders. *Trends In Cognitive Sciences*, 2(10), 389–398.
- Karmiloff-Smith, A. (2007). Atypical epigenesis. *Developmental Science*, 10(1), 84–88.
- Kastner, S., De Weerd, P., Pinsk, M.A., Elizondo, M.I., Desimone, R., & Ungerleider, L.G. (2001). Modulation of Sensory Suppression: Implications for Receptive Field Sizes in the Human Visual Cortex. *Journal of Neurophysiology*, 86(3) 1398–1411.
- Kern, J.K., Trivedi, M.H., Garver, C.R., Grannemann, B.D., Andrews, A.A., Savla, J. S., et al. (2006). The pattern of sensory processing abnormalities in autism. *Autism*, 10, 480–494.
- Kern, J.K., Garver, C.R., Carmody, T., Andrews, A.A., Trivedi, M.H. & Mehta, J.A. (2007). Examining sensory quadrants in autism. *Research in Autism Spectrum Disorders*, 1, 185–193.
- Kimura, D. (1999). *Sex and Cognition*. Cambridge, MA: MIT Press.
- Kovotsky, L., & Baillargeon, R. (1998). The development of calibration-based reasoning about collision events in young infants. *Cognition*, 67, 311–351.
- Lawson, J., Baron-Cohen, S., & Wheelwright, S. (2004). Empathising and Systemising in Adults with and without Asperger Syndrome. *Journal of Autism and Developmental Disorders*, 34(3) 301–310.
- Lee, P.S., Foss-Feig, J., Henderson, J.G., Kenworthy, L.E., Gilotty, L., Gaillard, W., & Vaidya, C.J. (2007). Atypical neural substrates of Embedded Figures Task performance in children with Autism Spectrum Disorder. *NeuroImage*, 38 (1), 184–193.
- Leslie, A.M. (1984). Spatiotemporal continuity and the perception of causality in infants. *Perception*, 13, 287–305.
- Leslie, A.M. (2004). ToMM, ToBy, and Agency: Core architecture and domain specificity. In Hirschfeld, L.A., & Gelman, S. A. (Eds.). *Mapping the Mind: Domain Specificity in Cognition and Culture*. Cambridge, UK: Cambridge University Press.
- Leslie, A.M., & Keeble, S. (1987). Do six-month-old infants perceive causality? *Cognition*, 25, 265–288.
- Lewald, J., & Guski, R. (2003). Cross-modal perceptual integration of spatially and temporally disparate auditory and visual stimuli. *Cognitive Brain Research*, 16(3), 468–478.

- Liss, M., Harel, B., Fein, D., Allen, D., Dunn, M., Feinstein, C., Morris, R., Waterhouse, L., & Rapin, I. (2001). Predictors and correlates of adaptive functioning in children with developmental disorders. *Journal of Autism and Developmental Disorders*, 31, 219 – 230.
- Losh, M., & Piven J. (2007). Social-cognition and the broad autism phenotype: identifying genetically meaningful phenotypes. *Journal of Child Psychology and Psychiatry*, 48(1), 105 – 112.
- Magnée, M.J., de Gelder, B., van Engeland, H., & Kemner, C. (2008). Audiovisual speech integration in pervasive developmental disorder: evidence from event-related potentials. *Journal of Child Psychology and Psychiatry*, 49(9), 995 – 1000.
- Manjaly, Z.M., Bruning, N., Neufang, S., Stephan, K. E., Brieber, S., Marshall, J.E., Kamp-Becker, I., Remschmidt, H., Herpertz-Dahlmann, B., Konrad, K., & Fink, G.R. (2007). Neurophysiological correlates of relatively enhanced local visual search in autistic adolescents. *NeuroImage*, 35, 283 – 291.
- Mann, T.A., & Walker, P. (2004). Autism and a deficit in broadening the spread of visual attention. *Journal of Child Psychology & Psychiatry & Allied Disciplines*, 44(2), 274 – 284.
- Martin, C. L., & Nagao, D. H. (1989). Some effects of computerized interviewing on job applicant responses. *Journal of Applied Psychology*, 74, 72 – 80.
- Mazefsky, C.A., & Oswald, D.P. (2006). The discriminative ability and diagnostic utility of the ADOS-G, ADI-R, and GARS for children in a clinical setting. *Autism*, 10(6), 533 – 549.
- McCleery, S. J., Allman, E., Carver, L., & Dobkins, K. (2007). Abnormal Magnocellular Pathway Visual Processing in Infants at Risk for Autism. *Biological Psychiatry*, 62(9), 1007 – 1014.
- McCloskey, M., Washburn, A., & Felch, L. (1983). Naïve physics: The straight-down belief and its origin. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 9, 636 – 649.
- McGurk, H., & McDonald, J. (1976). Hearing lips and seeing voices. *Nature*, 264, 746–748.
- Meredith, M.A., Nemitz, J.W., & Stein, B.E. (1987). Determinants of multisensory integration in superior colliculus neurons. I. Temporal factors. *Journal of Neuroscience*, 7, 3215 – 3229.
- Merin, N., Young, G.S., Ozonoff, S., & Rogers, S.J. (1997). Visual Fixation Patterns during Reciprocal Social Interaction Distinguish a Subgroup of 6-Month-Old Infants At-Risk for Autism from Comparison Infants. *Journal of Autism and Developmental Disorders*, 37(1), 108 – 121.
- Michotte, A. (1963). *The perception of causality*. Andover, MA: Methuen.

- Miller, E.K. (2001). Prefrontal cortex and the neural basis of executive functions. *Brain and Cognition*, 47, 22-22.
- Miller, E.K., Gochin, P.M., & Gross, C.G. (1993). Suppression of visual responses of neurons in inferior temporal cortex of the awake macaque monkey by addition of a second stimulus. *Brain Research*, 616, 25 – 29.
- Milne, E., Swettenham, J., & Campbell, R. (2005). Motion perception and autistic spectrum disorder: A review. *Current Psychology of Cognition*, 23 (1 – 2), 3 – 33.
- Minshew, N.J., & Goldstein, G. (1998). Autism as a disorder of complex information processing. *Mental Retardation and Developmental Disabilities Research Reviews*, 4, 129 – 136.
- Minshew N. J., Goldstein G., & Siegel D. J. (1997). Neuropsychologic functioning in autism: Profile of a complex information processing disorder. *Journal of the International Neuropsychological Society* 3, 303 - 316.
- Morgan, B., Maybery, M., & Durkin, K. (2003). Weak central coherence, poor joint attention, and low verbal ability: Independent deficits in early autism. *Developmental Psychology*, 39(4), 646 – 656.
- Mottron, L., & Burack, J. (2001). Enhanced perceptual functioning in the development of autism. In: Burack, Charman, Yirmiya, & Zelazo (Eds.), *The development of autism: Perspectives from theory and research*. (pp. 131–148). Mahwah, NJ: Erlbaum.
- Mottron, L., Burack, J.A., Iarocci, G., Belleville, S., & Enns, J.T. (2003). Locally oriented perception with intact global processing among adolescents with high-functioning autism: evidence from multiple paradigms. *Journal of Child Psychology And Psychiatry And Allied Disciplines*, 44(6), 904 – 913.
- Mottron, L., Burack, J. A., Stauder, J. E. A., & Robaey, P. (1999). Perceptual processing among high-functioning persons with autism. *Journal of Child Psychology and Psychiatry*, 40, 203–211.
- Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced Perceptual Functioning in Autism: An Update, and Eight Principles of Autistic Perception. *Journal of Autism and Developmental Disorders*, 36(1), 27 – 43.
- Murias, M., Webb, S.J., Greenson, J., & Dawson, G. (2007). Resting State Cortical Connectivity Reflected in EEG Coherence in Individuals With Autism. *Biological Psychiatry*, 62, 270 – 273.
- Murphy, M., Bolton, P. F., Pickles, A., Fombonne, E., Piven, J., & Rutter, M. (2000). Personality traits of the relatives of autistic probands. *Psychological Medicine*, 30, 1411–1424.

- Naber, F.B.A., Bakermans-Kranenburg, M.J., van Ijzendoorn, M.H., Dietz, C., van Daalen, E., Swinkels, S.H.N., Buitelaar, J.K., & van Engeland, H. (2007). Joint attention development in toddlers with autism. *European Child & Adolescent Psychiatry, 17*(3), 143 – 152.
- Naglieri, J. (1997). *The Naglieri Nonverbal Ability Test*. San Antonio: Psychological Corporation.
- Neubauer, A. C., Grabner, R.H., Fink, A., & Neuper, C. (2005). Intelligence and neural efficiency: Further evidence of the influence of task content and sex on the brain-IQ relationship. *Cognitive Brain Research, 25*(1), 217 – 225.
- Nettlebeck, T., & Wilson, C. (1985). A cross-sequential analysis of developmental differences in speed of visual processing. *Journal of Experimental Child Psychology, 40*, 1 – 22.
- Newcombe, N., Huttenlocher, J., & Learmonth, A. (1999). Infants' coding of location in continuous space. *Infant Behavior and Development, 22*(4), 483 – 510.
- O'Riordan, M., & Passetti, F. (2006). Discrimination in autism within different sensory modalities. *Journal of Autism and Developmental Disorders, 36*, 665–675.
- Ozonoff, S., & Jensen, J. (1999). Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders, 29*, 171–177.
- Ozonoff, S., & McEvoy, R.E. (1994). A longitudinal study of executive function and theory of mind development in autism. *Development and Psychopathology, 6*, 415-431.
- Ozonoff, S., Pennington, B.F., & Rogers, S. J. (1991). Executive Function Deficits in High-Functioning Autistic Individuals: Relationship to Theory of Mind. *Journal of Child Psychology and Psychiatry, 32*(7), 1081 – 1105.
- Ozonoff, S., Rogers, S. J., & Pennington, B.F. (1991). Asperger's Syndrome: Evidence of an Empirical Distinction from High-Functioning Autism. *Journal of Autism and Developmental Disorders, 32*(7), 1107 - 1122.
- Pack, C.C., Gartland, A.J., & Born, R.T. (2004). Integration of Contour and Terminator Signals in Visual Area MT of Alert Macaque. *Journal of Neuroscience, 24*(13), 3268 – 3280.
- Pellicano, E., Gibson, L., Maybery, M., Durkin, K., & Badcock, D.R. (2005). Abnormal global processing along the dorsal visual pathway in autism: a possible mechanism for weak visuospatial coherence? *Neuropsychologia, 43*(7), 1044 – 1053.

Pellicano, E., Maybery, M., Durkin, K., & Maley, A. (2006). Multiple cognitive capabilities/deficits in children with an autism spectrum disorder: “weak” central coherence and its relationship to theory of mind and executive control. *Development and Psychopathology*, 18(1), 77–98.

Piaget, J. (1964). Development and Learning. In R. Ripple & V. Rockcastle (Eds.), *Piaget Rediscovered* (pp. 7 -19). Cornell University Press.

Pinker, S. (1994). *The language instinct*. Harper Collins: New York.

Piven, J., & Palmer, P. (1997). Cognitive deficits in parents from multiple-incidence autism families. In M.E. Hertzog and E.A. Farber (Eds.) *Annual Progress in Child Psychiatry and Child Development, 1998*. Psychology Press.

Plaisted, K.C. (2001). Reduced generalization: An alternative to weak central coherence. In: Burack, J.A., Charman, A., Yirmiya, N. & Zelazo, P.R. (Eds). *Development and Autism: Perspectives from theory and research*. Lawrence Erlbaum Associates, New Jersey.

Plaisted, K.C., O’Riordan, M., Aitken, M., & Killcross, S. (submitted). Categorisation in autism: Evidence of a reduced prototype effect. Submitted to *Quarterly Journal of Experimental Psychology*.

Plaisted, K.C., O’Riordan, M., & Baron-Cohen, S. (1998). Enhanced discrimination of novel, highly similar stimuli by adults with autism during a perceptual learning task. *Journal of Child Psychology and Psychiatry*, 39, 765 – 775.

Premack, D., & Woodruff, G. (1978). Does the chimpanzee have a ‘theory of mind’? *Behavioral and Brain Sciences*, 4, 515 – 526.

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision*, 3, 179–197.

Rahman, O., Andersson, D., & Govier, E. (2005). A Specific Sexual Orientation-Related Difference in Navigation Strategy. *Behavioral Neuroscience*, 119(1), 311-316.

Rajendran, G. & Mitchell, P. (2007). Cognitive theories of autism. *Developmental Review*, 27, 224 – 260.

Ray, E. & Schlottman, A. (2007). The perception of social and mechanical causality in young children with ASD. *Research in Autism Spectrum Disorders*, 1, 266 – 280.

Remijn, G.B., Ito, H., & Nakajima, Y. (2004). Audiovisual Integration: An Investigation of the ‘Streaming-bouncing’ Phenomenon. *Journal of Physiological Anthropology and Applied Human Science*, 23(6), 243 – 247.

- Ring, H.A, Baron-Cohen, S., Wheelwright, S, Williams, S.C.R., Brammer, M., Andrew, C., & Bullmore, E.T. (1999). Cerebral correlates of preserved cognitive skills in autism: A functional MRI study of Embedded Figures Task performance. *Brain*, *122*(7), 1305 – 1315.
- Ritvo, R.A., Ritvo, E., Guthrie, D., & Ritvo, M. (2008). Clinical evidence that Asperger's disorder is a mild form of autism. *Comprehensive Psychiatry*, *49*(1), 1 – 5.
- Robert, M., & Ohlmann, T. (1994). Water-level representation by men and women as a function of rod-and-frame test proficiency and visual postural information. *Perception*, *23*, 1321–1333.
- Ropar, D., & Mitchell, P. (1999). Susceptibility to Illusions and Performance on Visuospatial Tasks in Individuals with Autism. *Journal of Child Psychology and Psychiatry*, *42*(4), 539 – 549.
- Rose, S.A., Feldman, J.F., & Wallace, I.F. (1992). Infant Information Processing in Relation to Six-Year Cognitive Outcomes. *Child Development*, *63*(5), 1126-1141.
- Rosenblum, L.D., Schmuckler, M.A., & Johnson, J.A. (1997). The McGurk effect in infants. *Perception & Psychophysics*, *59*(3), 347-357.
- Rutter, M., Bailey, A., & Lord, C. (2003). *SCQ: The Social Communication Questionnaire Manual*. Los Angeles, CA.:Western Psychological Services.
- Sakurai, K., & Grove, P. M. (2006). Auditory-induced bounce perception when visual trajectories are inconsistent with motion reversal. *Perception*, *35*, ECVF Abstract Supplement, 202.
- Sanabria, D., Correa, A., Lupianez, J., & Spence, C. (2004). Bouncing or streaming? Exploring the influence of auditory cues on the interpretation of ambiguous visual motion. *Experimental Brain Research*, *157* (4), 347 – 351.
- Saucier, D. M., Green, S. M., Leason, J., MacFadden, A., Bell, S., & Elias, L. J. (2002). Are sex differences in navigation caused by sexually dimorphic strategies or by differences in the ability to use the strategies? *Behavioral Neuroscience*, *116*, 403–410.
- Scheeren, A. M., & Stauder, J.E.A. (2008). Broader Autism Phenotype in Parents of Autistic Children: Reality or Myth? *Journal of Autism and Developmental Disorders*, *38*(2), 276 – 287.
- Scheier, C., Lewkowicz, D.J., & Shimojo, S. (2003). Sound induces perceptual reorganization of an ambiguous motion display in human infants. *Developmental Science*, *6*(3), 233 -241.
- Scholl, B., & Nakayama, K. (2002). Causal capture: Contextual effects on the perception of collision events. *Psychological Science*, *13*, 493 – 498.

Sekuler, R., Sekuler, A.B., & Lau, R. (1997). Sound alters visual motion perception. *Nature*, *384*, 308 – 309.

Shah, A., & Frith, U. (1983). An islet of ability in autistic children- a research note. *Journal of Child Psychology and Psychiatry*, *24*, 613 – 620.

Shah, A., & Frith, U. (1993). Why do autistic individuals show superiority on the Block Design Test? *Journal of Child Psychology and Psychiatry*, *34*(8), 1351 – 1364.

Shams, L., Kamitani, Y., Thompson, S., & Shimojo, S. (2002). Sound alters visual evoked potentials in humans. *Neuroreport*, *12*, 3849–3852.

Shutts, K., & Spelke, E.S. (2004). Straddling the perception–conception boundary. *Developmental Science*, *7*, 507–511.

Smith, E.G., & Bennetto, L. (2007). Audiovisual speech integration and lipreading in autism. *Journal of Child Psychology and Psychiatry*, *48*(8), 813 – 821.

Spelke, E.S. (1991). Physical knowledge in Infancy: Reflections on Piaget’s Theory. In S. Carey & R. Gelman (Eds.), *The Epigenesis of Mind; Essays on Biology and Cognition* (pp. 133 – 169). Hillsdale, NJ: Erlbaum.

Spelke, E.S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). The origins of knowledge. *Psychological Review*, *19*(4), 605 – 632.

Spelke, E. S. (2005). Sex Differences in Intrinsic Aptitude for Mathematics and Science?: A Critical Review. *American Psychologist*, *60*(9), 950 – 958.

Spelke, E.S., & Kinzler, K.D. (2007). Core knowledge. *Developmental Science*, *10*(1), 89 – 96.

Stein, B.E. (2005). The development of a dialogue between cortex and midbrain to integrate multisensory information. *Experimental Brain Research*, *166*, 305–315.

Stroop, J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology* *18*, 643–662.

Tadevosyan-Leyfer, O., Dowd, M., Mankoski, R., Winklosky, B., Putnam, S., & McGrath, L., et al. (2003). A principal component analysis of the autism diagnostic interview-revised. *Journal of American Academy of Child Adolescent Psychiatry*, *42*, 864 – 872.

Tsermentseli, S., O'Brien, J.M., & Spencer, J.V. (2007). Comparison of form and motion coherence processing in autistic spectrum disorders and dyslexia. *Journal of Autism Developmental Disorder*, *38*(7), 1201 – 10.

Thayer, J., & Johnsen, B.H. (2000) Sex differences in judgement of facial affect: A multivariate analysis of recognition errors. *Scandinavian Journal of Psychology*, *41*(3), 243 – 246.

- Tidmarsh, L., & Volkmar, F. R. (2003). Diagnosis and Epidemiology of Autism Spectrum Disorders. *Canadian Journal of Psychiatry*, 48(8), 517 – 525.
- Tremblay, C., Champoux, F., Voss, P., Bacon, B.A., Lepore, F., & Theoret, H. (2007). Speech and Non-Speech Audio-Visual Illusions: A Developmental Study. *PLoS ONE*, 2(8), e742. [Downloaded on 7th September, 2008].
- Trick, L.M., Audet, D., & Dales, L. (2003). Age differences in enumerating things that move: Implications for the development of multiple-object tracking. *Memory and Cognition*, 31(8), 1229-1237.
- Van der Smagt, M.J., Van Engeland, H., & Kemner, C. (2007). Brief Report: Can You See What is Not There? Low-level Auditory–visual Integration in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, 37(10), 2014 – 2019.
- Van Lang, N.D.J., Bouma, A., Sytma, S., Kraijer, D.W., & Minderaa, R.B. (2005). A comparison of central coherence skills between adolescents with an intellectual disability with and without comorbid autism spectrum disorder. *Research in Developmental Disabilities*, 27(2), 217 -226.
- Voyer, D., Voyer, S., & Bryden, M.P. (1995). Magnitude of sex differences in spatial abilities: a meta-analysis and consideration of critical variables. *Psychological Bulletin*, 117(2), 250-270.
- Wakabayashi, A., Baron-Cohen, S., & Wheelwright, S. (2006). Are autistic traits an independent personality dimension? A study of the Autism-Spectrum Quotient (AQ) and the NEO-PI-R. *Personality and Individual Differences*, 41(5), 873 – 883.
- Watkins, S., Shams, L., Tanaka, S., Haynes, J.D., & Rees, G. (2006). Sound alters activity in human V1 in association with illusory visual perception. *NeuroImage*, 3(3), 1247 – 1256.
- Wellman, H. M., & Gelman, S. A. (1992). Cognitive Development: Foundational Theories of Core Domains. *Annual Review of Psychology*, 43, 337 – 375.
- Wheelwright, S., & Baron-Cohen, S. (2001). The link between autism and skills such as engineering, math, physics, and computing. *Autism*, 5, 223–227.
- Wheelwright, S., Baron-Cohen, S., Goldenfeld, N., Delaney, J., Fine, D., Smith, R. Weil, L., & Wakabayashi, A. (2006). Predicting Autism Spectrum Quotient (AQ) from the Systemising Quotient-Revised (SQ-R) and Empathy Quotient. *Brain Research*, 1079(1), 47 – 56.
- Williams, D. (1994). *Somebody somewhere*. London: Doubleday.
- Williams, D. (2008). Weblog accessed on 14th September, 2008 [at <http://www.donnawilliams.net/about.0.html>].

- Williams, J.H., Massaro, D.W., Peel, N.J., Bosseler, A., & Suddendorf, T. (2004). Visual–auditory integration during speech imitation in autism. *Research in Developmental Disabilities, 25*(6), 559 – 575.
- Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: representation and the containing function of wrong beliefs in young children's understanding of deception. *Cognition, 13*, 103–128.
- Wing, L. (1981). Asperger's syndrome: A clinical account. *Psychological Medicine, 11*, 115-129.
- Wing, L. (1993). The definition and prevalence of autism: A review. *European Child & Adolescent Psychiatry, 2*(1), 61 – 74.
- Wing, L., & Gould, J. (1979). Severe impairments of social interaction and associated abnormalities in children: Epidemiology and classification. *Journal of Autism and Developmental Disorders, 9*(1), 11 – 29.
- Witkin, H.A. (1950). Individual Differences in ease of perception of Embedded Figures. *Journal of Personality, 19*(1), 1 – 15.
- Witkin, H.A., Oltman, P.K., Raskin, E., & Karp, S.A. (1971). *A manual for the Embedded Figures Test*. Paulo Alto, CA: Consulting Psychologists Press.
- Xu, F., Spelke, E.S., & Goddard, S. (2005). Number sense in human infants. *Developmental Science, 8*(1), 88 – 101.
- Zelazo, P. D., Carter, A., Reznick, J. S., & Frye, D. (1997). Early development of executive function: a problem-solving framework. *Review of General Psychology, 1*, 198–226.
- Zhou, F., Wong, V., & Sekuler, R. (2007). Multi-sensory integration of spatio-temporal segmentation cues: one plus one does not always equal two. *Experimental Brain Research, 180*(4), 651 – 654.
- Zilbovicius, M., Garreau, B., Samson, Y., Remy, P., Barthelemy, C., Syrota, A., & Lelord, G. (1995). Delayed maturation of the frontal cortex in childhood autism. *American Journal of Psychiatry, 152*, 248 – 252.

LIST OF APPENDICES

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Appendix A: Crash or Miss Game Instructions

Voice-over: Hello. We're going to play the 'crash or miss' game. All you have to do is watch two balls moving on the screen.

Image: Yellow smiley face

Voice-over: When you see the first ball crash into the second ball, press the red key.

Image 2: Red key

Voice-over: When you see the first ball miss the second ball, press the yellow key.

Image 3: Yellow key

Voice-over: Let's have a look!

Image 4: Yellow smiley face

[Demonstration animation: Unambiguous Miss with Simultaneous Sound]

Voice-Over: Let's look at another one.

Image 5: Yellow smiley face

[Demonstration animation: Ambiguous Event with Simultaneous Sound]

Voice-over: They're going quite fast – shall we practice?

Image 6: Smiley face

(Practice session with each type of trial introduced)

Noise: Applause

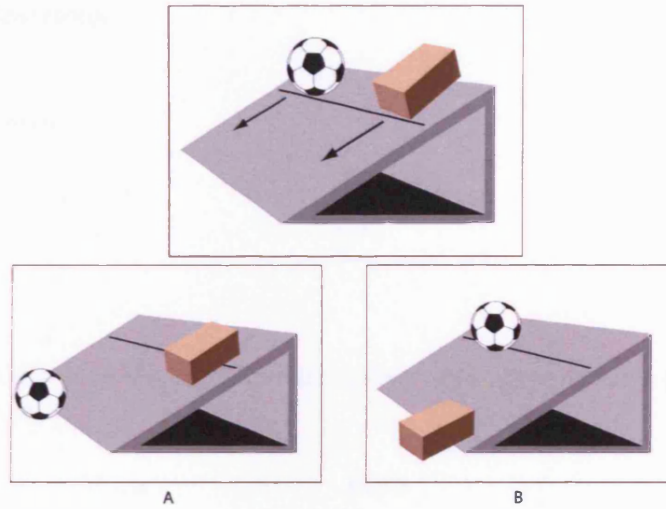
Image 7: Big gold star

Voice-over: You're really good!! Let's play the Crash or Miss Game!

Image 11: Smiley face

[Pause screen with text: Press Space Bar To Begin The Game]

Appendix B: What Happens Next? Task instructions



“This is called ‘What Happens Next?’ I’m going to show you a picture of something about to happen (point to ‘before’ picture). Now, either A (point to ‘after’ picture A) or B (point to ‘after picture B) happens next. Which one is it? Does A or B happen next?”

[Record Answer on Sheet; if two or more incorrect answers are given at any level of difficulty, stop at the END of that section].

Appendix C: The Crash or Miss Game Feedback Sheet

Verification questions

Participant Number:

Gender:

Date:

1. When both balls were the same colour (either both white or both green), what did you think you saw?

Crashes Misses Both

2. Were you aware of the 'clicks'?

Yes No

3. Did you notice that they didn't always happen at the same time?

Yes No

[Comments]

4. Do you think that the clicks affected what you saw?

Yes No

If yes, how?

5. Did you make up any rules about how to respond as you went along?

Yes No

If yes, what?

Appendix D: The Autism-Spectrum Quotient

The Adult Autism Spectrum Quotient (AQ)

Ages 16+

SPECIMEN, FOR RESEARCH USE ONLY.

For full details, please see:

S. Baron-Cohen, S. Wheelwright, R. Skinner, J. Martin and E. Clubley, (2001).
The Autism Spectrum Quotient (AQ) : Evidence from Asperger Syndrome/High Functioning Autism, Males and Females, Scientists and Mathematicians.
Journal of Autism and Developmental Disorders, 31, 15 – 17.

Participant code:

Gender:

Date of birth:..... Today's Date.....

How to fill out the questionnaire

Below are a list of statements. Please read each statement very carefully and rate how strongly you agree or disagree with it by circling your answer.

DO NOT MISS ANY STATEMENT OUT.

Examples

E1. I am willing to take risks.	definitely agree	slightly agree	slightly disagree	definitely disagree
E2. I like playing board games.	definitely agree	slightly agree	slightly disagree	definitely disagree
E3. I find learning to play musical instruments easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
E4. I am fascinated by other cultures.	definitely agree	slightly agree	slightly disagree	definitely disagree

1. I prefer to do things with others rather than on my own.	definitely agree	slightly agree	slightly disagree	definitely disagree
2. I prefer to do things the same way over and over again.	definitely agree	slightly agree	slightly disagree	definitely disagree
3. If I try to imagine something, I find it very easy to create a picture in my mind.	definitely agree	slightly agree	slightly disagree	definitely disagree
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.	definitely agree	slightly agree	slightly disagree	definitely disagree
5. I often notice small sounds when others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
6. I usually notice car number plates or similar strings of information.	definitely agree	slightly agree	slightly disagree	definitely disagree
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.	definitely agree	slightly agree	slightly disagree	definitely disagree
8. When I'm reading a story, I can easily imagine what the characters might look like.	definitely agree	slightly agree	slightly disagree	definitely disagree
9. I am fascinated by dates.	definitely agree	slightly agree	slightly disagree	definitely disagree
10. In a social group, I can easily keep track of several different people's conversations.	definitely agree	slightly agree	slightly disagree	definitely disagree
11. I find social situations easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
12. I tend to notice details that others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
13. I would rather go to a library than a party.	definitely agree	slightly agree	slightly disagree	definitely disagree
14. I find making up stories easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
15. I find myself drawn more strongly to people than to things.	definitely agree	slightly agree	slightly disagree	definitely disagree
16. I tend to have very strong interests which I get upset about if I can't pursue.	definitely agree	slightly agree	slightly disagree	definitely disagree
17. I enjoy social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
18. When I talk, it isn't always easy for others to get a word in edgeways.	definitely agree	slightly agree	slightly disagree	definitely disagree
19. I am fascinated by numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree

	agree	agree	disagree	disagree
20. When I'm reading a story, I find it difficult to work out the characters' intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
21. I don't particularly enjoy reading fiction.	definitely agree	slightly agree	slightly disagree	definitely disagree
22. I find it hard to make new friends.	definitely agree	slightly agree	slightly disagree	definitely disagree
23. I notice patterns in things all the time.	definitely agree	slightly agree	slightly disagree	definitely disagree
24. I would rather go to the theatre than a museum.	definitely agree	slightly agree	slightly disagree	definitely disagree
25. It does not upset me if my daily routine is disturbed.	definitely agree	slightly agree	slightly disagree	definitely disagree
26. I frequently find that I don't know how to keep a conversation going.	definitely agree	slightly agree	slightly disagree	definitely disagree
27. I find it easy to "read between the lines" when someone is talking to me.	definitely agree	slightly agree	slightly disagree	definitely disagree
28. I usually concentrate more on the whole picture, rather than the small details.	definitely agree	slightly agree	slightly disagree	definitely disagree
29. I am not very good at remembering phone numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
30. I don't usually notice small changes in a situation, or a person's appearance.	definitely agree	slightly agree	slightly disagree	definitely disagree
31. I know how to tell if someone listening to me is getting bored.	definitely agree	slightly agree	slightly disagree	definitely disagree
32. I find it easy to do more than one thing at once.	definitely agree	slightly agree	slightly disagree	definitely disagree
33. When I talk on the phone, I'm not sure when it's my turn to speak.	definitely agree	slightly agree	slightly disagree	definitely disagree
34. I enjoy doing things spontaneously.	definitely agree	slightly agree	slightly disagree	definitely disagree
35. I am often the last to understand the point of a joke.	definitely agree	slightly agree	slightly disagree	definitely disagree
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.	definitely agree	slightly agree	slightly disagree	definitely disagree
37. If there is an interruption, I can switch back to what I was doing very quickly.	definitely agree	slightly agree	slightly disagree	definitely disagree
38. I am good at social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree

39. People often tell me that I keep going on and on about the same thing.	definitely agree	slightly agree	slightly disagree	definitely disagree
40. When I was young, I used to enjoy playing games involving pretending with other children.	definitely agree	slightly agree	slightly disagree	definitely disagree
41. I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).	definitely agree	slightly agree	slightly disagree	definitely disagree
42. I find it difficult to imagine what it would be like to be someone else.	definitely agree	slightly agree	slightly disagree	definitely disagree
43. I like to plan any activities I participate in carefully.	definitely agree	slightly agree	slightly disagree	definitely disagree
44. I enjoy social occasions.	definitely agree	slightly agree	slightly disagree	definitely disagree
45. I find it difficult to work out people's intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
46. New situations make me anxious.	definitely agree	slightly agree	slightly disagree	definitely disagree
47. I enjoy meeting new people.	definitely agree	slightly agree	slightly disagree	definitely disagree
48. I am a good diplomat.	definitely agree	slightly agree	slightly disagree	definitely disagree
49. I am not very good at remembering people's date of birth.	definitely agree	slightly agree	slightly disagree	definitely disagree
50. I find it very easy to play games with children that involve pretending.	definitely agree	slightly agree	slightly disagree	definitely disagree

**Developed by:
The Autism Research Centre
University of Cambridge**

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Appendix E: Intuitive Physics Test (Baron-Cohen, Wheelwright, Spong, Scahill & Lawson, 2001).

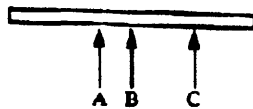
[Downloaded from <http://www.autismresearchcentre.com/tests/default.asp>; October, 2005. Sample page only provided]

This section aims to find out whether you can easily understand how things work and function.

Each question has a diagram by it, from which the answer can be worked out. After each question there is a choice of answers. Only one is correct. When you think you have found the correct answer, please indicate your choice by putting a circle around it. An example is shown below.

The section should not take any more than 10 minutes. Please try to answer all the questions as quickly and as accurately as you can, and then enter the total time taken to complete this section in the box at the end.

Example



Which arrow will balance the beam?
 (a) A (b) B (c) C (d) all equal

NOTE THE TIME BEFORE YOU START!

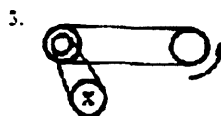
Questions



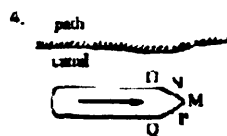
If the wheel rotates as shown, P will
 (a) move to the right and stop
 (b) move to the left and stop
 (c) move to and fro
 (d) none of these



When the two screws are turned the same amount as shown, the ball will move towards
 (a) F (b) G (c) H (d) J (e) K



Which way does wheel X move?
 (a) either (b) (c) (d) stays still



To move the boat easily in the direction shown, the rope would be best attached to
 (a) M (b) N (c) O (d) P (e) Q

APPENDIX F: AQ Subscale Statistics (Experiment 4)

Group	n	AQ subscale	Mean (SD)	Range
Female	57	Social Skills	1.21 (1.74)	0 – 10
		Attention Switching	3.67 (1.84)	0 – 8
		Attention to Detail	4.18 (2.32)	0 – 8
		Communication	2.33 (1.74)	0 – 9
		Imagination	1.74 (1.61)	0 – 7
		Total	11.26 (2.47)	2 – 27
Male	48	Social Skills	1.73 (1.66)	0 – 6
		Attention Switching	4.10 (1.86)	0 – 9
		Attention to Detail	3.79 (1.79)	0 – 8
		Communication	2.17 (2.05)	0 – 9
		Imagination	2.52 (1.73)	0 – 6
		Total	14.31 (5.79)	3 – 27
Total	105	Social Skills	1.45 (1.72)	0 – 10
		Attention Switching	3.87 (1.85)	0 – 9
		Attention to Detail	4.00 (2.17)	0 – 8
		Communication	2.26 (1.88)	0 – 9
		Imagination	2.10 (1.70)	0 – 7
		Total	13.67 (5.50)	2 – 27

APPENDIX G: AQ Subscale Score/Intuitive Physics Correlations by Gender (Experiment 4c)

Group	n	AQ subscale	PPMC (<i>r</i>)
Female	57	Social Skills	.03
		Attention Switching	.06
		Attention to Detail	.02
		Communication	.07
		Imagination	.05
		Total	.08
Male	48	Social Skills	.05
		Attention Switching	-.07
		Attention to Detail	.01
		Communication	.01
		Imagination	.25
		Total	.07
Total	105	Social Skills	.07
		Attention Switching	.02
		Attention to Detail	-.01
		Communication	.03
		Imagination	.20*
		Total	.10

* Correlation is significant at the 0.05 level (2-tailed).

APPENDIX H: AQ Subscale Score/Intuitive Physics Correlations by AQ Group (Experiment 4c)

AQ Group	n	AQ subscale	PPMC (r)
Low	12	Social Skills	-.21
		Attention Switching	.22
		Attention to Detail	.00
		Communication	-.10
		Imagination	-.36
		Total	.10
Medium	80	Social Skills	.08
		Attention Switching	-.08
		Attention to Detail	.06
		Communication	-.05
		Imagination	.23*
		Total	.11
High	13	Social Skills	-.06
		Attention Switching	.19
		Attention to Detail	-.63*
		Communication	.31
		Imagination	.11
		Total	-.22
Total	105	Social Skills	.07
		Attention Switching	.02
		Attention to Detail	-.01
		Communication	.03
		Imagination	.20*
		Total	.10

* Correlation is significant at the 0.05 level (2-tailed).

APPENDIX I: AQ Subscale Statistics (Experiment 5)

Group	n	AQ subscale	Mean (SD)	Range
Female	104	Social Skills	2.19 (2.00)	0 – 8
		Attention Switching	4.60 (2.09)	1 – 10
		Attention to Detail	5.42 (2.05)	1 – 10
		Communication	2.00 (1.53)	0 – 6
		Imagination	2.50 (1.54)	0 – 8
		Total	16.71 (5.07)	7 – 31
Male	61	Social Skills	2.31 (2.09)	0 – 9
		Attention Switching	4.87 (1.78)	2 – 9
		Attention to Detail	5.80 (2.40)	1 – 10
		Communication	2.98 (1.84)	0 – 8
		Imagination	2.95 (2.06)	0 – 8
		Total	18.92 (6.15)	10 – 40
Total	165	Social Skills	2.24 (2.03)	0 – 9
		Attention Switching	4.70 (1.98)	1 – 10
		Attention to Detail	5.56 (2.18)	2 – 10
		Communication	2.36 (1.71)	0 – 8
		Imagination	2.67 (1.76)	1 – 8
		Total	17.53 (5.58)	7 – 40

APPENDIX J: SCQ SCORES FOR PARTICIPANTS WITH ASD (EXPERIMENT 6)

Diagnostic Group	Participant	SCQ Scores
<i>Asperger Syndrome/ PDD-NOS</i>	1	32
	2	20
	3	23
	4	28
	5	13
	6	19
	7	20
	8	34
	9	27
	10	22
	11	23
	<i>Mean</i>	23.72
<i>Autism</i>	1	34
	2	17
	3	24
	4	26
	5	27
	6	33
	7	35
	8	32
	<i>Means</i>	28.5
Total	19	25.74

