EXPLORING SPEECH PROCESSING IN HIGH-FUNCTIONING ADULTS WITH AUTISM SPECTRUM DISORDERS: THE COGNTIVE, BEHAVIOURAL AND CLINICAL CORRELATES ASSOCIATED WITH ATYPICAL AUDITORY PROCESSING

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CERTIFICATION

I certify that the work presented in this thesis is my own.

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DEDICATION

I dedicate this thesis to my mother and best friend. Without her constant, love, support and belief in me I would not have been able to accomplish everything I have.

ABSTRACT

Although high-functioning individuals with Autism Spectrum Disorders (ASD) develop a range of language skills, results from both behavioural and neuroimaging studies suggest that speech perception is atypical. Previous research carried out with children with ASD has revealed enhanced sensitivity to the psychoacoustic qualities of speech, but the extent that this is characteristic of adults has yet to be investigated. Indeed, little is known about the impact of atypical auditory processing on speech perception in intellectually high-functioning adults. The aim of this thesis is to identify any specific difficulties in speech perception and to investigate potential links between these and the social and communication deficits and sensory abnormalities characterising ASD.

The studies described in this thesis test the effects of atypical perceptual processing using auditory Stroop paradigms and same-different pitch detection tasks and also address questions about how temporal and prosodic manipulations influence memory encoding and retrieval in sentence repetition tasks. The main findings showed that whilst adults with ASD were affected by prosodic and temporal manipulations to speech during higher-order tasks, this was similar to that observed in typically developing adults. Furthermore, adults with ASD did not reveal superior speech pitch discrimination previously observed in children with ASD. Taken together these findings suggest that high-functioning adults with ASD respond to perceptual manipulations carried out on speech stimuli in similar ways to typical controls. However, correlation and regression analyses carried out on the cognitive, behavioural and clinical data suggest that different mechanisms underlie perceptual and recall performance in the two groups and intelligence and symptom severity appear to be associated with the extent that atypical perception, encoding and recall of speech stimuli are manifested.

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CHAPTER 1: GENERAL INTRODUCTION

Historical Overview of ASD

The term 'autistic' was first used by Kanner (1943) to describe a group of 11 children with "autistic disturbance of affective contact". In his article he described these individuals as being characterised by a profound lack of social engagement, severe communication problems, unusual responses to their environment and resistant to change. A year later Asperger (1944/1991) described a syndrome he called "autistic psychopathology" characterised by social abnormalities. Written in German, his description remained relatively unknown until it was described by Wing (1981) and later became the basis for Asperger syndrome (AS) in the DSM-IV-TR (2000). Rutter (1978) further refined Kanner's original description, outlining four essential features: onset prior to 30 months, impaired social development, impaired communicative development and unusual behaviours or 'insistence on sameness'. Rutter's description provided the basis of the first official categorical definition of Autism that appeared in the third version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-III) under the name 'Infantile Autism' (1980). However the description was restrictive, individual symptoms were not outlined and in order for a diagnosis to be made all criteria had to be met (Volkmar, 1998). The DSM-III-R (1987) consisted of major changes to the conceptualisation of what was then called "autistic disorder", as it outlined specific behaviours and contained guidelines for the number and pattern of symptoms needed for a diagnosis to be made. Importantly, these changes increased the reliability of the diagnosis and the disorder was recognised as a pervasive, life-long condition. Although there were few changes in the DSM-IV (1998), Asperger syndrome was included for the first time and the diagnostic criteria for the two disorders is similar to what is currently used in the DSM-IV-TR (2000) (Goldstein & Ozonoff, 2008).

Conceptualisations of autism have continuously evolved since the first description of the disorder in 1943, which is reflective of the inherent difficulties in defining and classifying a disorder that is heterogeneous by nature. Current diagnostic criteria within the DSM-IV-TR (2000) define Autism Spectrum Disorders (ASD) as neurodevelopmental disorders characterized by impairments across several domains. These abnormalities form three distinct clusters: (1) impairments in social interaction, (2) deficits in communication and language abilities and (3) deficits in cognitive flexibility represented by restricted and repetitive interests. Within each cluster, the DSM-IV-TR describes a set of specific behaviours or symptoms. In order for individuals to receive a diagnosis of autism they need to present with at least two behaviours from the social cluster and one each from the communication and stereotyped behaviours clusters. Additionally, a diagnosis requires delays or abnormal functioning prior to age 3 in at least one of the three domains. Also included in the ASD classification is Asperger syndrome, a disorder that is characterised by similar diagnostic criteria to autism but is not associated with a delay in adaptive behaviour, language or cognitive development (Goldstein & Ozonoff, 2008). As a spectrum disorder, ASD is heterogeneous in nature and research has shown that the core symptoms vary in severity between and within individuals and over time (Helt et al., 2008; Jones & Klin, 2009). Currently the prevalence rates are estimated at around 100 per 10,000 or 1% of the child population (Rice, 2009). A similar prevalence rate has been found in adults in the UK from a household survey in which 1.8% of males and 0.8% had received diagnosis (Brugha, Bankart, et al., 2011).

The extreme heterogeneity seen in ASD is one of the many factors fuelling the significant diagnostic changes that will be made within the upcoming DSM-5 (http://www/dsm5.org). The new Diagnostic and Statistical Manual of Mental Disorders takes a more dimensional approach to the classification of ASDs and formally acknowledges that autism is represented by a complex set of behaviours that are believed to derive from a currently unknown set of neurological causes (Lord & Jones, 2012). Instead of a 3-dimensional approach, the DSM-5 proposes 2 dimensions, social/communication deficits and fixed interests/repetitive behaviours. This change reflects an increased understanding of the many difficulties inherent in attempts to separate social and communicative behaviours. In order to receive a diagnosis individuals will be required to meet all three of the behavioural criteria laid out in the social/communication dimension as well as at least 2 of the 4 behaviours described in the restricted and fixed interests dimension. Importantly, unusual sensory behaviours will be formally included under the restricted and fixed interest domain, highlighting the growing recognition of the prevalence of sensory abnormalities experienced by individuals with ASD. Furthermore, a diagnosis requires that the combined symptoms limit the everyday functioning of the individual. Another significant change to the diagnostic criteria will involve the removal of conditions such as Asperger syndrome, which will instead be replaced with a more detailed classification of the “Severity level for ASD”. Individuals will receive a severity rating for each domain indicating whether they “require support”, “require substantial support”, or “require very substantial support” (http://www/dsm5.org).

The proposed changes to diagnostic criteria in the DSM-5, especially the decision to remove the distinction between Asperger Syndrome, PDD-NOS and Autism, have caused researchers to raise concerns over the potential impact this will have on the conceptualisation of ASD (Singer, 2012). In particular, recent research has suggested that with the DSM-5 only about 60% of those currently diagnosed with an ASD will still meet diagnostic criteria (McPartland, Reichow & Volkmar, 2012; Worley & Matson, 2012; Mandy, Charman, Gilmour & Skuse, 2011; Taheri & Perry, 2012). However, critics of these studies have noted that these studies are retrospective, often based on questionnaire data and do not take into account the possible increase in diagnostic rates with the inclusion of new symptoms such as sensory abnormalities (Lord & Jones, 2012). Although much debate has surrounded the proposed diagnostic and classification changes of ASD within the DSM-5, according to Swedo and colleagues (2012) the number of individuals receiving a diagnosis is not expected to change and individuals with existing diagnoses should not need to be re-diagnosed. This assertion is further supported by a recent study with a more extensive data set that found that the proposed criteria are no less sensitive than those in the DSM-IV-TR (Huerta, Bishop, Duncan, Hus & Lord, 2012). Whilst it is undeniable that the DSM-V will influence our understanding of ASD, the specific impact of these changes will remain relatively unclear until the changes are officially adopted and utilised by clinicians and therefore the present thesis was conducted and interpreted based on the current DSM-IV-TR criteria.

The current diagnostic criteria set out in the DSM-IV-TR further defines the communication cluster in ASD, specifying that a significant delay in language or a clear deficit in the ability to carry on a conversation is essential (American Psychiatric Association, 2000). This is not surprising as Kanner noted a host of communication abnormalities in his original description of Autism. Only 8 of the 11 children he described were verbal and their speech was noted to contain several unusual characteristics. In particular, he noted pronoun reversal, echolalia, the use of neologisms and abnormal prosody. More recently, researchers have estimated that between 25-50% of individuals with ASD never acquire functional language (Gillberg & Coleman, 2000; Klinger, Dawson & Renner, 2002). Many verbally able individuals with ASD present with a history of language delay (Baird et al., 2008), but are fluent by later school years (Smith, Mirenda & Zaidman-Zait, 2007). However, Frith and Happé (1994) suggest that many individuals with ASD and seemingly good language skills have difficulty using language for the purpose of communicating. It has also been suggested that individuals with ASD primarily use language for requests or protests and rarely use communication acts to facilitate social interaction or establish joint attention (Mundy & Stella, 2000). Although the presentation of language impairments is incredibly diverse across the population, they appear to be a key feature in predicting the course the disorder will take in an individual (Rutter, 1970; Venter, Schopler & Lord, 1992).

While not specifically mentioned in the DSM-IV-TR diagnostic criteria, sensory processing abnormalities across modalities are frequently noted in individuals with ASD (Leekam, Nieto, Libby, Wing & Gould, 2007). Indeed, Kanner (1943) and Asperger (1944/1991) noted abnormal responses to sensory stimulation in their original reports (Minshew & Hobson, 2008). More recently these abnormalities have been noted in empirical studies as well as autobiographical accounts (i.e. Grandin, 1992). These abnormalities have an estimated frequency of 60% to 90% (Kern et al., 2007) and can include atypical auditory processing, insensitivity to pain and atypical responses to visual and olfactory stimuli (Gerland, 2003). Furthermore, these difficulties are apparent across the spectrum, including Asperger syndrome (Dunn, Myles & Orr, 2002). Despite the high prevalence of sensory abnormalities, Rogers and Ozonoff (2005) noted that there is little empirical work that offers an explanation of these abnormalities in ASD. However, there is an increasing consensus that such abnormalities are likely to have an impact on the development of social and cognitive abilities due to an increased avoidance of social stimuli (Ben-Sasson et al., 2007). This avoidance could easily contribute to delayed language onset in autism (Luyster, Kadlec, Carter & Tager-Flusberg, 2008). Thus, this postulation gives rise to the question of what impact auditory processing abnormalities may have on the development of language in ASD.

Atypical Auditory Processing

Research has shown atypical neural processing of auditory information in individuals with ASD. Such effects are most powerfully observed in studies including speech and language stimuli. Two recent review articles (Haesen, Boets & Wagemans, 2011; O'Connor, 2012) provide an in-depth review of the behavioural, neurological and neuroanatomical research on auditory processing in ASD. Overall these reviews provide evidence for a diverse range of auditory processing abnormalities in this group. For example, atypical orientation to auditory stimuli, perception of pure tones, loudness, complex stimuli, prosody and processing auditory information in noise have all been demonstrated. An overview of the relevant auditory processing literature will be provided below and a more in-depth discussion of specific studies will be provided in the relevant experimental chapters of this thesis.

In the auditory modality, behavioural studies of ASD have shown enhanced pitch discrimination and memory for simple and complex tones (Applebaum, Egel, Koegel & Imhoff, 1979; Bonnel et al., 2003, 2010; Heaton, 2003, 2005; Heaton, Hermelin & Pring, 1998, 1999; Heaton, Hudry, Ludlow & Hill, 2008; Heaton, Williams, Cummins & Happé, 2008; Jones et al., 2009; Mottron, Peretz & Menard, 2000; O'Riordan & Passetti, 2006). The original studies were based on case study reports of exceptional pitch discrimination and memory in autistic savants. Heaton et al. (1998) identified superior pitch identification and memory for single notes in children with autism and suggested these abilities were indicative of absolute pitch abilities in musically naïve children. Similar results were found for pitch identification and memory of tones embedded in musical cords in children with autism (Heaton, 2003). Subsequent studies have investigated other aspects of pitch processing including discrimination and categorisation. Heaton (2009) compared the performance of a child with Asperger syndrome and age and IQ matched peers on a series of discrimination tasks involving melodic or isolated pitch changes. Although the child with AS performed similarly to controls on trials involving melodic changes, he exhibited superior performance when identifying isolated pitch changes. Mottron et al. (2000) replicated these findings with a group of high-functioning adolescents with autism. Further studies focused on the identification of isolated pure and complex tone stimuli in same/different pitch discrimination tasks and uncovered enhanced pitch discrimination in children with ASD (Bonnel et al., 2003; Heaton, 2005; O'Riordan & Passetti, 2006). Evidence suggests, however, that enhanced pitch abilities are not as prevalent in adolescents and adults with ASD and that these abilities are often associated with increased levels of language impairment. Jones et al. (2009) reported enhanced pitch discrimination of pure tones in a subgroup of adolescents with ASD characterised by higher IQs and delayed language onset. Additionally, Bonnel et al. (2010) noted that superior pitch discrimination seemed to be characteristic of adults with autism, but not adults with a diagnosis of Asperger syndrome. Furthermore, a subgroup of ASD adolescents with superior pitch discrimination identified in a study by Heaton, Williams, et al. (2008) were characterised by a larger range of language related impairments. Taken together, the results from Jones et al. (2009), Bonnel et al. (2010) and Heaton, Williams, et al. (2008) suggest that atypical pitch processing in adolescents and adults with ASD could be related to language level and development.

There have also been numerous electrophysiological and neuroimaging studies, many of which tested perception of pitch change, that further support the suggestion that enhanced processing of low complexity auditory stimuli is characteristic of individuals with ASD. Earlier studies demonstrated that the cortical response evoked by an unexpected novel auditory stimulus among familiar sounds is smaller in children with autism than in controls (Courchesne, Kilman, Galambos & Lincoln, 1984; Lincoln, Courchesne, Harms & Allen, 1993). More recently, studies focusing on abnormal mismatch negativity (MMN) in ASD have observed larger amplitudes and earlier latencies in comparison to typically developing controls, which provide further evidence for superior performance on low-level auditory tasks (Ferri et al., 2003; Lepistö et al., 2005, 2008). Similar studies have focused on children with Asperger syndrome and have observed larger MMN amplitudes in these children relative to age matched typically developing controls (Kujala et al., 2007, 2010; Lepistö et al., 2006). Additionally, children with ASD showed abnormal MMNs in response to non-speech pitch changes. In comparison with typical controls, children with autism showed significantly shorter latencies (Gomot et al., 2011; Gomot, Giard, Adrien, Barthélémy & Bruneau, 2002). Taken together, these results suggest that individuals with ASD, including those on the lower functioning end of the spectrum, have higher levels of neurological reactivity to pitch deviance.

Several behavioural studies have also examined perceptual processing of the acoustic features of speech in individuals with ASD. Järvinen-Pasley and Heaton (2007) compared pitch discrimination abilities in children with ASD and their typically developing peers on pairs of same or different music, speech and music/speech stimuli. The results showed that whilst as a group children with ASD demonstrated similar pitch discrimination skills across all three stimulus types, pitch discrimination on the two stimulus types involving speech content showed dramatic decreases for the typical control group. These findings led the researchers to suggest that auditory processing may be characterised by reduced domain specificity in ASD. An alternative explanation is that these results could reflect a weakened semantic processing bias. Järvinen-Pasley, Pasley and Heaton (2008) and Järvinen-Pasley, Wallace, Ramus, Happé & Heaton (2008) examined contour processing of sentences that were accompanied by visual representations of the pitch contours or the semantic content of the sentences in children with ASD and matched controls. Although both groups' primary processing mode was linguistic, as evidenced by their selection of the semantic rather than the perceptually matched visual stimuli, the tendency to process the stimuli linguistically rather than perceptually was significantly weaker in individuals with ASD. These findings were further supported in subsequent studies by the same research group that demonstrated superior processing of the perceptual components of speech in the group of children with HFA and AS, in comparison with their typically developing peers. Speech has many constantly fluctuating aspects, including pitch, tempo and timbre. If these perceptual aspects of speech are more salient than its linguistic content, the individuals' understanding may well be compromised.

In contrast with enhanced perceptual functioning reported in studies assessing the processing of simple, low-level auditory information, studies utilizing more complex stimuli have reported atypical performance that is more consistent with impairments observed in other studies testing orientation to auditory stimuli (Dawson, Meltzoff, Osterling, Rinaldi & Brown, 1998; Dawson et al., 2004; Kuhl, Coffey-Corina, Padden & Dawson, 2005; Paul, Chawarska, Fowler, Cicchetti & Volkmar, 2007). Dawson et al. (2004) examined orientation to social and non-social auditory stimuli in 3-4 year old children with ASD and mental and age-matched controls and found that children with ASD were less likely to orient to auditory stimuli in general, with the most abnormal orientation seen in response to social stimuli. These findings were replicated by Dawson et al. (1998) with 5-6 year old children with ASD. Kuhl et al. (2005) further examined auditory orientating behaviours in response to motherese and synthesized non-speech analogues in toddlers with ASD. Their results revealed reduced orientation to motherese in toddlers with ASD. This finding was replicated by Paul et al. (2007) who also found that children with ASD who were more likely to orient to motherese had better language skills.

A combination of behavioural (Alcántara, Weisblatt, Moore & Bolton, 2004; Groen, Zwiers, van der Gaag & Buitelaar, 2008), electrophysiological (Ceponiene et al., 2003; Kujala, Lepistö, Nieminen-von Wendt, Näätänen & Näätänen, 2005) and brain imaging (Boddaert et al., 2003, 2004; Gervais et al., 2004) research demonstrates that increases in complexity in auditory information are associated with diminished performance on behavioural tests and reduced functional brain activity in ASD participant groups. At the behavioural level Alcántara et al. (2004) found a reduced ability to perceive speech in noise in individuals with HFA and AS. The authors interpreted this finding as a reduced ability to integrate information gained during glimpses present in temporal dips in noise, in individuals with ASD. Groen et al. (2008) aimed to replicate Alcántara et al.'s findings using two-syllable words embedded in spectral and temporal background noises. Whilst no significant group differences were reported in the study, adolescents with HFA showed significantly less advantages on conditions with temporal dips, suggesting that they were less able to integrate information gained from temporal dips in background noise.

Evidence from electrophysiological studies further support difficulties processing complex stimuli in individuals with ASD. Several MMN studies found that children with AS show longer MMN latencies relative to controls in response to infrequent changes to consonant and vowel stimuli (Jansson-Verkasalo et al., 2003; Lepistö et al., 2006).

Research with AS adults also demonstrated similar findings of delayed MMN latencies and smaller amplitudes relative to typically developing adults on tasks involving changes in vocal prosody (Kujala et al., 2005). Impaired processing of auditory stimuli has also been found using more complex oddball paradigms (Dunn, Gomes & Gravel, 2008; Kujala et al., 2010; Lepistö et al., 2009). These results are further supported by ERP studies examining the P3a subcomponent that indicates attention switching. Ceponiene et al. (2003) failed to identify the P3a component when listening to vowel stimuli during an oddball task in children with ASD compared with their age-matched peers. Furthermore, Lepistö et al. (2006) observed smaller P3a amplitudes when listening to vowel, but not non-speech stimuli in children with AS relative to typically developing controls. These findings suggest that some of the difficulties they experience when processing complex stimuli may occur at the attentional rather than the sensory level.

Finally, evidence from brain imaging studies suggests that diminished auditory processing of complex stimuli may stem from atypical or reduced activation of the left frontal temporal regions that may also be associated with enhanced activation of right frontal temporal regions (Boddaert et al., 2003, 2004; Gomot et al., 2006; Groen et al., 2009; Müller et al., 1999; Redcay & Courchesne, 2008; Tesink et al., 2009; Wang, Lee, Sigman & Dapretto, 2006). Gervais et al. (2004) found that brain regions that are typically activated in response to vocal stimuli in typically developing individuals are not activated to the same extent in adults with ASD. This adds further support to the suggestion that these individuals process complex stimuli in an atypical fashion. Flagg, Cardy, Roberts and Roberts (2005) reported a reverse maturational pattern for lateralization in children with ASD who also had language impairments indicating that they matured towards right hemisphere dominance for vowel processing rather than the left hemisphere dominance seen in their typically developing peers. Redcay and

Courchesne (2008) further confirmed atypical lateralization during speech perception in 2-3 year old children with ASD. Unlike typically developing children who were more likely to recruit their left hemisphere during speech perception, individuals with ASD recruited their right hemisphere more often. Boddaert et al. (2003, 2004) suggested that this abnormality may be more prominent when processing the temporal aspects of complex auditory stimuli. This is because right rather than left hemisphere patterns of cortical activation are typically observed during the processing of temporally complex speech-like stimuli.

Taken together, the behavioural, neurological and neuroanatomical research provides clear evidence for atypical auditory processing in individuals with ASD. Behavioural and electrophysiological studies have reported enhanced pitch processing abilities for pure and complex tones in individuals with ASD, although it appears that this ability may be more widespread in childhood and confined to subgroups of adolescents and adults with ASD. Research has also identified enhanced discrimination of the perceptual components of complex musical and non-musical stimuli, including speech in individuals with ASD. Whilst many studies have demonstrated superior auditory discrimination, abnormalities in orienting to auditory stimuli are more consistent with attentional impairments and evidence from electrophysiological and brain-imaging studies suggest that diminished auditory processing of more complex auditory stimuli is characteristic in individuals with ASD.

Autistic Traits as a Continuum

Behaviours that were once considered to be characteristic of a rare group of individuals are now conceptualised as part of a broad range of individual differences that are distributed throughout the general population (Constantino & Todd, 2003). Researchers and clinicians have increasingly embraced the idea that as a spectrum disorder, ASD lies on a continuum that extends into the typically developing population. Thus, autistic traits are exhibited by typically developing individuals, albeit at lower levels of severity. Given this assertion, it is plausible to suggest that some of the behaviours observed in individuals with ASD on experimental tasks may also be evident, albeit to a lesser extent, in typically developing individuals who possess higher levels of autistic traits. The Adult Autism Spectrum Quotient (AQ) (Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001) has been utilised in numerous studies examining the effects of high levels of autistic traits on behaviour in typically developing populations. High scores on the AQ in the typical population have been shown to be strongly related to clumsiness (Moruzzi, Ogliari, Ronald, Happé & Battaglia, 2011), lower relationship satisfaction in husbands (Pollmann, Finkenauer & Begeer, 2010) and even gender identity disorder in females (Jones et al., 2012).

Research utilizing this test to investigate auditory and language processing have shown associations between autistic traits in the typical population and atypical auditory processing (Gomot, Belmonte, Bullmore, Bernard & Baron-Cohen, 2008; Stewart & Ota, 2008). In a behavioural study examining the extent that typically developing adults can make phonetic categorization shifts to disambiguate speech-like stimuli Stewart & Ota (2008) found that higher levels of autistic traits were associated with a reduced influence from lexical information during speech perception. This effect appeared to be most related to levels of autistic traits on the 'attention switching' and 'imagination' components of the AQ. Gomot et al. (2008) used functional neuroimaging to examine which brain regions were involved in the detection of novel auditory stimuli in children with and without ASD. Their results revealed that children with ASD exhibited superior discrimination on the task and also recruited a larger network of brain areas during auditory detection. Within the typically developing group, associations were found between higher levels of autistic traits and increased neural network activation in response to novel stimuli. This study was important in extending the continuum approach to ASD by investigating brain functioning. Furthermore, Lindell and Withers (2008) found that typically developing individuals with low levels of autistic traits demonstrated clear left hemisphere dominance for language, whereas those with higher levels of autistic traits exhibited reduced left hemisphere dominance similar to that observed in individuals with ASD. Research has also demonstrated associations between autistic traits and neural structure and function within other domains. Hagen et al. (2011) discovered an association between higher AQ scores in typically developing adults and decreased white matter in the posterior superior temporal sulcus that is implicated in processing social stimuli. These findings suggest that the inclusion of typically developing individuals with higher levels of autistic traits in the control group is a fruitful way to increase our understanding of the ASD continuum.

Theoretical Models of Information Processing in Autism

Current theoretical models of cognition in autism are relevant to questions about auditory processing. The first of these models, the weak central coherence theory (WCC) (Frith, 2003; Happé, 1999; Happé & Frith, 2006) suggests that individuals with autism demonstrate an impaired ability to process information at the global level. Thus, any given stimulus is likely to be processed in a detail-focused style. This means that constituent (local) parts are assessed within their own context, rather than being processed in conjunction with other constituents in a (global) whole. According to this theory, persons with ASD often demonstrate strengths on perceptual tasks in which the propensity to process stimuli at a global level would hamper performance. Foxton et al.'s (2003) findings supported the WCC theory in an experiment that required participants to match local pitch direction changes amid global interference. They found that participants with ASD obtained higher scores than controls on the matching tasks that involved structural interference at the global level, indicating that their impaired ability to assess the stimuli globally resulted in what appeared to be an increased differentiation of local features.

In contrast, the enhanced perceptual functioning (EPF) model (Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert & Burack, 2006) argues that increased performance on perceptual tasks is due to ASD individuals' enhanced local processing abilities rather than a global deficit. Thus, while such individuals can process information globally, their more specialised local perception system allows them more flexibility in the activation of different processing levels than controls in using one processing level over another. Mottron et al. (2000) demonstrated this concept of flexibility through a series of auditory tasks in which children with ASD and matched controls were required to make "same/different" discriminations while information at the local and global levels was systematically manipulated. Their findings supported the EPF model by establishing that the ASD group did not show any deficit on conditions measuring global processing, while at the same time uncovering superior performance on tasks focused on testing local processing.

Arguably, the WCC theory and EPF model share many similarities and it is often unclear if there is a true distinction between the two or whether the varying accounts are products of experimental design alone (Kellerman, Fran & Gorman, 2005). Both posit that cognition in autism is perceptually and locally biased, whether due to relatively overdeveloped perceptual processing (EPF) or a deficit in global processing (WCC). The importance of these theories, therefore, is that they attempt to account for abnormalities within the local and/or global processing systems that do appear to characterise individuals with ASD. The idea of enhanced perceptual processing could offer an explanation for findings of enhanced pitch sensitivity or reports of hypersensitivity to sound, whereas a deficit in global processing would better address ASD individuals' diminished ability to process auditory information at a functional level (Kellerman et al., 2005).

An interesting account of auditory processing in ASD has recently been proposed by Samson, Mottron, Jemel, Belin and Ciocca (2006). The neural complexity hypothesis (NCH) suggest that deficits in auditory processing in ASD increase in line with increasing complexity in stimuli. Considered within the context of Johnson, Nicol and Kraus's (2005) suggestion that one neural stream processes complex components of the speech signal, rapidly changing formants, etc. whilst the other processes relatively sustained pitch information (e.g. prosody), a complexity explanation for speech processing abnormalities in ASD is highly plausible. According to the NCH, individuals with ASD should show superior performance, relative to their typically developing peers, on tasks involving pure tone discrimination. However, they should also experience increased difficulty relative to typical individuals when processing spectrally or temporally complex stimuli. Less complex pure tone auditory stimuli is processed within the primary auditory cortical area A1 that requires relatively little neuro-integrative processing. As stimuli become more complex, more extensive neural circuitry is required (i.e. primary and associative auditory cortices, A1 and A2), which leads to poorer performance in individuals with ASD.

Autism Spectrum Disorders in Adults

Although ASD is a pervasive disorder that persists throughout the lifespan, much has to be learned about the developmental trajectory and presentation of the core deficits in adolescents and adults with this disorder (Seltzer et al., 2003). As previously discussed, the term 'autistic' was first used in 1943 and became more common in the 1960s. Thus, the first groups of children identified with the disorder have only recently begun to enter old age (Happé & Charlton, 2012). Howlin and Moss (2012) and Mukaetova-Ladinska, Perry, Baron and Povey (2012) reviewed follow-up studies of adults who received their ASD diagnosis as children and highlighted the lack of clear information about the long-term outcomes for these individuals. Data from the few studies available suggests that there may be a general decrease in autistic symptomatology into adulthood, although there also appears to be a decrease in adaptive skills in these individuals (Totsika, Felce, Kerr & Hastings, 2010). Mukaetova-Ladinska et al. (2012) conducted a literature search for research published between 1946 and 2011 and noted that although nearly 18,000 studies have been published on ASD, only approximately 4,000 of these studies have focused on the adult population. Thus, whilst there is a wealth of research into the presentation of ASD in childhood, relatively little is known about changes in symptomatology overtime. This underscores the importance of research exploring ASD in adulthood.

One of the first outcome studies on individuals with ASD was conducted by Kanner (1973) who reported a generally poor outcome for 96 adults who were in their twenties and thirties. Eleven individuals were reported as having a job, 7 living independently in their own homes and only one individual was married and had a child (Howlin, Goode, Hutton & Rutter, 2004). Although early diagnosis and intervention may have led to improvements in outcomes for individuals with ASD, less than 20% are considered to have a good outcome and are living independently or semi-independently. Furthermore, within the 23 outcome studies reviewed, an average of 49% of individuals were reported to be in education or some form of work, 14% were married and 25% had at least one friend (Howlin & Moss, 2012). Thus, although research suggests that symptomatology is decreasing in adulthood, it is clear that adults with ASD experience significant psychosocial and vocational difficulties. Several factors have been found to affect the outcome of adults with ASD including intellectual ability, language development and early autistic symptomatology. In general, individuals with higher IQs (above 75), functional speech development before the age of 5 and less severe symptoms in the repetitive and fixed interests domain have reported better outcomes in adulthood (Howlin & Moss, 2012). Although interventions for children with ASD are continually increasing, very few services are available for adults. Research into the presentation of ASD in adults will not only provide a better understanding of the disorder as a whole and it's developmental trajectory, but it could also help inform the development of important services and interventions for individuals on the spectrum.

Rationale

Whilst disturbances in speech perception are likely to contribute to the communication deficits characterising Autism Spectrum Disorder (ASD), surprisingly little is known about how auditory processing abnormalities, identified in a number of electrophysiological and brain imaging, studies are manifested behaviourally in high-functioning adults with ASD. However, the importance of addressing this question is highlighted by research showing that language impairments may limit the psychosocial and vocational opportunities of intellectually able adults with ASD (Howlin, Alcock & Burkin, 2005). Well conducted research into language skills in adults with ASD may serve to increase our understanding of the contribution of sensory and perceptual difficulties to the communication deficit characterising the disorder and will also contribute to the theoretical and empirical base that informs the development of intervention services for these individuals.

One of the reasons why so little is known about language difficulties in adults with ASD is that the types of standardised language tests that provide detailed profiles across language components and are widely used to test children with language difficulties (e.g. CELF; Semel, Wiig & Secord, 1987), have yet to be developed for use with able adults with ASD. Experimental and EEG studies of language with this group have been useful in identifying difficulties in isolated aspects of speech perception, however few, if any studies have linked atypical speech perception with perceptual processing abnormalities endemic in ASD, or attempted to relate them to measures of symptom severity, using standardised diagnostic measures. Therefore a primary aim of the current thesis is to draw links between existing social and communication deficits and speech processing difficulties within the a high-functioning adult ASD group.

Aims

1. To test hypotheses about perceptual and cognitive processing, in respect to speech processing, drawn from current theories of autism.
2. To increase understanding of the heterogeneity in speech perception deficits in high-functioning adults with ASD by identifying the cognitive and behavioural correlates.
3. To contribute to the growing literature on the continuum conceptualisation of ASD by examining the effects of ASD traits on perceptual processing of speech within a typically developing population.
4. To provide behavioural data on speech processing in high-functioning adults with ASD that will inform the development of future electrophysiological and neuroimaging investigations.
5. To provide data that will be informative for professionals who deliver services to adults with Autism Spectrum Disorders.

CHAPTER 2: METHODS

SUMMARY

This chapter outlines the background measures used to assess participants' cognitive abilities, communication difficulties, sensory abnormalities and autistic traits. The matching criteria used during participant recruitment for the experimental paradigms in this thesis are also discussed. The general procedure and statistical analysis methods are detailed. Issues of statistical power and ethical considerations are also outlined and discussed.

INTRODUCTION

A primary aim of this thesis is to explore the extent to which perception of speech is disturbed within high-functioning adults with ASD and to identify any cognitive, behavioural, or clinical correlates associated with such disturbances. As stated in chapter one, the types of tests used to study language skills in children with ASD (e.g. CELF; Semel, et al., 1987) are not suitable for use with high-functioning adults with this disorder. As this is the case, speech processing was probed in a series of experimental designs, most of which were newly developed for use in the studies described in this thesis.

Detailed information about individual participants was collected prior to participation in the experimental paradigms. The language tests included in the test battery include measures of receptive vocabulary (PPVT) (Dunn & Dunn, 1997), productive vocabulary (WASI) (Wechsler, 1999) and tests that measure verbal concept formation and abstract verbal reasoning (WASI) (Wechsler, 1999). The Communication

Checklist (Bishop, Whitehouse & Sharp, 2009) yields scores for language structure and pragmatic skills. These measures as well as the Sensory Profile (Brown & Dunn, 2002), Autism Spectrum Quotient (Baron-Cohen et al., 2001) and Autism Diagnostic Observation Schedule (Lord, Rutter, DiLavore & Risi, 2001) were also obtained in order to examine the various presentation of autistic symptomatology within individuals.

Participants

19 adults with high-functioning ASD (with IQ scores of 70 or above) were recruited. Four participants were female and 15 were male. Their chronological ages ranged between 23 years 9 months and 59 years 8 months. All of the adults in the ASD group were recruited from local support groups or had previously participated in research at Goldsmiths College and City University. All ASD participants' pre-existing diagnoses were confirmed by the author using ADOS module 4. The author completed her ADOS training at Guy's Hospital in London prior to the recruitment phase of the study.

The ASD individuals who participated in the experiments described in this thesis were all living without direct support and travelled into the university for testing sessions independently. Although co-morbid developmental disorders were observed in 33.8% of a recently tested sample of children with ASD (Williams, Thomas, Sidebotham, Edmond, 2008), only two individuals reported any co-morbid diagnoses and in both cases dyslexia was identified. As previously discussed, echolalia is also often observed at early developmental stages in ASD and often is associated with increased language development and communication abnormalities. Three of the 19 ASD participants reported definite echolalia during childhood and a further 4 individuals indicated that they may have experienced mild echolalia as children. All of the ASD participants reported a minimum education level of a GCSE qualification or equivalent and some had obtained undergraduate and postgraduate degrees (table 2-1).

19 adults with typical development (controls) were group matched to the ASD group on age, gender, receptive vocabulary, working memory, as well as on verbal, performance and full scale IQ scores (see following section). Four of the participants were female and 15 were male. Their chronological ages ranged between 25 years 1 month and 52 years 8 months. Control participants were recruited through an opportunity sample. All control participants' were screened for ASD using the Autism Spectrum Quotient (Baron-Cohen et al., 2001). Scores on this test ranged from 3 to 21, which is well below the cut-off score of 32 proposed by Baron-Cohen et al. (2001).

Typically developing participants were also all living without directed support and travelled to the university independently. One individual in the control group reported a diagnosis of dyslexia and no one reported instances of echolalia during childhood. Similar to the ASD group, all of the typically developing adults had a minimum education level of a GCSE qualification or equivalent and several had obtained undergraduate and postgraduate degrees as well (table 2-1).

Table 2-1. ***Summary of participants' education levels***

	GCSE Qualification	A-Level Qualification	Some Undergraduate	Undergraduate Degree	Postgraduate Degree
ASD	4	2	3	5	5
TD	4	4	3	1	7

The two groups did not differ significantly on any of the measures that they were matched on: age, IQ, receptive vocabulary or working memory (table 2-3). Thus, it can be concluded that any group differences on the experimental tasks were not due to a difference in age, cognitive ability or working memory.

All 38 of the adults described participated in experiments one, two, three and four. However, the pilot studies for experiments two and three and experiments 5a, 5b, 6a and 6b utilised a smaller subset of participants. The constitution of these groups is reported experiment-by-experiment in the relevant chapters.

BACKGROUND MEASURES

Cognitive Correlates

Weschler Abbreviated Scales of Intelligence

The Weschler Abbreviated Scales of Intelligence (WASI) (Wechsler, 1999) was used as a measure of intellectual and cognitive functioning. The WASI is made up of four subtests with Vocabulary and Similarities resulting in a verbal IQ score (VIQ), Block Design and Matrix Reasoning producing a performance IQ score (PIQ) and their combined scores generating an individual's full-scale IQ score (FSIQ). The Vocabulary subtest that measures word knowledge is made up of 32 items in which the individual is given a word and asked to produce a verbal definition of the word. Similarities tap into verbal reasoning skills and consist of 22 items that require the individual to identify the underlying concept shared by two words. Block Design measures a number of performance abilities, including visual perception and organisation. This subtest requires individuals to replicate 13 two-dimensional patterns using two-tone cubes under timed conditions. The final subtest, Matrix Reasoning, measures visual information processing and consists of 35 items that require individuals to indicate which of five picture fragments best completes the partial picture/pattern presented. Raw scores from each subtest were converted to t-scores, ranging between 20 and 80, based on chronological age (table 2-2). T-scores for each subtest in the verbal, performance and full-scale categories were summed and converted to standardised IQ scores. ASD and TD groups were matched on their VIQ, PIQ and FSIQ scores (Fig. 2-1). These scores were also used to explore questions about the extent that performance on the experimental paradigms was associated with intellectual functioning. There was no significant difference between the two groups on their standardised scores on the WASI (Full-Scale, *t*(32.47)= -1.23, *ns*; Verbal, *t*(36)= -0.99, *ns*; Performance, *t*(36)= -1.24, *ns*) (Table 2-3).

Table 2-2. *Summary of t-scores for WASI subtests*

	ASD		TD	
	Mean (SD)	Range	Mean (SD)	Range
Vocabulary	56.76 (11.82)	23-71	59.58 (8.84)	31-70
Similarities	57.76 (9.22)	35-67	59.05 (6.18)	44-69
Block Design	57.12 (8.84)	41-70	60.74 (6.56)	49-72
Matrix Reasoning	59.94 (5.92)	49-68	60.16 (8.39)	36-70

Peabody Picture Vocabulary

The Peabody Picture Vocabulary Test (PPVT) (Dunn & Dunn, 1997) is a test of receptive vocabulary with adult norms. Individuals listened to words read by the researcher and were asked to indicate which of four pictures best depicted the words they heard. The number of correct answers given were summed into raw scores then converted into standardised scores for analysis. ASD and TD groups were matched on their PPVT standardised scores (Fig. 2-1). These scores were also used to examine whether receptive vocabulary impacted on performance on the experimental tasks. The groups did not differ on their standardised receptive vocabulary scores (*t*(36)= -0.12, *ns*) (Table 2-3).

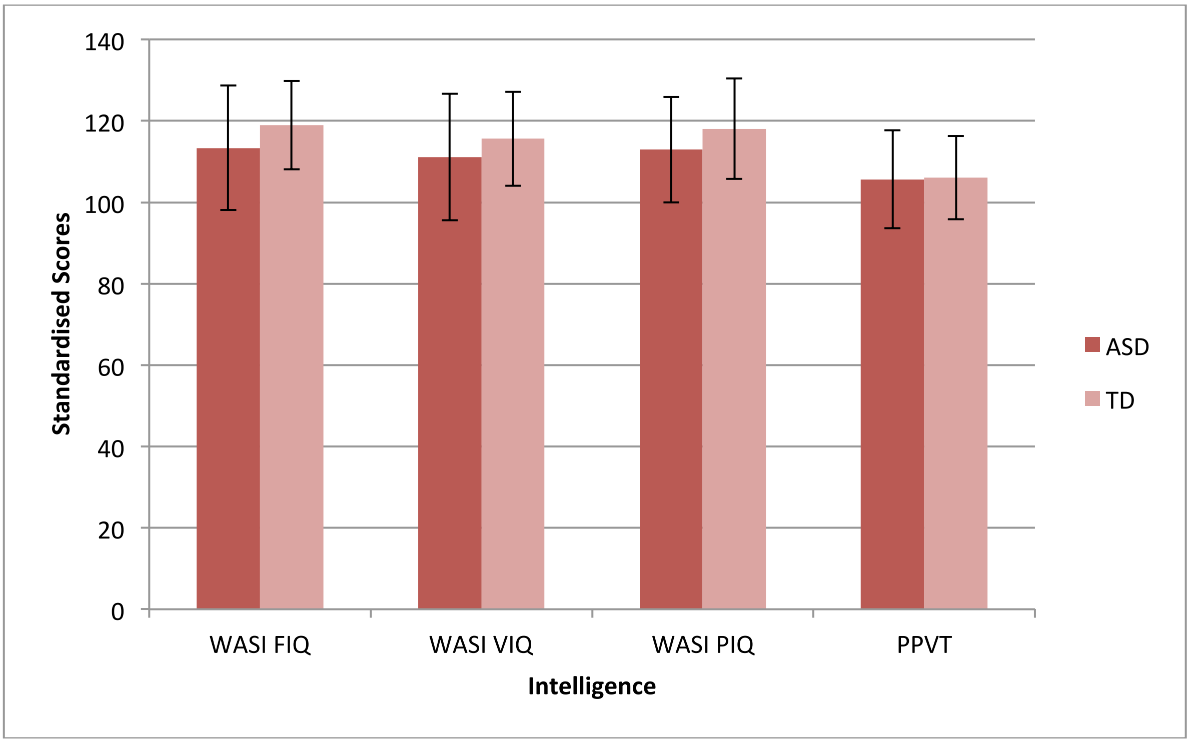

Figure 2-1. *Standardised scores on intelligence background measures*

Working Memory

In order to assess participants' working memory capacity, the digit span subtest from the Weschler Adult Intelligence Scale – Fourth Edition (WAIS-IV) (Wechsler, 2008) was used. This subtest consists of two tasks, forward (16 items) and backwards (14 items) digit span. Individuals listened to a series digits read aloud by the researcher and were asked to repeat them in either forward or backward order. Scores across the two tasks were combined to generate an overall measure of working memory. The ASD and TD groups were matched on their forward, backward and overall digit span scores (Fig. 2-2). These scores were also used to assess the extent that working memory was associated with performance on the experimental tasks. There was no significant difference between the two groups on their working memory capacity (Total, $t(36)= 0.35$, *ns*; Forwards, $t(36)= -0.27$, *ns*; Backwards $t(36)= 0.82$, *ns*) (Table 2-3).

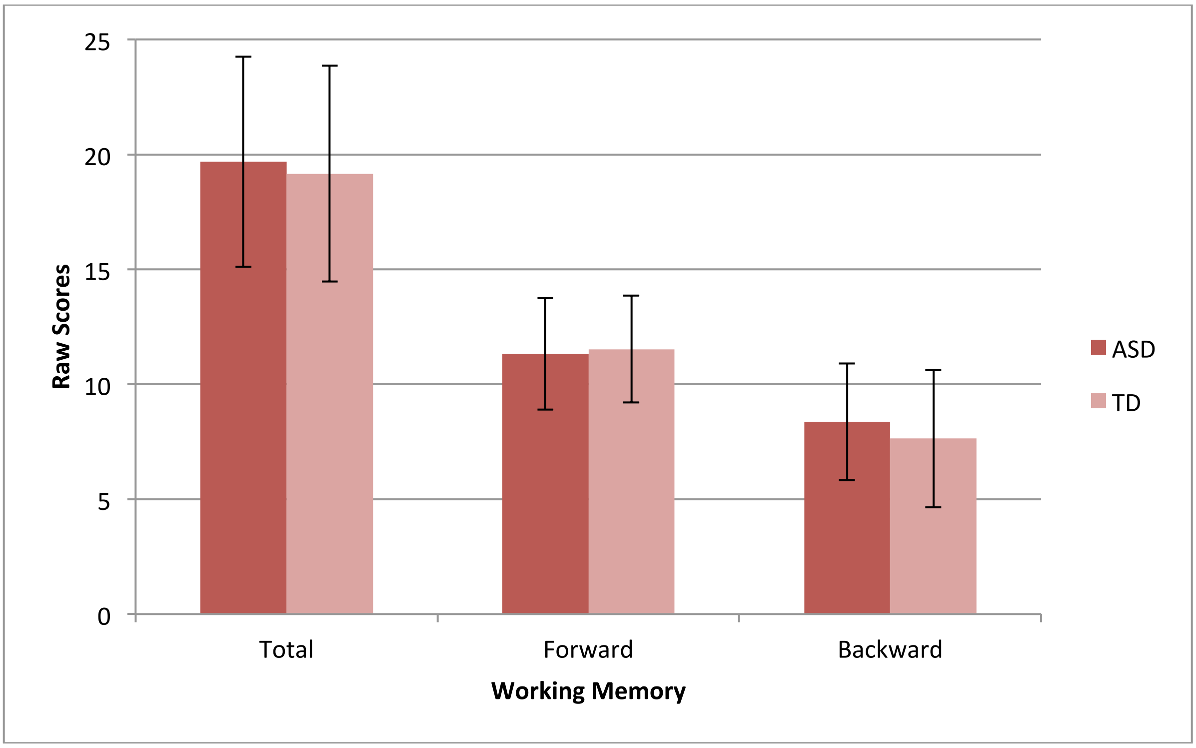

Figure 2-2. *Digit span scores on working memory measure*

Behavioural Correlates

Communication Checklist – Self Report

The Communication Checklist – Self Report (CC-SR) (Bishop, et al., 2009) was administered to provide information on any difficulties in speech, language, or interaction that may affect the participants' communication abilities. The CC-SR is a 70-item questionnaire that examines three factors of communication: Language Structure ("I make false starts or search for the right word"), Pragmatic Skills ("I am told that I keep talking about things that others are not interested in") and Social Engagement ("I find it hard to know when people are upset or annoyed"). For each question participants were instructed to indicate whether the statement applied to them 0= less than once a week (or never), 1= about once a week, 2= once or twice a day, or 3= several times a day (or all the time). Higher scores on the CC-SR indicated an increased level of communication difficulties. Due to the heterogeneous nature of the ASD and TD groups, raw scores were used rather than standard scores to allow for a greater variance in participants' performance (Fig. 2-3). Raw scores were also used to examine whether self-reported communication difficulties were associated with performance on the experimental tasks.

A statistically significant difference was found between the two groups on their total Communication Checklist scores ($t(24.02) = 5.54$, $p<0.001$) as well as all three of the factors, Language Structure ($t(21.78) = 3.26$, $p<0.01$), Pragmatics ($t(29.21) = 3.95$, $p<0.001$) and Social Engagement ($t(36) = 7.68$, $p<0.001$) (Table 2-3). The ASD group scored higher than the TD group on all of the CC-SR measures, demonstrating a significantly greater level of self-reported communication difficulties.

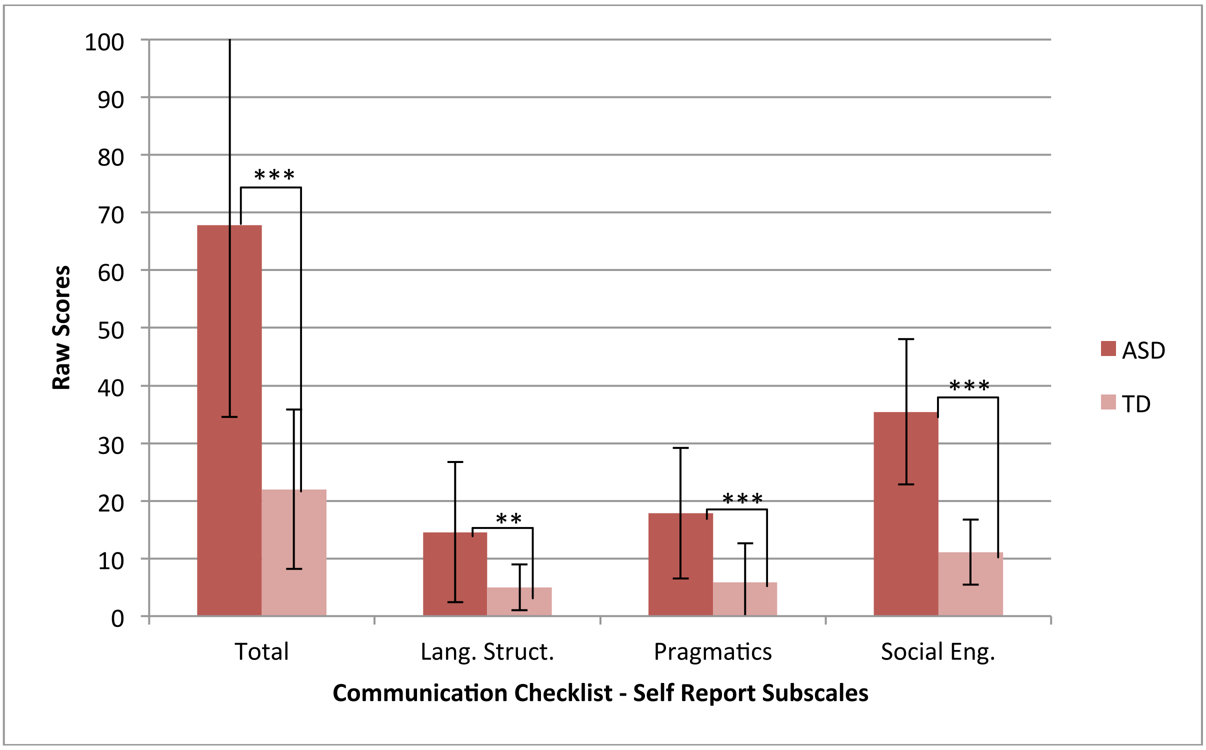

Figure 2-3. *Raw scores on communication checklist subscales*
*Note: *p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

Adult/Adolescent Sensory Profile

Whilst sensory abnormalities are not currently included in DSM-IV-TR (American Psychiatric Association, 2000) they are widely prevalent in individuals with

ASD (e.g. Leekam, et al., 2007) and may be implicated in language processing difficulties in ASD. Therefore measures of sensory abnormalities using the Adult/Adolescent Sensory Profile (SP) test (Brown & Dunn, 2002) were also obtained. The SP is a 60 item questionnaire that examines sensory processing patterns across six sensory processing categories including: taste/smell, movement, visual, touch, activity and auditory processing. Participants' raw scores across the six categories are used to derive their quadrant scores identified as: Low Registration ("I don't get jokes as quickly as others"), Sensation Seeking ("I like to wear colourful clothing"), Sensory Sensitivity ("I am distracted if there is a lot of noise around") and Sensation Avoiding ("I stay away from crowds"). For each question participants were instructed to indicate whether the statement applied to them almost never, seldom, occasionally, frequently, or almost always. Higher scores within each quadrant represented increased sensory abnormalities. Participants' overall quadrant scores as well as their quadrant scores within the auditory processing category were obtained for analysis (Fig. 2-4). These scores were also used to assess whether sensory abnormalities were associated with performance on the experimental tasks.

The groups differed significantly on their total Sensory Profile scores ($t(36)= 5.39$, $p<0.001$) as well as their scores on three of the four quadrants, Low Registration ($t(29.42)= 6.20$, $p<0.001$), Sensory Sensitivity ($t(36)= 6.04$, $p<0.001$) and Sensation Avoiding ($t(36)= 5.27$, $p<0.001$). However, the groups did not differ on the Sensation Seeking quadrant ($t(36)= -1.28$, *ns*) (Table 2-3). On the three quadrants in which the groups differed significantly, the ASD group had higher scores than the TD group, indicating a greater level of sensory abnormalities.

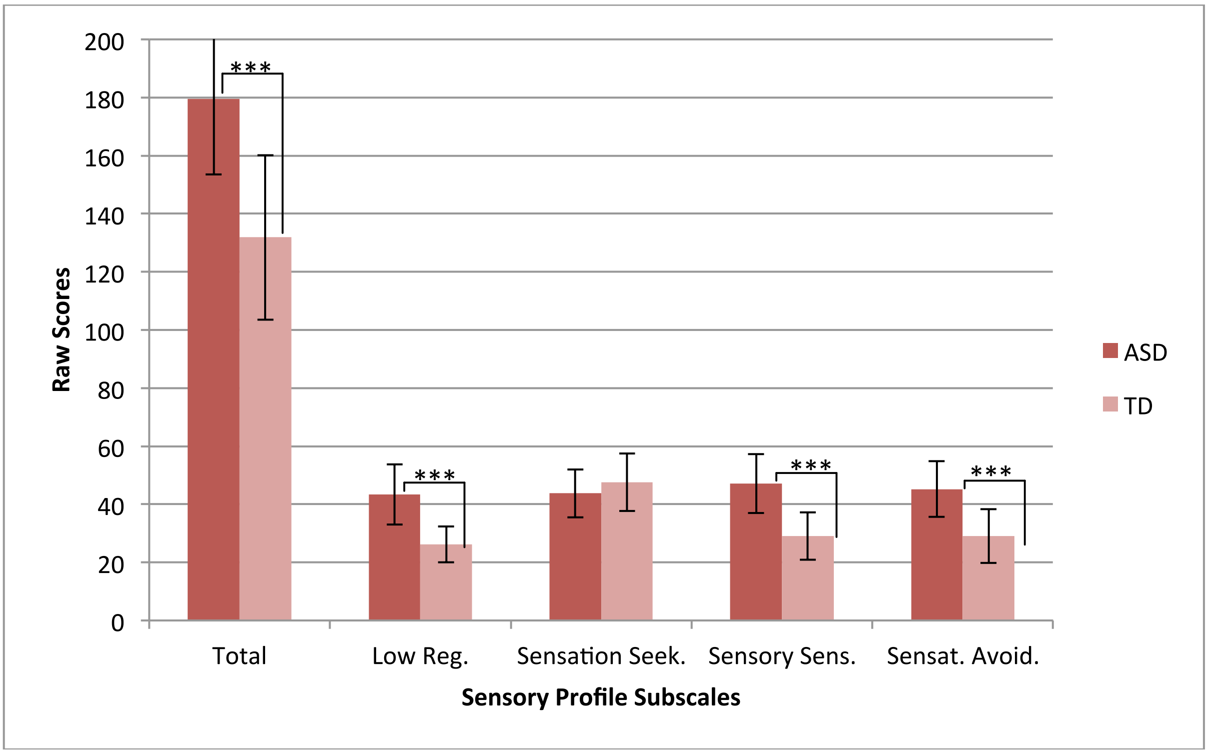

Figure 2-4. *Raw scores on sensory profile subscales*
*Note: *p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

Clinical Correlates

Adult Autism Spectrum Quotient

In order to assess the self-reported levels of autistic traits in participants the Adult Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001) was administered. The AQ is a 50 item questionnaire that examines five factors: Social Skills ("I would rather go to a library than a party"), Attention Switching ("I frequently get so absorbed in one thing that I lose sight of other things"), Attention to Detail ("I often notice small sounds when others do not"), Communication ("Other people frequently tell me that what I've said is impolite, even though I think it is polite") and Imagination ("When I'm reading a story, I find it difficult to work out the characters' intentions"). For each question participants were instructed to indicate the level to which they agreed with the statement: definitely agree, slightly agree, slightly disagree and definitely disagree. Participants received one point each time they reported autistic-like behaviour either mildly or strongly. Within the

AQ autistic-like behaviour is characterised by poor social, communication, or imagination skills, exceptional attention to detail and either poor attention switching or a strong focus of attention (Baron-Cohen et al., 2001). Participants' raw scores within each of the 5 factors as well as their total AQ score were used as a measure of autistic traits in both the ASD and typically developing group (Fig. 2-5). AQ scores were also used to assess whether autistic traits were associated with experimental task performance.

Significant group differences in the levels of autistic traits were found on total AQ scores $t(36)= 10.67$, $p<0.001$ as well as on the 5 factors of the AQ: Social Skills ($t(25.61)= 7.88$, $p<0.001$), Attention Switching ($t(36)= 10.26$, $p<0.001$), Attention to Detail ($t(36)= 5.25$, $p<0.001$), Communication ($t(26.01)= 6.69$, $p<0.001$) and Imagination ($t(36)= 5.79$, $p<0.001$) (Table 2-3). The ASD group scored higher than the TD group on all of the AQ measures, which demonstrates a significantly greater level of self-reported autistic traits in the participants with ASD. It is important to note, however, that there was an overlap between the ASD and TD groups on total AQ scores. One typically developing participant and one ASD participant each scored 21, representing the highest and lowest scores respectively in each group. This is not unexpected given the spectrum nature of ASD and the fact that the AQ is a self-report measure. As the results from the AQ were not used diagnostically and there were significant group differences on the overall scores as well as all the subscale scores, this overlap was not concerning.

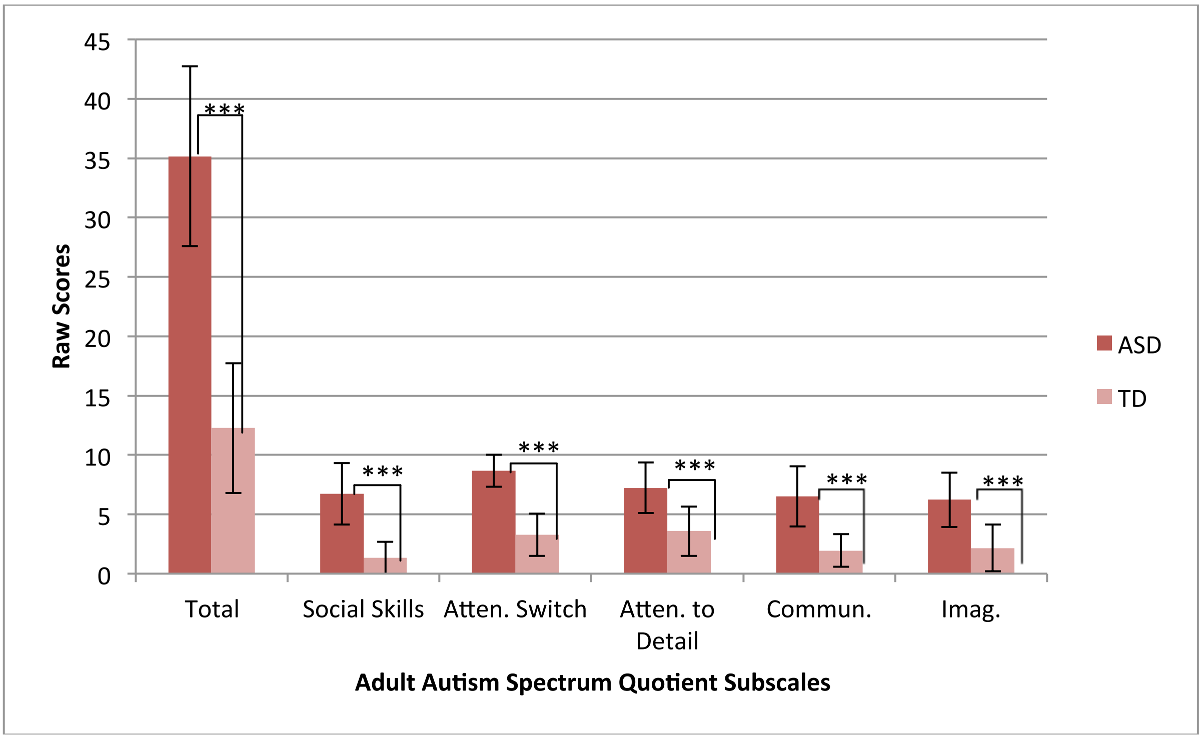

Figure 2-5. *Raw scores on AQ subscales*
*Note: *p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

Autism Diagnostic Observation Schedule

All of the ASD individuals who participated in the experiments described in this thesis had previously been diagnosed by clinicians in accordance the with *Diagnostic and Statistical Manual of Mental Disorders* (4^{th} ed., rev.; American Psychiatric Association, 2000). ASD participants' pre-existing diagnoses were confirmed by administering the Autism Diagnostic Observation Schedule (ADOS) (Lord, et al., 2001). The ADOS is a semi-structured observation assessment that gives the administrator an opportunity to assess social and communication behaviours relevant to a diagnosis of autism or another pervasive developmental disorder. Only behaviours that appear during the interview are assessed. The ADOS provides a standard score representing autistic symptom severity in the areas of: Communication ("stereotyped/idiosyncratic use of words or phrases"), Reciprocal Social Interaction ("empathy/comments on others' emotions"), Imagination and Creativity ("spontaneous, inventive, creative activities or comments in conversation") and Repetitive Behaviours ("excessive interest in or references to unusual or highly specific topics or objects"). A subset of coded items for each subscale generated a total raw score that could range between 0-8 for Communication, 0-16 for Social Interaction, 0-2 for Imagination and 0-8 for Stereotyped Behaviours and Repetitive Interests. In order to receive a diagnosis, individuals need to score above a predetermined threshold on the Communication (2 for ASD, 3 for Autism) and Reciprocal Social Interaction (4 for ASD, 6 for Autism) factors and also above a threshold on their combined scores across those two factors, thus generating an overall Diagnostic score (7 for ASD, 10 for Autism). Of the 19 ASD participants recruited, 2 did not meet overall diagnostic criteria on the ADOS. However, as all participants had previously been diagnosed by a clinician and the results from the background assessment tests and the experimental tasks did not change if those individuals were excluded, they were retained in the final sample. Individuals' scores across the 4 factors as well as their Diagnostic score were used as a measure of symptom severity within the ASD group. ADOS scores were also used to assess the extent that experimental task performance was associated with levels of autistic symptom severity in the ASD group.

Table 2-3. *Participant background data summary*

	ASD N= 19		TD N= 19		
	Mean (SD)	Range	Mean (SD)	Range	*p* values
CA	40y8m (11.33)	23y9m-59y8m	38y3m (9.00)	25y1m-52y9m	0.568
Cognitive Correlates					
WASI Full Scale[a]	113.37 (15.27)	78-133	118.95 (10.84)	87-134	0.203
WASI Verbal[a1]	111.16 (15.57)	71-132	115.58 (11.52)	83-135	0.326
WASI Performance[a2]	112.95 (12.97)	92-129	118.05 (12.21)	96-136	0.221
PPVT[b]	105.63 (12.07)	76-123	106.05 (10.24)	84-125	0.908
WM-Total[c]	19.68 (4.57)	13-30	19.16 (4.69)	13-28	0.728
WM-Forward[c1]	11.32 (2.43)	7-16	11.53 (2.32)	8-15	0.786
WM-Backward[c2]	8.37 (2.54)	4-14	7.63 (2.98)	4-13	0.418
Behavioural Correlates					
CC-SR-Total[d]	67.84 (33.28)	32-159	22.00 (13.81)	1-50	<0.001*
CC-Lang. Struct.[d1]	14.58 (12.19)	1-49	5.00 (3.97)	0-16	<0.01*
CC-Pragmatics[d2]	17.84 (11.35)	0-39	5.89 (6.71)	0-25	<0.001*
CC-Social Eng.[d3]	35.42 (12.58)	19-71	11.11 (5.65)	1-24	<0.001*
Sensory Profile-Total[e]	179.58 (26.09)	130-218	131.89 (28.36)	32-160	<0.001*
SP-Low Reg.[e1]	43.42 (10.41)	27-62	26.16 (6.23)	10-35	<0.001*
SP-Sensation Seek.[e2]	43.79 (8.29)	31-63	47.58 (9.88)	12-58	0.209
SP-Sensory Sens.[e3]	47.16 (10.19)	23-62	29.05 (8.18)	4-39	<0.001*
SP-Sensat. Avoid.[e4]	45.21 (9.54)	31-61	29.11 (9.31)	6-48	<0.001*
Clinical Correlates					
AQ-Total[f]	35.16 (7.59)	21-45	12.26 (5.45)	3-21	<0.001*
AQ-Social Skills[f1]	6.72 (2.58)	3-10	1.32 (1.38)	0-4	<0.001*
AQ-Atten. Switch[f2]	8.67 (1.37)	6-10	3.26 (1.79)	0-6	<0.001*
AQ-Atten. to Detail[f3]	7.22 (2.13)	1-10	3.58 (2.10)	0-7	<0.001*
AQ-Commun.[f4]	6.50 (2.55)	2-10	1.95 (1.39)	0-5	<0.001*
AQ-Imagination[f5]	6.22 (2.29)	2-10	2.16 (1.98)	0-7	<0.001*
ADOS-Diagnostic[g]	9.58 (3.55)	5-17	N/A	N/A	N/A
ADOS-Commun.[g1]	2.84 (1.54)	1-6	N/A	N/A	N/A
ADOS-Soc. Int.[g2]	6.74 (2.70)	3-12	N/A	N/A	N/A
ADOS-Imag.[g3]	1.05 (0.70)	0-2	N/A	N/A	N/A
ADOS-Rep. Behav.[g4]	1.58 (1.02)	0-3	N/A	N/A	N/A

Note: CA= chronological age, ASD= Autism Spectrum Disorders, TD= typically developing
[a]Weschler Abbreviated Scales of Intelligence (WASI), standard score (Wechsler, 1999)
[a1]WASI Verbal IQ; [a2]WASI Performance IQ
[b]Peabody Picture Vocabulary Test (PPVT), standard score (Dunn & Dunn, 1997)
[c]Working Memory Digit Span (WM), Weschler Adult Intelligence Scales, (Wechsler, 2008)
[c1]WM Forward Digit Span; [c2]WM Backward Digit Span
[d]Communication Checklist – Self Report (CC-SR), raw score (Bishop et al., 2009)
[d1]CC-SR Language Structure; [d2]CC-SR Pragmatics; [d3]CC-SR Social Engagement
[e]Adult/Adolescent Sensory Profile (SP), (Brown & Dunn, 2002)
[e1]SP Low Registration; [e2]SP Sensation Seeking; [e3]SP Sensory Sensitivity; [e4]SP Sensation Avoiding
[f]Adult Autism Spectrum Quotient (AQ), (Baron-Cohen et al., 2001)
[f1]AQ Social Skills; [f2]AQ Attention Switching; [f3]AQ Attention to Detail; [f4]AQ Communication; [f5]AQ Imagination
[g]Autism Diagnostic Observation Schedule (ADOS), diagnostic total (Lord et al., 2001)
[g1]ADOS Communication; [g2]ADOS Reciprocal Social Interaction; [g3]ADOS Imagination & Creativity; [g4]ADOS Repetitive Behaviours

Characterising ASD Traits

As discussed in the previous chapter, research has increasingly begun to recognise the idea that as a spectrum disorder, ASD lies on a continuum that extends into the typically developing population. Thus, autistic traits are exhibited by typically developing individuals, albeit at lesser levels. One of the primary aims of this thesis was to examine the continuum approach to ASD by investigating the extent that higher levels of autistic traits, as assessed by the AQ, were influencing performance on the experimental tasks in a similar fashion in both the ASD and typically developing groups. Another key component of this investigation is the extent that autistic traits are related to performance on any of the other background measures utilised in this thesis. Tables 2-4 and 2-5 summarise the significant correlations between levels of autistic traits in both ASD and typically developing individuals and their performance on the other cognitive and behavioural measures described above.

Table 2-4. *Correlations between AQ scores and cognitive measures*

ASD; **TD**	AQ-SS	AQ-AS	AQ-AD	AQ-C	AQ-I	AQ-Tot
WASI						
VIQ	NS	0.52*	NS	0.50*	0.61**	NS
PIQ	NS	NS	NS	0.56*	0.66***	NS
FSIQ	NS	0.51*	NS	0.57*	0.69**	NS
PPVT	NS	0.71***	0.67**	0.71***	NS	NS
Working Mem.						
Forward	NS	NS	NS	NS	NS	NS
Backward	NS	NS	0.60**	NS	NS	NS
Total	NS	NS	0.59**	NS	NS	NS

Note: Red= significant in ASD group; Blue= significant in TD group; NS= non-significant in both groups; AQ-SS= Social Skills; AQ-AS= Attention Switching; AQ-AD= Attention to Detail; AQ-C= Communication; AQ-I= Imagination; AQ-Tot= Total AQ Score

Table 2-5. *Correlations between AQ scores and behavioural measures*

ASD; TD	AQ-SS	AQ-AS	AQ-AD	AQ-C	AQ-I	AQ-Tot
CC-SR-Total	0.48*	NS	NS	0.55*	0.53*	0.55*
CC-Lang. Structure	NS	0.46*	NS	NS	NS	NS
CC-Pragmatics	0.47*	0.47*	NS	0.53*	0.54**	0.63**
CC-Social Eng.	0.62**	NS	NS	0.58*	0.54*	0.59**
SP-Total	0.58**	0.54*	NS	0.65**	0.53*	0.62**
SP-Low Reg.	0.71**	0.51*	NS	0.75***	NS	0.62**
SP-Sensation Seek.	NS	NS	NS	NS	NS	NS
SP-Sensory Sens.	0.57**	0.53*	NS	0.60**	0.50*	0.61**
SP-Sensat. Avoid.	0.62**	0.54*	NS	0.58**; 0.52*	NS	0.66***; 0.60**

Note: Red= significant in ASD group; Blue= significant in TD group; NS= non-significant in both groups; AQ-SS= Social Skills; AQ-AS= Attention Switching; AQ-AD= Attention to Detail; AQ-C= Communication; AQ-I= Imagination; AQ-Tot= Total AQ Score

It is interesting to note the different set of correlations between autistic traits, as measured by the AQ and performance on the other background measures in the ASD and typically developing groups. Interestingly, individuals with ASD who are reporting more autistic traits, especially in the realms of attention switching, communication and imagination also have higher receptive vocabulary scores and higher scores on verbal, performance and full-scale IQ measures. There were no significant correlations between IQ and autistic traits in the typically developing group, however correlations did suggest that higher autistic traits in the realm of attention to detail were related to better working memory. Some of the most interesting correlations appeared when comparing autistic traits to performance on the Communication Checklist and Sensory Profile. Within the ASD group higher levels of self-reported autistic traits in the realms of social skills, communication, imagination and total AQ scores were strongly related to higher levels of self-reported communication deficits and sensory abnormalities. Conversely, within the typically developing group, higher levels of autistic traits in the realm of attention switching were mildly related to higher levels of self-reported communication deficits and sensory abnormalities. Thus, it appears as though higher levels of self-reported autistic traits are related to different cognitive and behavioural correlates in ASD and typically developing individuals.

Screening Measures

Audiometry

Due to the auditory nature of the experimental tasks, participants were screened for hearing loss using an Amplivox 240 Portable Diagnostic Audiometer. Hearing thresholds were measured in the right and left ears between 125-8000Hz. Normal hearing was assessed as an absolute threshold between 0 dB and 20 dB at each frequency. All participants were found to have hearing within the normal range.

METHODS

General Procedure

Ethics Statement

The studies presented in this thesis were passed by the ethics committee at Goldsmiths College, University of London. Informed, written consent was obtained from all participants and they were paid standard fess (£7/hour) for their participation and their travel expenses were reimbursed.

Materials and Procedure

Participants completed all testing at Goldsmiths College, University of London during two 2.5-hour sessions with breaks at regular intervals. In order to avoid practise effects and fatigue, the order of presentation of all experimental stimuli and background measures was randomized across sessions. All of the tasks were administered on a Dell desktop computer and participants heard the stimuli through Sennheiser HD 202 Headphones. The experimenter was present throughout both testing sessions in order to offer encouragement and ensure that participants were giving each task their full attention. Prior to each experimental task participants were given a brief overview, told that they could withdraw their participation at any time and their consent was sought. At the end of each task as well as at the end of the entire experimental session participants had the opportunity to ask questions and verbal debriefings were given.

Experimental Paradigms

This thesis incorporates six behavioural studies with novel paradigms that were designed to assess different aspects of speech processing. Experiment one employed a same/different pitch discrimination task to examine the extent that previous findings of superior pitch discrimination across speech and non-speech stimuli in children with ASD would also be present in high-functioning adults. Experiments two, three and four each investigated the effects of perceptual manipulations on speech encoding and memory during sentence repetition tasks. Performance on all three of these tasks was assessed through both accuracy and reaction time measures. Experiments 5a, 5b, 6a and 6b investigated perceptual and semantic processing biases utilizing auditory Stroop tasks which required participants to identify semantic or perceptual components of speech including, pitch and timbre, amid competing auditory information.

Statistical Analyses

The experimental studies to be described were analysed using parametric statistical procedures. Where relevant assumptions were met, one-way ANOVA, repeated measures ANOVA and t-tests were conducted. Thus, prior to all statistical analyses data cleaning was performed to check for normal distributions and that assumptions of homogeneity of variance and sphericity were met. All of the tests conducted were 2-tailed with an alpha value of 0.05 and Bonferroni corrections were applied where appropriate.

Due to the heterogeneous nature of ASD, the good cognitive skills of the ASD participants and the rigorous matching procedures adopted in the studies, large group differences on the experimental studies were not predicted. However, it was hypothesised that and individual's performance on the experimental tasks would be influenced by the cognitive, behavioural, and clinical correlates outlined earlier in this chapter. One of the primary purposes of this thesis was to provide the basis of the author's future research. The measures and subscales previously discussed have the potential to distinguish between the underlying mechanisms driving auditory perception in individuals with and without ASD. Due to the large number of potential variables that may impact on an individual's auditory processing, an aim of the present thesis was to reduce these in order to enhance future research. Therefore, at the end of each experimental study exploratory correlation analyses were conducted using the dependent variables as well as the background measures and their respective factors, outlined above. Multiple linear regressions were also performed with the significant variables from the preceding correlation analyses in order to further examine the extent that specific cognitive, behavioural and clinical correlates explained the variance in performance on the experimental tasks within each group. It is important to note that due to the exploratory nature of these analyses, the 28 background measures and subscales utilised and the relatively small group sizes in comparison to the number of variables, these analyses should be interpreted with caution and with respect to the aim of reducing the number of potential underlying mechanisms investigated in future research into auditory perception individuals with ASD. It is important to note that these tests were exploratory in nature due to the small group sizes.

Outliers

One of the primary aims of this thesis was to examine how the heterogeneity that characterises Autism Spectrum Disorders relates to atypical auditory processing. Thus, although small samples sizes were used statistical outliers were not removed because variability within the two groups was of particular interest. Outliers were considered to be special cases of particular ability or difficulty that would further reflect the heterogeneous nature of ASD. Additional practice items with feedback, encouragement from the experimenter and within-task breaks were employed in order to greatly reduce the degree to which boredom, fatigue, or failure to understand the task requirements could lead to specific cases of outliers. The decision to retain any possible outliers was applied to each experiment regardless of whether the outlier improved or diminished the statistical findings.

Statistical Power

Statistical power is often an issue in experimental studies carried out with ASD participant groups. This is because sample sizes are often relatively small and there is a high degree of variability of performance within groups. Low power can result in an increased possibility of a Type II error and lead to difficulties interpreting the results. Although it is possible to calculate estimates of expected power, this was difficult due to the novel paradigms employed throughout this thesis. However, preliminary sample size estimates were conducted for three of the experiments in this thesis based on previous published studies as well as pilot studies conducted and reported in chapters four and five. Experiment one aimed to replicate Heaton, Hudry, et al.'s (2008) finding of enhanced pitch discrimination in children with ASD and utilised the same stimuli and procedure. Therefore, a sample size analysis was conducted based on the means and standard deviations reported by Heaton and colleagues, which reported that 16 individuals per group would be sufficient in order to achieve acceptable statistical power of 0.80. Additional sample size analyses were conducted based on the means and standard deviations reported in the pilot studies for experiments two and three. Similar to experiment one, these analyses suggested that sample sizes of 15 individuals per group would be necessary to achieve statistical power of 0.80. Furthermore, a literature review revealed that auditory processing studies with ASD individuals have typically included groups of between 14-20 individuals (Adams & Jarrold, 2009; Bonnel et al., 2003, 2010; Foxton et al., 2003; Heaton, Hudry, et al., 2008; Järvinen-Pasley & Heaton, 2007; Järvinen-Pasley, Wallace, et al., 2008; Mottron et al., 2000), thus a group of 19 individuals is on the higher end and should provide sufficient power within the broader context of ASD research. Furthermore, previous studies with clinical populations have suggested that reliable results can be obtained from reaction time studies with participant groups ranging between 8-17 individuals (Jolliffe & Baron-Cohen, 1997). The preliminary sample size analyses combined with the sample sizes of previous studies of individuals with ASD that utilised similar methodologies suggest that the proposed sample size of 19 individuals per group in the present thesis are similar to, and even higher than, what would be necessary to achieve reliable results with sufficient statistical power.

CONCLUSION

A great deal of consideration was given to the matching criteria during participant recruitment for the experimental studies presented in this thesis. Due to the high ratio of males to females on the autistic spectrum, the gender ratio in the control group was matched with that of the ASD group. ASD is a neurodevelopmental disorder and the extent that the developmental trajectory of different aspects of functioning, including auditory processing, differs from that of the typically developing population is not clear. Furthermore, verbal IQ, in particular vocabulary, is known to have an impact on performance on language related tasks and previous studies have suggested that performance IQ may contribute to the ability to process the perceptual aspects of auditory objects, including speech. Thus the ASD and TD groups were carefully matched on chronological age and scores on all of the IQ measures detailed above. Additionally, as several of the paradigms described in this thesis required verbal recall and research shows that individuals with ASD may experience difficulties on working memory tasks (Poirier, Martin, Gaigg & Bowler, 2011) the groups were also matched on working memory. Whilst the ASD and TD group showed highly significant differences on tests of communication difficulties, sensory abnormalities, autistic traits and levels of autistic symptomatology it should be noted that there was considerable variability within the ASD group and to some extent the TD group. Therefore, it is expected that this heterogeneity may lessen the degree to which clear group difference will emerge on the experimental paradigms.

CHAPTER 3: ENHANCED PITCH PROCESSING

SUMMARY

Whilst increased sensitivity to pitch information has been reported in individuals with ASD, relatively little is known about the impact of atypical auditory processing on speech perception in intellectually high-functioning adults. Previous research carried out with children with ASD has revealed enhanced sensitivity to the psychoacoustic qualities of speech but the extent that this is characteristic in adults has yet to be investigated. The present study aimed to replicate Heaton, Hudry, et al.'s (2008) findings of superior pitch discrimination across speech and non-speech stimuli in children with ASD with a group of 19 high-functioning adults with ASD and age and intelligence matched typically developing controls. The findings failed to reveal superior discrimination in the ASD group. In order to further explore these findings, data from groups of children and adolescents with high-functioning ASD and matched controls was compared with the data from the adults. Results revealed a significant increase in pitch discrimination abilities from childhood and adolescence into adulthood within typically developing individuals whilst the performance within the ASD groups remained stable over time. Possible implications for the developmental trajectory of pitch discrimination in typically developing and ASD individuals and the associations with language abilities will be discussed.

INTRODUCTION

In line with the theories of weakened global or enhanced local/perceptual processing discussed in chapter one of this thesis are experimental findings showing increased sensitivity to pitch as well as superior pitch memory. The first of these studies was carried out by Heaton, Hermelin and Pring (1998) and tested identification and memory for musical tones in musically naïve children with and without ASD. The results revealed superior recall for single notes in the ASD group in comparison with the age and intelligence matched controls. These findings were supported by results from a single case study in which a musically untrained child diagnosed with ASD demonstrated absolute pitch ability and enhanced pitch discrimination (Heaton, Hermelin & Pring, 1999) and from group studies showing enhanced pitch memory, labelling and disembedding (Heaton, 2003), as well as superior discrimination of musical pitch intervals (Heaton, 2005). Consistent with these studies are results obtained by Mottron, Peretz and Menard (2000) who found superior performance in a group of 13 children with ASD on a discrimination task involving non-transposed, contour-preserved melodies.

Subsequent findings have identified that children with ASD are generally more accurate than their typically developing peers at identifying pitches of pure tone stimuli. For example, Bonnel et al. (2003) used signal detection analysis to examine the performance of autistic children on “same/different” and “high/low” discrimination tasks using pure tones. Their findings uncovered superior performance in the ASD group across both tasks, demonstrating enhanced pitch processing in low-level auditory tasks. This finding was extended by O’Riordan & Passetti (2006) who showed that children with high-functioning autism (HFA) perceived two tones of converging frequencies to be different later in the sequence than age and IQ matched typically developing children, indicative of superior auditory discrimination. Furthermore, Heaton, Davis and Happé

(2008) investigated pitch perception and absolute pitch in an intellectually able adult with ASD and found that his pitch naming skills generalised from music to linguistic stimuli. Parental report data presented in the study suggested that absolute pitch had been in evidence prior to the onset of language and may have caused difficulties in generalising across male and female speakers at early developmental stages.

The suggestion that increased sensitivity to pitch information might influence perception of speech has been investigated in a number of group studies. For example, in a study carried out by Järvinen-Pasley and Heaton (2007) in which participants performed same/different judgments on pitch manipulated stimulus pairs (music-music, speech-speech, or speech-music), children with ASD performed equally well across the different stimulus pairs. In contrast, typically developing children showed significantly poorer levels of discrimination on the speech-speech and speech-music stimulus pairs. An interesting result from this study was that the two groups did not differ on the music-music condition and the ASD superiority only emerged on conditions testing discrimination of pitch change in speech. The deterioration of performance within the typically developing group was most apparent on the speech-music pairs condition that required across domain discrimination and this led the authors to hypothesise that auditory processing in ASD may be characterised by reduced domain specificity. An examination of the response biases across the two groups of participants in the study suggested that the children with ASD were demonstrating a significantly reduced bias to process auditory information at the semantic level. In another study, in which participants were asked to match prosodically manipulated sentences to visual representations of either contour shapes or semantically related scenarios, children with ASD showed a weaker semantic bias than age and intelligence matched controls (Järvinen-Pasley, Wallace, et al., 2008). These results raise intriguing questions about the implications of enhanced pitch discrimination for speech perception.

Whilst the results from the studies discussed above suggest that enhanced pitch is characteristic of children with ASD at the group level, the results from several studies suggest that such an effect is constrained to only a sub-group of adolescents and adults that is characterised by increased levels of language impairments. Heaton, Williams, Cummins and Happé (2008) studied pitch memory and discrimination in adolescents with ASD and matched typical controls and observed superior performance in a subgroup of 9% of the ASD group. They also noted a larger range of language related impairments in the ASD subgroup with superior pitch identification relative to the rest of the ASD group. Jones et al. (2009) examined increased sensitivity to pitch in pure tones in a large sample of 72 adolescents with ASD. While their findings did not replicate those of Bonnel et al. (2003) in revealing superior performance across the whole of their ASD group, they did identify a subgroup comprising 20% of the ASD sample that demonstrated 'exceptional' abilities on "same/different" pitch discrimination tasks. Individuals within the subgroup were more likely to have a history of language delay, suggesting an association between age of language onset and increased sensitivity to pitch information. Furthermore, Bonnel et al. (2010) examined enhanced discrimination of pitch in pure tone stimuli in groups of adults with autism, Asperger syndrome (AS) and age-matched controls. Their results revealed superior pitch perception in the autism group, but not in the AS group which was characterised by fewer language impairments. The inconsistency in findings showing increased sensitivity to pitch throughout the entire group or only in a subgroup of individuals may result, in part, from differences in the paradigms used across the various studies. Discriminating differences in two pure tones and discriminating differences in speech contours are likely to rely on different cognitive mechanisms, some of which may not distinguish ASD and typically development. But it is also likely that the extreme heterogeneity within ASD also contributes and this underscores the need for studies that examine a range of auditory processing abilities within a single sample of individuals.

Many of these results have been discussed in the context of “assets” in ASD, for example in preserved or enhanced musical processing (Heaton, 2009; Miller, 1989; Mottron, Peretz, Belleville & Rouleau, 1999). However, the results of recent studies drawing links between language impairment and enhanced pitch perception in ASD have theoretical and clinical implications and merit further investigation. As previously mentioned in chapter 1, it is possible that enhanced pitch perception abilities may result from reduced attention to linguistic information. Previous research has shown that individuals with ASD fail to show the normal preference for speech over non-speech stimuli (Blackstock, 1978; Kuhl et al., 2005) at early developmental stages and this may have implications for speech specialisation at the neural level (Kuhl et al., 2005). Alternatively, however, it could be that an increased awareness of perceptual information results in hypersensitivity and stimulus overload that would impair the processing of speech information. However, given the heterogeneity characterising ASD it is unlikely that one explanation will hold true for all individuals with this diagnosis. O’Connor (2012) concludes her excellent review of the research into auditory processing in ASD by suggesting that we will gain a better understanding of the true significance of superior pitch processing in ASD once we know more about the behavioural phenotypes of individuals demonstrating these abilities.

EXPERIMENT 1: TESTING PITCH DISCRIMINATION IN LINGUISTIC AND NON-LINGUISTIC STIMULI

Aims

The present study aims to assess pitch discrimination abilities in high-functioning adults with ASD across speech and non-speech stimuli. The rationale and design for this experiment are derived from Heaton, Hudry, Ludlow and Hill's (2008) study in which children with ASD and matched controls performed same/different judgments on pitch manipulated word, non-word and analogue pitch stimulus pairs. Their results revealed superior discrimination of pitch changes across all pairs in the ASD group. An aim of experiment 1 is to determine whether enhanced pitch processing abilities continue into adulthood in ASD. Therefore, by incorporating stimuli across varying domains within a group of high-functioning adults with ASD the present study will also be able to specifically address the concept of enhanced perceptual processing in ASD across development.

Another aim of the present study is to test Järvinen-Pasley, et al.'s (2008) hypothesis of reduced domain specificity at a perceptual level in individuals with ASD. A difficulty inherent in this type of investigation is that perception of pitch information is powerfully affected by domain. So whilst a listener with normal hearing thresholds will perceive a semitone difference between tones as highly salient, an equivalent degree of pitch difference across speech-sounds will be far more difficult to discern. Therefore three pitch contour shifts will be utilised to examine varying levels of perceptual difficulty across speech and non-speech stimulus pairs.

According to Kellerman, Fran and Gorman's (2005) review, previous studies examining atypical auditory processing have identified both enhancements and impairments in ASD. As well as reflecting the uneven cognitive profile characteristic of ASD, these contradictory findings may also reflect the heterogeneity found across ASD. Therefore the final aim of the present study is to examine how cognitive, behavioural and clinical correlates influence performance on pitch-processing tasks in both typically developing adults and those with ASD. In the ASD sample the relationship between the skills and deficits measured by the background tests and performance on the experimental tasks may provide new insights into enhanced processing of pitch in ASD as a whole and the individuals who exhibit this ability.

Hypotheses

1. Individuals with ASD will demonstrate enhanced pitch discrimination of linguistic and analogue tone stimuli in comparison to typically developing adults.
2. The marked difference in pitch discrimination of word and complex tone stimuli that will be seen in the TD group will be less notable in the ASD group.
3. Within the ASD group, individuals who experience higher levels of sensory abnormalities, communication deficits and autistic symptomatology will exhibit superior pitch discrimination abilities.
4. It is hypothesised that TD individuals with higher levels of autistic traits, as measured by the AQ, will show increased pitch discrimination abilities.

METHODS

Participants

All 38 participants described in chapter two of this thesis participated in the present study.

Experimental Methods

Experimental Stimuli

The two stimulus types in experiment one assessed the discrimination of pitch changes in speech and non-speech stimuli. The paradigm and stimuli were developed and utilized in a behavioural study carried out with children and adolescents with ASD and typical development (Heaton, Hudry, et al., 2008) and revealed significantly increased sensitivity to changes in pitch contours in ASD participants.

The first stimulus type was designed to assess pitch discrimination at the most complex level, speech. The stimuli consisted of commonly used monosyllabic words (e.g. boot, got, hit) recorded by an adult British English speaking female. The original word stimuli were processed using PRAAT software (Boersma, 2001) to create four types of stimulus pairs. In the first pair, the original stimulus was presented twice. However, in the second, third and fourth pairs, the original stimulus was presented followed by a second stimulus in which the pitch contours had been shifted by two, three, or six semitones. The second, third and fourth pairs represented high, moderate and low levels of difficulty respectively. Ten of each of the four types of stimulus pair was presented to each participant in a computer generated random order, resulting in a total of 40 speech stimuli pairs of which 10 were 'same' pairs and 30 were 'different'.

The second stimulus type was designed to assess an intermediate level of pitch complexity by utilizing analogue tones of the speech contours derived from the stimuli in the first task. The manipulations to the analogue tone stimuli were generated according to the method described above. As in the first task, the second set of experimental stimuli consisted of 40 pairs, 10 that were the 'same' and 30 that were 'different' by two, three, or six semitones.

Procedure

For each stimulus type participants were administered 10 practice trials in which a recorded instruction stated “Listen carefully, are these two the same?” followed by the stimulus pair. The participant was instructed by the researcher to indicate whether the two words in the pair were the same or different pitch by pressing a button on a computer keyboard labelled “S” or “D”. During the practice trails, participants received feedback after each stimulus pair indicating whether or not they had answered correctly. Following the 10 practice trials, 40 experimental trials were administered in the same format, but without the recorded instruction or feedback.

In order to avoid practise effects and fatigue, the order of presentation of the two stimulus types was counterbalanced across sessions. During both tasks the experimenter sat with the participant offering encouragement regardless of their performance on the task. Raw scores for each of the tasks were obtained by counting the number in which the participant’s had responded correctly with a maximum of 40. Raw scores were converted to percentages for the analysis.

Analysis

A factorial analysis of variance (ANOVA) was used to analyse the data from experiment one. Within-subjects factors were stimulus type (2 levels; words and analogue pitch contours of words) and pitch interval (4 levels; same, small, medium and large pitch differences) and there was a between-subjects factor of group (2 levels; ASD and TD). The dependent variable was the percentage of correct responses made by each participant across the 10 trials at each pitch interval in each of the two stimulus types.

RESULTS

Accuracy Analysis

Means, standard deviations and ranges of the percentage or correct scores across pitch intervals for word and analogue contour tasks are shown in table 3-1.

Table 3-1. *Exp 1 mean percentage correct scores, standard deviations and ranges*

ASD	Words		Analogue Contours	
	Mean (SD)	Range	Mean (SD)	Range
Same	92.10 (16.18)	40.00-100.00	95.79 (9.01)	70.00-100.00
Small	40.00 (27.28)	10.00-100.00	64.74 (34.05)	20.00-100.00
Medium	63.16 (28.49)	10.00-100.00	73.68 (33.37)	10.00-100.00
Large	87.37 (20.23)	40.00-100.00	91.05 (15.60)	50.00-100.00
Total	70.66 (17.48)	40.00-100.00	81.31 (20.84)	37.50-100.00
TD	Words		Analogue Contours	
	Mean (SD)	Range	Mean (SD)	Range
Same	95.79 (9.61)	60.00-100.00	98.42 (5.01)	80.00-100.00
Small	53.16 (27.29)	10.00-100.00	73.15 (26.68)	30.00-100.00
Medium	73.68 (25.21)	30.00-100.00	84.74 (21.18)	30.00-100.00
Large	93.68 (11.64)	60.00-100.00	95.79 (6.07)	80.00-100.00
Total	79.08 (14.49)	50.00-97.50	88.03 (13.53)	55.00-100.00

Note: Mean percentage correct scores (out of a maximum of 100)

A mixed factorial analysis of variance (ANOVA) was performed on the data from experiment one. Mauchly's test of sphericity was significant, $\chi^2(5)= 39.02$, $p<0.001$ for the main effect of pitch interval, indicating that the assumption of sphericity had been violated. The assumption of sphericity was also violated for the stimulus type by pitch interval interaction, $\chi^2(5)= 26.38$, $p<0.001$. Therefore, the F-values were corrected for the main effect of pitch interval and the stimulus type by pitch interval interaction using the Greenhouse-Geisser corrected values of the degrees of freedom (Field, 2009). No correction was needed for the main effects of stimulus type or group (variables contained only 2 levels).

The analysis showed that whilst the mean pitch discrimination scores were poorer for the ASD group compared with the typically developing participants (M= 75.99, SD=

18.06 for ASD and M= 83.55, SD= 13.04 for TD) (Fig. 3-1) this difference was not statistically significant, $F(1, 38)= 2.19$, $p= 0.148$.

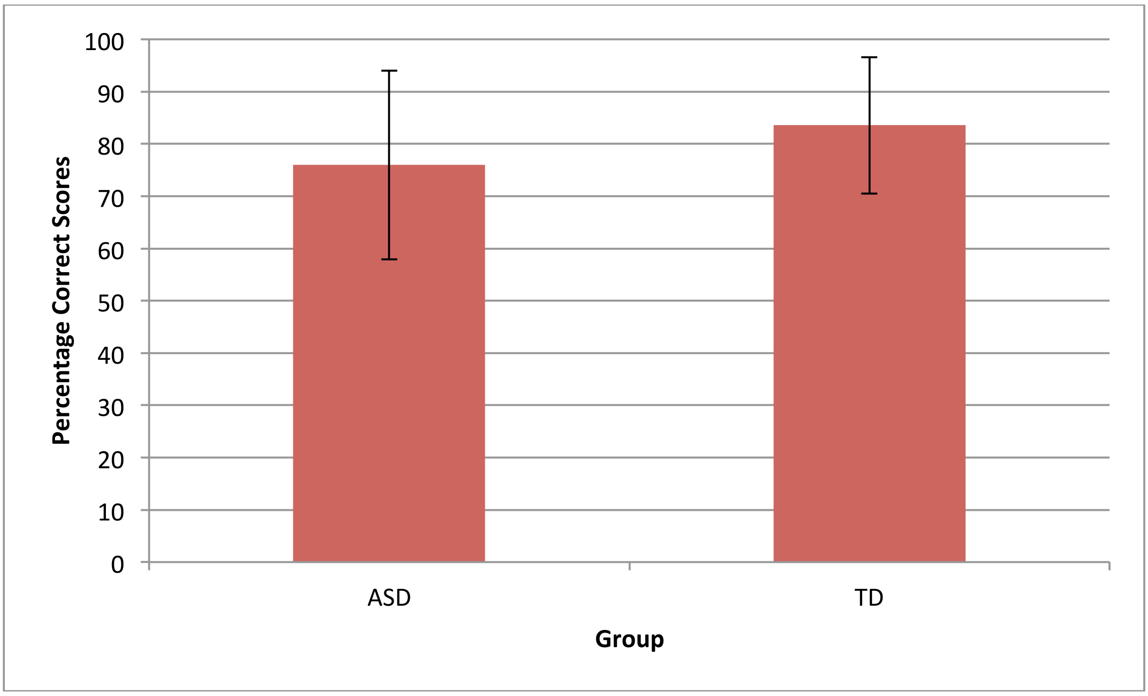

Figure 3-1. *Exp 1 main effect of group*

The analysis, however, revealed a significant main effect of stimulus type, $F(1, 38)= 26.15$, $p<0.001$ with participants scoring higher on the analogue contour stimuli condition (M= 84.67, SD= 17.66) than on the word stimuli condition (M= 74.87, SD= 16.40) (Fig. 3-2). There was no significant stimulus type by group interaction, $F(1, 38)= 0.20$, $p= 0.658$. Thus, the performance of participants across both groups was poorer when speech content was included in the stimuli.

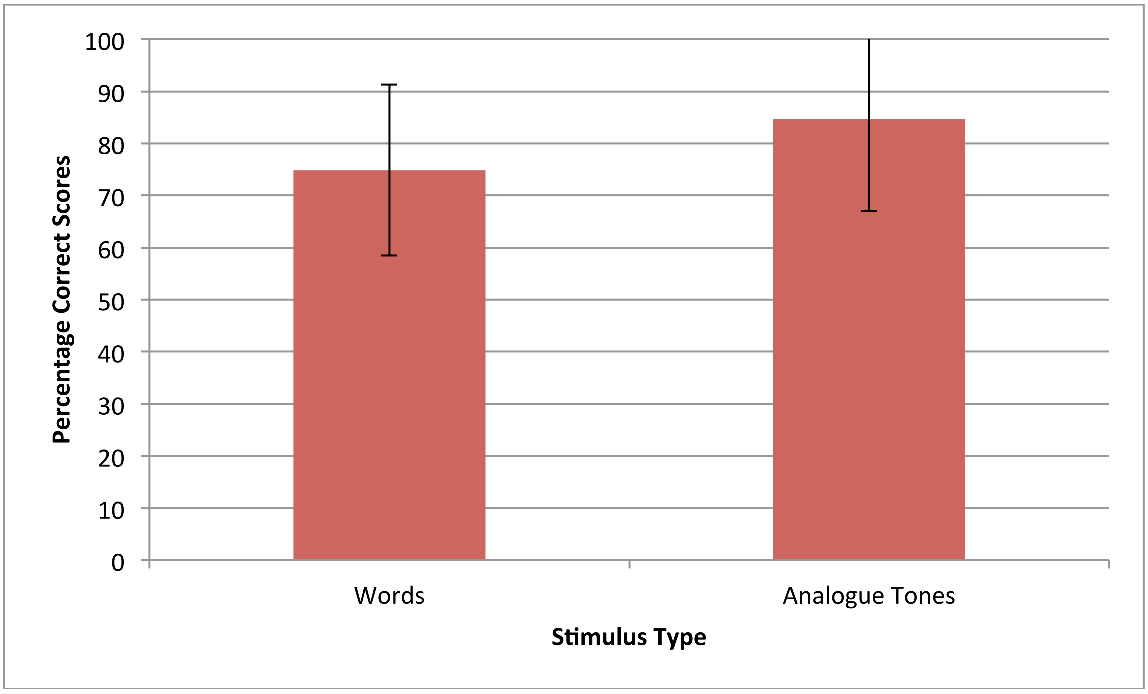

Figure 3-2. *Exp 1 main effect of stimulus type*

The main effect of pitch interval was also found to be highly significant, $F(1.78, 38) = 67.34$, $p<0.001$. Participants' ability to correctly discriminate "different" pitches improved as the size of the pitch interval difference increased (all comparisons $p<0.001$) (Fig. 3-3). Participants were able to correctly discriminate the "same" and large "different" conditions to the same extent $p= 0.291$ (N.B. with a Bonferroni corrected p threshold). However, there was no significant pitch interval by group interaction, $F(3, 38) = 0.81$, $p= 0.48$.

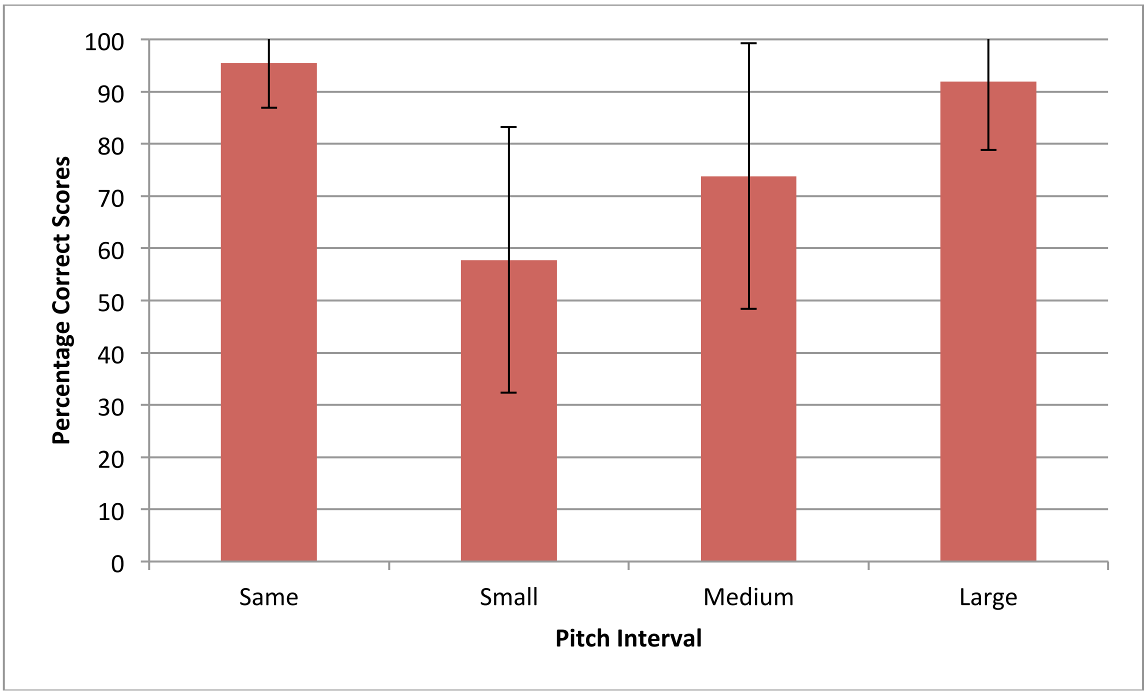

Figure 3-3. *Exp 1 main effect of pitch interval*

The analysis also revealed a significant stimulus type by pitch interval interaction, $F(2.08, 38) = 9.02$, $p<0.001$ (Fig. 3-4). Post hoc pairwise comparisons (N.B. with a Bonferroni corrected p threshold of 0.013) revealed that participants made significantly more correct decisions on the "small", $t(37) = -4.85$, $p<0.001$ and "medium", $t(37) = -3.10$, $p<0.01$ pitch intervals in the analogue contour condition than on the word condition. However, there was no significant difference in the participants' performance across conditions when stimuli were separated by a large pitch interval, $t(37) = -1.48$, $p = 0.147$ or when there was no pitch difference, $t(37) = -1.53$, $p = 0.136$. The stimulus type by pitch interval by group interaction was not significant, $F(3, 38) = 0.13$, $p = 0.941$, indicating that the pattern of performance was very similar across conditions.

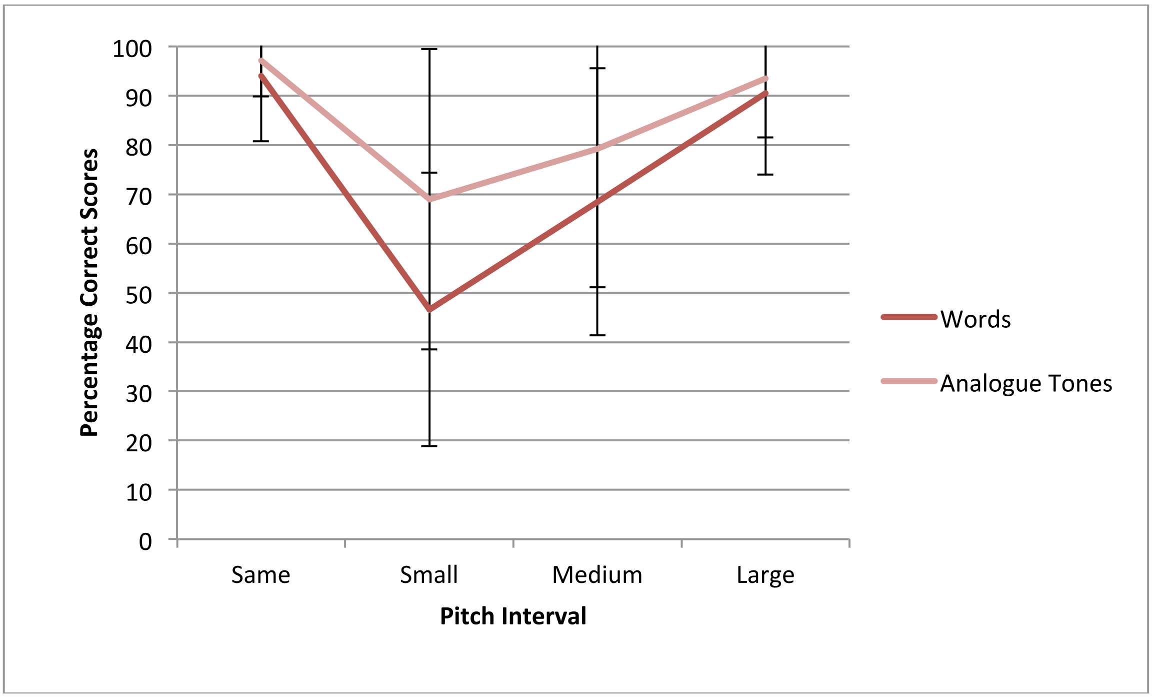

Figure 3-4. *Exp 1 stimulus type x pitch interval interaction*

Correlation Analysis

An important aim of experiment one was to identify the cognitive, behavioural and clinical correlates of enhanced pitch in individuals with ASD. Whilst the results failed to observe superior pitch discrimination at the group level in the ASD sample, this is not consistent with the large body of previous work on pitch discrimination in this group and exploration of factors associated with enhanced pitch remained of interest. As the large and same conditions do not measure fine-grained enhanced pitch discrimination, they were excluded from the correlation analysis. Performance on the small and medium pitch difference conditions were highly correlated with each other within both the word (r= 0.644, p<0.001) and analogue tone (r= 0.847, p<0.001) tasks. Therefore, the scores on the small and medium pitch differences were combined for each task to make two dependent variables for the correlation analyses.

In order to assess the cognitive correlates of enhanced pitch, a correlation analysis was performed. Participants' percentage correct scores for the word and analogue tone stimuli along with participants' WASI Verbal, WASI Performance, WASI Full Scale, PPVT, WM forward, WM backward and WM total scores were used in the correlation.

There were no significant correlations between ASD participants' WASI and PPVT scores and their pitch discrimination abilities. However, within the ASD group, participants' forward, backward and total digit span scores were significantly positively correlated with their pitch discrimination abilities during the analogue tone task (Table 3-2). This suggests that individuals with ASD who had better working memory scores demonstrated superior pitch processing abilities on non-linguistic stimuli. There were no significant correlations between TD participants WASI or working memory scores and their pitch discrimination abilities. However, there was a significant positive correlation between receptive vocabulary scores in the TD group and their performance on the 'small difference' condition of the analogue tone task, $r= 0.472$, $p<0.05$. The positive correlation indicated TD participants with higher receptive vocabulary scores were more likely to accurately identify small pitch differences in tones.

Table 3-2. *Exp 1 correlations between cognitive measures and enhanced pitch*

ASD	Forward Digit Span	Backward Digit Span	Total Digit Span
Word	0.16	0.27	0.24
Analogue Tone	0.53*	0.62**	0.62**

*Note: *p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

In order to assess the behavioural correlates of enhanced pitch, a correlation analysis was performed. Participants' percentage correct scores for the word and analogue tone stimuli along with participants' Communication Checklist – Language Structure, Communication Checklist – Pragmatic Skills, Communication Checklist – Social Engagement and Communication Checklist – Total standard scores and their Sensory Profile – Low Registration, Sensory Profile – Sensation Seeking, Sensory Profile –

Sensory Sensitivity, Sensory Profile – Sensation Avoiding and Sensory Profile – Total scores were used in the correlation.

There were no significant correlations between ASD participants' Communication Checklist and Sensory Profile scores and their pitch discrimination abilities. However, there were significant positive correlations between TD participants' performance on the word task and their scores on the low registration, $r = 0.47$, $p < 0.05$ and sensation avoiding, $r = 0.55$, $p < 0.01$, subscales of the sensory profile. Thus as typically developing participants reported higher levels of low registration and sensation avoiding behaviours, they were better able to identify pitch changes in speech. There were no significant correlations between TD participants' pitch discrimination abilities and their scores on the Communication Checklist.

In order to assess the clinical correlates of enhanced pitch, a correlation analysis was performed. Participants' percentage correct scores for the word and analogue tone stimuli along with participants' Autism Spectrum Quotient – Social Skills, Autism Spectrum Quotient – Attention Switching, Autism Spectrum Quotient – Attention to Detail, Autism Spectrum Quotient – Communication, Autism Spectrum Quotient – Imagination and Autism Spectrum Quotient – Total and ASD participants' ADOS – Communication, ADOS – Reciprocal Social Interaction, ADOS – Diagnostic, ADOS – Imagination and Creativity and ADOS – Stereotyped and Repetitive Behaviours scores were used in the correlation.

There were no significant correlations between ASD participants' AQ scores and their pitch discrimination abilities. However, within the TD group there was a significant positive correlation between participants' performance on the word task and their self-reported levels of autistic traits on the attention to detail subscale, $r = 0.46$, $p < 0.05$. Thus, as control participants exhibited higher levels of autistic traits on the attention to detail subscale they were more accurately able to detect pitch changes in speech. There were no correlations between either group's performance on the analogue tone task and their levels of autistic traits.

ASD participants' percentage correct scores on the analogue tone task were significantly negatively correlated with their reciprocal social interaction r= -0.69, p<0.001 and diagnostic r= -0.62, p<0.01 ADOS scores. Thus, ASD participants' with higher symptom severity scores on the reciprocal social interaction and diagnostic ADOS subscales were having more difficulty accurately identifying pitch changes in analogue tones.

All significant correlations between participants' scores on all levels of the background measures and their performance on the word and analogue tones pitch intervals of the experimental stimuli are summarised below (table 3-3).

Table 3-3. *Exp 1 summary of sig. correlations between pitch discrimination and background measures*

ASD; **TD**	Word Pitch Discrimination	Tone Pitch Discrimination
Cognitive Correlates		
PPVT	NS	0.47*
Working Memory		
Total		0.62**
Forward	NS	0.53*
Backward		0.62**
Behavioural Correlates		
Sensory Profile		
Low Registration	0.47*	NS
Sensation Avoiding	0.55**	NS
Clinical Correlates		
AQ		
Attention to Detail	0.46*	NS
ADOS		
Reciprocal Social Interaction	NS	-0.69**
Diagnostic Score	NS	-0.62**

Note: Red= significant in ASD group; Blue= significant in TD group; NS= non-significant in both groups; **p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

Regression Analysis

Word Stimuli

In order to examine the extent that the significant cognitive, behavioural and clinical correlates in the table above accounted for the variance in performance on the word task in ASD and typically developing participants two multiple linear regressions were performed. The dependent variable was the pitch discrimination scores for the combined small and medium pitch differences in the word task. The predictor variables were individuals' scores on the low registration and sensation avoiding subscales of the Sensory Profile and their scores on the attention to detail subscale of the AQ. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

The results revealed that there was no significant linear relationship between ASD participants' pitch discrimination scores on the word task and the predictor variables with a multiple correlation of 0.29, [$F(1,19)= 1.05$, $p= 0.322$; adjusted $R^2= 0.00$]. Thus, there did not appear to be a relationship between the predictor variables and pitch discrimination abilities on the word task in the ASD population.

The results did however reveal a significant linear relationship between typically developing participants' pitch discrimination scores during the word task and the predictor variables. Table 3-4 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the predictor variables on the pitch discrimination scores during the analogue tone task in the typically developing group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.55, [$F(1,19)= 7.58$, $p<0.01$; adjusted $R^2= 0.27$]. Thus, roughly 27% of the variability in typically developing participants' pitch discrimination scores during the word task was predicted by their scores on the sensation avoiding subscale of the Sensory Profile. A closer look at the un-standardised regression coefficients indicates that higher levels of sensory abnormalities in the realm of sensation avoiding predicted an increase of 1.4% in a TD individual's pitch discrimination scores.

Table 3-4. *Exp 1 multiple regression of pitch discrimination for TD participants during word task*

	B	SE *B*	β	*t*	*p*
SP-Sensation Avoiding	1.40	0.51	0.55	2.27	0.010**

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

Analogue Tone Stimuli

In order to examine the extent that the significant cognitive, behavioural and clinical correlates in the table above accounted for the variance in performance on the analogue tone task in ASD and typically developing participants two multiple linear regressions were performed. The dependent variable was the pitch discrimination scores for the combined small and medium pitch differences in the analogue tone task. The predictor variables were individuals' scores on the PPVT, forward digit span, backward digit span, total digit span and the reciprocal social interaction and diagnostic score subscales of the ADOS. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

Table 3-6 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t*) and significance (*p*) for the predictor variables on the pitch discrimination scores during the analogue tone task in the ASD group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.77, [$F(2,19)= 11.84$, $p<0.001$; adjusted $R^2= 0.55$].Thus, roughly 55% of the variability in ASD participants' pitch discrimination scores during the analogue tone task was predicted by their backwards digit span score and level of symptom severity on the reciprocal social interaction subscale of the ADOS. A closer look at the un-standardised regression coefficients indicates that higher working memory scores on digit span predicted an increase of 5% in an ASD individual's pitch discrimination scores, whereas higher reciprocal social interaction scores on the ADOS predicted a decrease of 6% in an pitch discrimination scores.

Table 3-5. *Exp 1 multiple regression of pitch discrimination for ASD participants during tone task*

	B	SE *B*	β	*t*	*p*
WM-Backward Digit Span	5.02	2.26	0.39	2.22	0.041*
ADOS-Recip. Social Interac.	-6.20	2.12	-0.52	-2.92	0.010*

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

The results also revealed a significant linear relationship between typically developing participants' pitch discrimination scores during the analogue tone task and the predictor variables. Table 3-6 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t*) and significance (*p*) for the predictor variables on the pitch discrimination scores during the analogue tone task in the typically developing group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.72, [$F(1,19)= 4.49$, $p<0.05$; adjusted $R^2= 0.18$]. Thus, roughly 17% of the variability in typically developing participants' pitch discrimination scores during the analogue tone task was predicted by their receptive vocabulary score on the PPVT. A closer look at the un-standardised regression coefficients indicates that higher receptive vocabulary scores predicted an increase of 1% in a TD individual's pitch discrimination scores.

Table 3-6. *Exp 1 multiple regression of pitch discrimination for TD participants during tone task*

	B	SE *B*	β	*t*	*p*
PPVT- Receptive Vocabulary	1.05	0.48	0.47	2.21	0.041*

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

Comparison with Child and Adolescent Data

Whilst discrimination of analogue tones was linked to cognitive and clinical correlates in the ASD group and discrimination of speech pitch was linked to behavioural correlates in the TD group, the results presented above failed to replicate the significant group differences found in Heaton, Hudry, et al.'s (2008) study demonstrating enhanced pitch discrimination abilities in children with ASD. In order to further explore this discrepancy and attempt to understand the developmental trajectory of pitch processing in ASD the adult data from the present study was compared with previously obtained adolescent data (J. Mayer's MSc dissertation, 2009) and the child data from Heaton, Hudry, et al.'s (2008) child study.

The child and adolescent cohorts were each comprised of 14 children with ASD and 14 children with moderate learning difficulties and typical development. The two groups within the two cohorts were matched for chronological age and either verbal mental age (child cohorts) or performance IQ (adolescent cohorts). For both studies receptive vocabulary was assessed using the British Picture Vocabulary Scales (BPVS; Dunn, Dunn, Whetton & Burley, 1997). The children and adolescents were recruited from specialist and mainstream schools and school records were used to verify that individuals with ASD had been diagnosed by a paediatrician using current criteria. The adult cohort contained the 19 individuals with ASD and the 19 typically developing individuals described in chapter two of this thesis.

Table 3-7. *Exp 1 cohort comparison child, adolescent and adult participants' data*

	CA (months)		Receptive Vocabulary [a]	
	Mean (SD)	Range	Mean (SD)	Range
ASD Child	126.07 (47.53)	83-177	82.36 (18.00)	50-105
Control Child	126.28 (28.47)	60-169	77.71 (13.94)	53-106
ASD Adolescent	165.64 (23.46)	116-197	71.50 (22.94)	46-126
Control Adolescent	162.93 (10.54)	144-208	100.07 (16.14)	72-129
ASD Adult	482.79 (136.00)	285-716	105.63 (12.07)	76-123
Control Adult	459.79 (108.64)	301-632	106.05 (10.24)	84-125

Note: CA= chronological age, ASD= autism spectrum disorders
[a]British Picture Vocabulary Scales (BPVS), standard score (Dunn et al., 1997) (child and adolescent data) or Peabody Picture Vocabulary Test (PPVT), standard score (Dunn & Dunn, 1997) (adult data)

An ANOVA was conducted with within-subjects factors of stimulus type (2 levels; words and analogue contours of words) and pitch interval (4 levels; same, small, medium and large pitch differences) and between-subjects factor of group (6 levels; ASD adult, ASD adolescent, ASD child, TD adult, TD adolescent and TD child). The dependent variable was the percentage of correct responses made by each participant across the 10 trials at each pitch interval in each of the two stimulus types.

Means, standard deviations and ranges of the percentage or correct scores across pitch intervals for the word and analogue contour tasks are shown in table 3-8.

Table 3-8. *Exp 1 cohort comparison mean percentage correct scores, standard deviations and ranges*

ASD Child	Words		Analogue Contours	
N= 14	Mean (SD)	Range	Mean (SD)	Range
Same	89.28 (13.28)	60.00-100.00	89.28 (12.69)	60.00-100.00
Small	61.43 (29.05)	00.00-100.00	77.14 (28.94)	20.00-100.00
Medium	77.14 (22.68)	30.00-100.00	85.71 (19.50)	40.00-100.00
Large	85.71 (28.48)	00.00-100.00	88.57 (17.91)	50.00-100.00
Total	78.39 (18.54)	35.00-100.00	85.18 (16.74)	50.00-100.00
Control Child	Words		Analogue Contours	
N= 14	Mean (SD)	Range	Mean (SD)	Range
Same	79.28 (23.36)	30.00-100.00	85.00 (17.87)	50.00-100.00
Small	35.00 (28.22)	00.00-90.00	43.57 (29.77)	10.00-100.00
Medium	43.57 (32.49)	00.00-100.00	46.43 (28.98)	00.00-100.00
Large	52.14 (31.91)	00.00-100.00	74.28 (18.28)	40.00-100.00
Total	52.50 (22.81)	25.00-97.50	62.32 (18.22)	37.50-100.00
ASD Adolescent	Words		Analogue Contours	
N= 14	Mean (SD)	Range	Mean (SD)	Range
Same	90.00 (16.17)	50.00-100.00	85.71 (17.85)	40.00-100.00
Small	56.43 (30.03)	10.00-100.00	70.00 (29.61)	20.00-100.00
Medium	65.71 (29.80)	10.00-100.00	77.86 (26.94)	20.00-100.00
Large	81.43 (25.97)	10.00-100.00	86.43 (18.65)	50.00-100.00
Total	73.39 (21.49)	27.50-97.50	80.00 (19.83)	50.00-100.00
Control Adolescent	Words		Analogue Contours	
N= 14	Mean (SD)	Range	Mean (SD)	Range
Same	95.71 (6.46)	80.00-100.00	90.71 (17.30)	40.00-100.00
Small	36.43 (22.05)	00.00-80.00	52.86 (37.09)	00.00-100.00
Medium	50.00 (21.48)	20.00-90.00	65.00 (26.53)	20.00-100.00
Large	77.14 (15.41)	60.00-100.00	81.43 (16.57)	50.00-100.00
Total	64.82 (13.03)	52.50-97.50	72.50 (20.02)	40.00-100.00
ASD Adult	Words		Analogue Contours	
N= 19	Mean (SD)	Range	Mean (SD)	Range
Same	92.10 (16.18)	40.00-100.00	95.79 (9.01)	70.00-100.00
Small	40.00 (27.28)	10.00-100.00	64.74 (34.05)	20.00-100.00
Medium	63.16 (28.49)	10.00-100.00	73.68 (33.37)	10.00-100.00
Large	87.37 (20.23)	40.00-100.00	91.05 (15.60)	50.00-100.00
Total	70.66 (17.48)	40.00-100.00	81.31 (20.84)	37.50-100.00
Control Adult	Words		Analogue Contours	
N= 19	Mean (SD)	Range	Mean (SD)	Range
Same	95.79 (9.61)	60.00-100.00	98.42 (5.01)	80.00-100.00
Small	53.16 (27.29)	10.00-100.00	73.15 (26.68)	30.00-100.00
Medium	73.68 (25.21)	30.00-100.00	84.74 (21.18)	30.00-100.00
Large	93.68 (11.64)	60.00-100.00	95.79 (6.07)	80.00-100.00
Total	79.08 (14.49)	50.00-97.50	88.03 (13.53)	55.00-100.00

Note: Mean percentage correct scores (out of a maximum of 100)
Child data from Heaton et. al (2008c); Adolescent data from J. Mayer's MSc Dissertation (2009)

In order to assess the discrepancy between the present data from adults and previous data from children and adolescents, a mixed factorial analysis of variance

(ANOVA) was performed on the data across the groups for conditions one and two. Mauchly's test of sphericity was significant for the main effect of pitch interval, $\chi^2(5)$= 70.83, p<0.001 and the stimulus type by pitch interval interaction, $\chi^2(5)$= 20.67, p<0.001. Therefore, the F-values were corrected using the Greenhouse-Geisser corrected values of the degrees of freedom (Field, 2005). No correction was needed for the main effects of stimulus type or group (variables contained only 2 levels).

The analysis revealed a significant main effect of group with the non-autistic children experiencing significantly more difficulty than all of the other groups (ASD adult, M= 75.99, SD= 18.06; ASD adolescent, M= 76.70, SD= 19.01; ASD child, M= 81.78, SD= 17.02; Control adult, M= 83.55, SD= 13.04; Control adolescent, M= 68.66, SD= 14.53; and Control child, M= 57.41, SD= 18.90) (Fig. 3-5) when performing pitch discriminations $F(1, 93)$= 4.89, p<0.001.

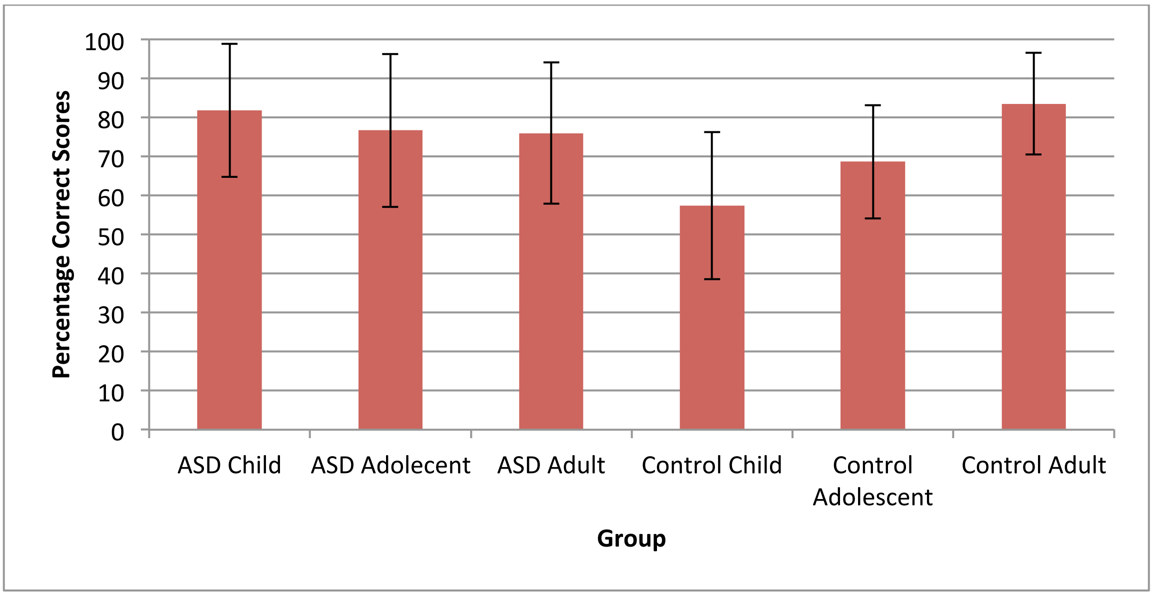

Figure 3-5. *Exp 1 cohort comparison main effect of group*

In order to further examine the significant main effect of group, a trend analysis was conducted. Within the control groups there were significant linear trends, indicating that as age group progressed, pitch discrimination abilities increased proportionately. This trend was present in word, $F(1, 44)= 20.31$, $p<0.001$ and analogue tone, $F(1, 44)= 18.27$, $p<0.001$, stimulus pairs as well as their overall pitch discrimination scores, $F(1, 44)= 23.19$, $p<0.001$. However, within the ASD groups, there were no significant linear trends, indicating that as age group progressed, pitch discrimination abilities remained relatively stable, regardless of whether the stimulus pair contained words, $F(1, 44)= 1.33$, $p= 0.255$, or analogue tones, $F(1, 44)= 0.32$, $p= 0.575$ and this was also true of their overall pitch discrimination scores, $F(1, 44)= 0.81$, $p= 0.372$. These results demonstrate that there do not appear to be any developmental change in enhanced pitch within the ASD population, however non-autistic individuals appear to acquire more accurate pitch discrimination abilities at a later developmental stage than the ASD group.

The analysis also revealed a significant main effect of stimulus type, $F(1, 93)= 38.16$, $p<0.001$, with no significant stimulus type by group interaction, $F(5, 93)= 0.25$, $p= 0.937$. Participants scored higher on the analogue contour stimuli condition (M= 78.22, SD= 19.70) than on the word stimuli condition (M= 69.81, SD= 19.59) (Fig. 3-6). Thus, the performance of participants across all six groups was poorer when stimuli included speech content.

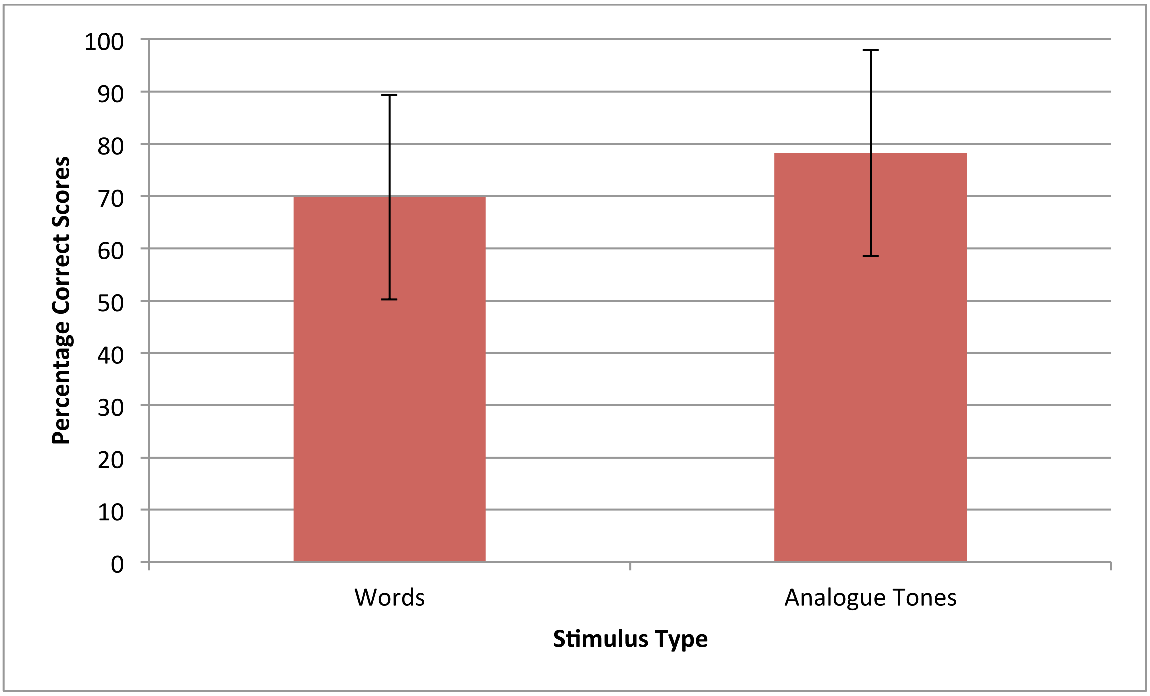

Figure 3-6. *Exp 1 cohort comparison main effect of stimulus type*

The main effect of pitch interval was also found to be highly significant, $F(1.94, 93) = 125.63$, $p<0.001$. Participants' demonstrated the highest level of accuracy when discriminating "same" pitches and their ability to correctly discriminate "different" pitches significantly improved as the size of the pitch interval difference increased (all comparisons $p<0.001$) (Fig. 3-7) (N.B. with a Bonferroni corrected p threshold).

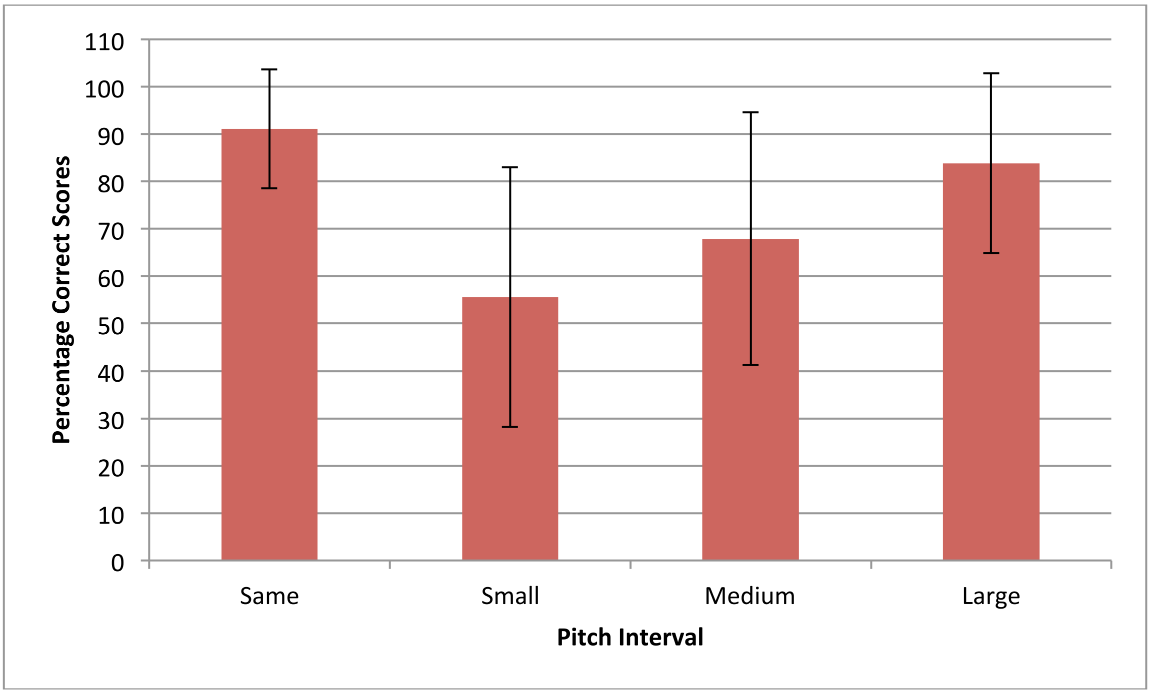

Figure 3-7. *Exp 1 cohort comparison main effect of pitch interval*

Additionally, there was a significant pitch interval by group interaction, *F*(15, 94)= 2.81, *p*<0.001 (Fig. 3-8). In order to further explore this interaction Gabriel post hoc pairwise comparisons were carried out and revealed that children in the control group were experiencing significantly more difficulty correctly discriminating pitches across all four of the pitch intervals than one or more of the other groups (Table 3-9).

Table 3-9. *Exp 1 cohort comparison Gabriel pairwise comparisons across groups and pitch intervals*

	Control Children			
	Same	Small	Medium	Large
ASD Child	NS	*p*<0.05	*p*<0.01	*p*<0.01
ASD Adolescent	NS	NS	NS	*p*<0.05
ASD Adult	NS	NS	NS	*p*<0.001
Control Adolescent	NS	NS	NS	NS
Control Adult	*p*<0.0	NS	*p*<0.01	*p*<0.001

Note: NS= non-significant in both groups; **p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

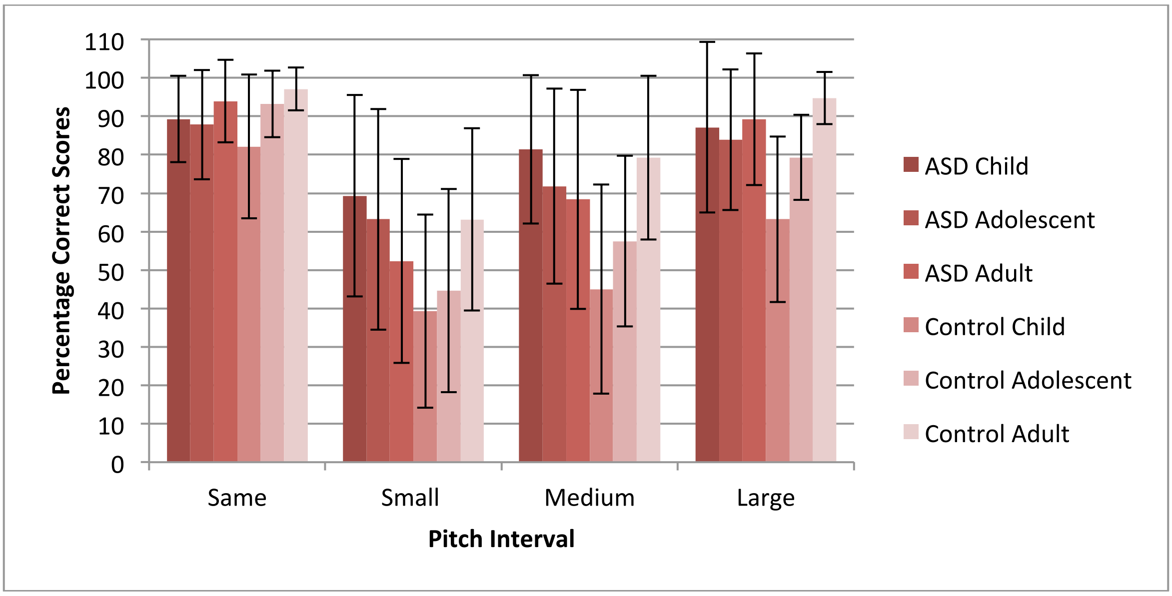

Figure 3-8. *Exp 1 cohort comparison pitch interval x group interaction*

Finally, the analysis also revealed a significant stimulus type by pitch interval interaction, $F(2.55, 93)= 10.15$, $p<0.001$ (Fig. 3-9). Post hoc pairwise comparisons (N.B. with a Bonferroni corrected *p* threshold of 0.013) revealed that participants made significantly more correct decisions on the "small", t(93)= -6.21, $p<0.001$, "medium", t(93)= -4.40, $p<0.001$ and "large" t(93)= -2.91, $p<0.01$ pitch intervals during the analogue contour stimuli than during the word stimuli. However, there was no significant difference in the participants' performance between the two tasks when the pitches were the same, t(93)= -0.45, $p= 0.650$. In addition, the stimulus type by pitch interval by group interaction was not significant, $F(15, 93)= 1.38$, $p= 0.154$, indicating that the interaction between stimulus type and pitch interval was generally the same across all six groups.

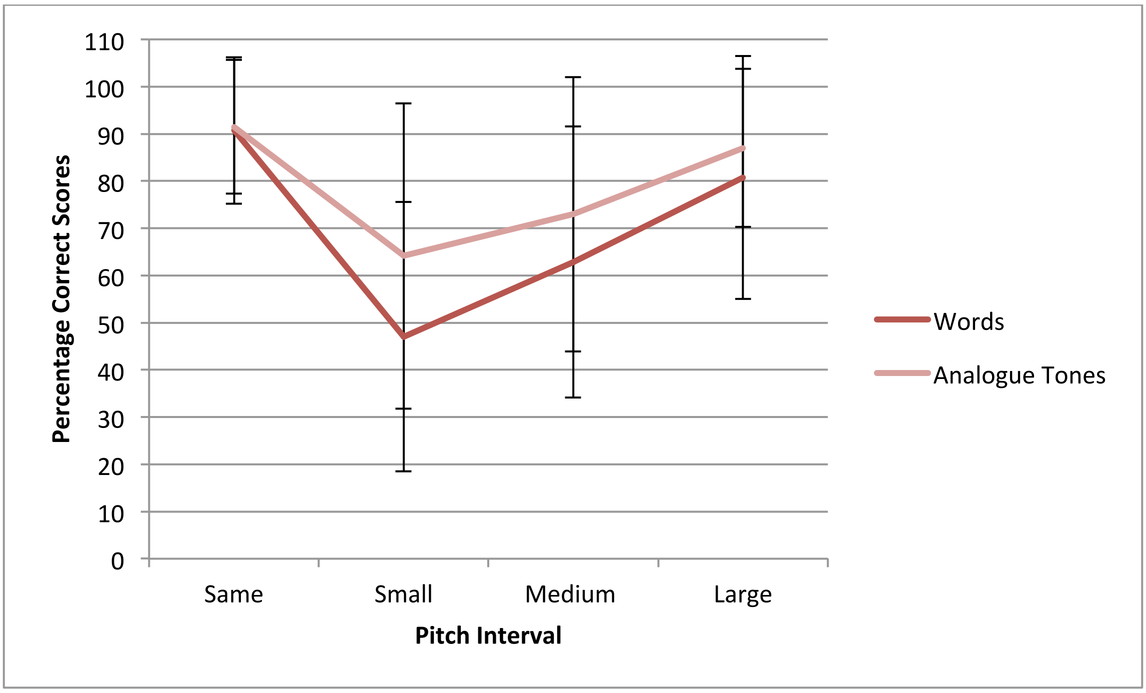

Figure 3-9. *Exp 1 cohort comparison stimulus type x pitch interval interaction*

DISCUSSION

The results from experiment one did not uncover enhanced pitch discrimination in adults with ASD in comparison to their typically developing peers. However, a similar pattern of performance to earlier findings by Heaton, Hudry, et al. (2008) were revealed with both groups demonstrating better pitch discrimination of analogue contours compared to words and performance improving as the pitch difference between the stimuli increased. Furthermore, the results from the comparison with child and adolescent data revealed a significant increase in pitch discrimination abilities from childhood and adolescence into adulthood within non-autistic individuals whilst the performance within the ASD cohorts remained relatively stable. These results suggests that perhaps adults with ASD in the present study were not demonstrating enhanced pitch discrimination not because their ability to identify perceptual information had decreased with age, but rather because non-autistic individual had become more aware of perceptual information in auditory stimuli over the course of their development.

The first hypothesis of experiment one was that individuals with ASD would demonstrate enhanced pitch in comparison to typically developing adults. The present did not confirm the first hypothesis or replicate Heaton, Hudry et al.'s (2008) findings, instead it showed that there was no significant difference in overall performance between the two groups. In fact, typically developing adults performed slightly better than individuals with ASD across all of the conditions. Furthermore, even on the most difficult pitch discrimination conditions where there was a small or medium pitch interval, adults with ASD did not demonstrate an enhanced sensitivity to pitch change in comparison to typically developing controls. Therefore, the present study did not provide support for previous studies that demonstrated enhanced discrimination of linguistic stimuli (Heaton, Williams, et al., 2008; Järvinen-Pasley & Heaton, 2007; Järvinen-Pasley, Pasley, et al., 2008). The results from the present study are more consistent with findings by Heaton et al. (2008) Jones et al. (2009) showing that atypical auditory discrimination abilities were not characteristic of most individuals with ASD. Taken together with the findings from the present study, it appears as though enhanced pitch discrimination abilities in individuals with ASD are more common in childhood and perhaps limited to a small selection of ASD individuals in adolescence and adulthood. Possible explanations for this change in pitch discrimination abilities will be further discussed with respect to the findings from the developmental comparison analysis. Furthermore, some evidence has suggested that enhanced pitch discrimination abilities are most characteristic of individuals who show significant language problems. For example Bonnel et al. (2010) found superior discrimination of pure tones in a group of individuals with autism, but not in an Asperger syndrome group. The adults with ASD in the present study were high-functioning and presented with normal to high language abilities. Thus, the findings from experiment one showing unremarkable pitch processing in high-functioning adults appear to provide some support for this argument.

The second hypothesis of the present study postulated that as individuals with ASD show a weaker semantic processing bias than their typically developing peers they would show similar levels of discrimination performance across speech and analogue conditions. However, both groups performed significantly better on the pitch analogue stimuli than they did on speech stimuli and this hypothesis was not supported. Furthermore, as there was no stimulus type by group interaction or pitch interval by group interaction, the results from the present study suggest that both groups were equally affected by a semantic processing bias, in the sense that speech was more difficult to process at the perceptual level than non-speech. The post-hoc comparisons on the significant stimulus type by pitch interval interaction confirmed that both groups experienced increased difficulty discriminating pitches in linguistic stimuli when the difference was small or medium. Thus, in the present study, individuals with ASD do not appear to have a weakened semantic processing bias, as defined above, compared with their typically developing peers. Additionally, it is possible that everyone may do worse on the semantic conditions because the psychoacoustic properties of speech make it difficult to disembed pitch and this problem is less marked in the analogue stimuli

However, one limitation of the present study is that the paradigm does not lend itself to signal detection analyses due to the disproportionate percentage of trials in which the stimulus pairs contained different pitches. In order to further examine Järvinen-Pasley et al.'s (2008) hypothesis of reduced domain specificity at a sensory level in individuals with ASD future research should utilise paradigms that lend themselves to this type of analysis. Increasing the number of 'same' stimulus pairs until there is an equal probability of same and different pairs would allow for the calculation of the c-statistic, which examines participants' response biases. The C-statistic enables researchers to determine whether individuals with ASD demonstrate a weakened semantic processing bias in comparison to typically developing individuals by examining individuals' tendencies to identify stimulus pairs as 'same' or 'different' across linguistic and non-linguistic stimuli.

The third hypothesis of the present study was to examine how cognitive, behavioural and clinical correlates may influence auditory processing in individuals with ASD. Previously, researchers have linked language deficits to atypical auditory processing that characterises autism spectrum disorders (Järvinen-Pasley & Heaton, 2007; Järvinen-Pasley, Pasley, et al., 2008; Järvinen-Pasley, Wallace, et al., 2008; Kjelgaard & Tager-Flusberg, 2001). However receptive vocabulary and verbal IQ scores were not significantly correlated with pitch discrimination abilities on either the word or the tone task in the ASD group. This suggests that language may not be as closely associated with atypical auditory processing as researchers previously thought. However, it is important to note that the individuals who participated in this study represent the very high-functioning end of ASD. Future research should aim to explore whether the association between language deficits and atypical auditory processing is present in lower functioning individuals. Nevertheless, exploratory regression analyses found that higher working memory scores predicted an increase of 5% in an ASD individual's pitch discrimination scores during the analogue tone tasks. This suggests that individuals who have better working memories also have an easier time identifying pitch changes in complex tones. Furthermore, higher levels of symptom severity on the reciprocal social interaction subscale of the ADOS predicted a decrease of 6% in an individual's pitch discrimination scores during the analogue tone task. Thus, it appears that individuals who are experiencing more autistic symptomatology are having more difficulty identifying pitch changes in complex tones.

More intriguing perhaps is the pattern of relationships found between typically developing participants' performance on the experimental tasks and cognitive, behavioural and clinical correlates. Within the TD group higher scores on the sensation avoiding subscale of the Sensory Profile and receptive vocabulary scores on the PPVT predicted an increase of 1% in a TD individual's pitch discrimination scores during the word and analogue tone tasks respectively. The relationship between sensation avoiding and an individual's ability to identify pitch changes in words suggests that typically developing individuals who are experiencing more sensory processing abnormalities are better able to discriminate pitch changes in speech. Thus, this result tentatively suggests that typically developing individuals who experience higher levels of ASD symptomatology in terms of sensory processing abnormalities are better able to identify more subtle perceptual changes to speech stimuli. This could provide support for the final hypothesis of this experiment and the argument that the tail of the ASD spectrum extends to typically developing individuals.

An interesting question addressed in this chapter was why experiment one failed to replicate Heaton, Hudry, et al.'s (2008) findings of enhanced pitch discrimination abilities in children with ASD in this adult sample. The adult data from the present study was compared with adolescent data previous collected during J. Mayer's MSc dissertation (2009) and the child data from Heaton, Hudry, et al.'s (2008) study. The results revealed that whilst non-autistic and ASD adults show similar levels of pitch discrimination on the experimental task, the developmental trajectories leading to these performance levels distinguish the two groups. This suggests that adults with ASD in the present study are not demonstrating enhanced pitch discrimination not because their ability to identify perceptual information has decreased, but rather because typically developing individuals have become more aware of perceptual information in auditory stimuli over the course of their development. This could perhaps be due to the fact that typically developing individuals are initially biased towards focusing on semantic information at the expense of perceptual processing. However, once their language processing abilities are fully established they are able to effectively process the two streams of information, semantic and perceptual, simultaneously. Conversely, the local processing bias, often found in ASD, may cause individuals to process both streams of information simultaneously from an early age. Such an approach to auditory processing could explain the language deficits found in ASD as well as the enhanced awareness of perceptual information revealed in previous research and suggested by the EPF theory. In order to further explore this question of the developmental trajectory of atypical auditory processing in ASD, future research should utilise neuroimaging techniques and longitudinal studies with extensive language and music profiling to examine the areas of the brain that are involved in different aspects of auditory processing and map changes over time.

Whilst the developmental trajectory data offers an intriguing explanation for some of the atypical auditory processing seen in ASD, this finding should be interpreted with caution. The comparison across age groups utilised cross-sectional data that was collected as part of three separate studies, thus although matching criteria was consistent within each cohort, it was not consistent across cohorts. Additionally, both the child and adolescent cohorts included intellectually lower-functioning ASD individuals and in order to match across groups the control groups contained some individuals with mild to moderate learning difficulties. Thus although the present study suggests that the developmental trajectory of auditory processing may be atypical in ASD, future studies should seek to employ a longitudinal cohort design, in which ASD groups are carefully matched on diagnostic measures and verbal and non-verbal intelligence. In addition, to more closely examine the relationship between sensory processing abnormalities and receptive vocabulary, future studies should also seek to examine the interaction between the development of these abilities and co-occurring perceptual and semantic processing biases in these individuals. The data presented here suggests that the enhanced perception of pitch information may be characteristic at early stages of development in ASD and may also be relatively independent of cognitive abilities. The EPF theory of ASD (Mottron, et al., 2006) suggests that the default setting of autistic perception is more locally oriented than that of individuals without ASD and the present results are consistent with this. For those without ASD, speech pitch discrimination abilities appear to come on line later in development when individuals possess cognitive abilities that enable them to adopt specific processing strategies.

Previous research has suggested that findings of enhanced pitch processing of speech in children with ASD are important given the frequently reported deficits in prosodic and semantic processing. Furthermore it has been suggested that overly selective attention towards the perceptual components of speech may hinder the development of higher-level language processing and even in some cases inhibit language acquisition in individuals with ASD (Schreibman, Kohlenberg & Britten, 1986). However, the results from the present study suggest that the tendency to focus on the perceptual components of the speech signal previously found in children with ASD does not persist into adulthood. Thus, the question of whether attentional resources normally allocated to the semantic, or meaningful aspects of speech, are implicated in language perception difficulties in ASD still remains unclear. The clinical literature abounds with descriptions of children with ASD who appear to demonstrate increased understanding of instructions that are either monotone or sung, although this has yet to be investigated empirically. Experiment three will therefore investigate whether changes in the pitch contours of sentences directly limit encoding of speech in intellectually high-functioning adults with ASD.

CHAPTER 4: PROSODY AND SENTENCE RECALL

SUMMARY

Although abnormal prosody appears to be a pervasive feature in individuals with ASD, most research has focused on expressive rather than receptive prosody. Whilst there are numerous anecdotal reports of comprehension improvements in response to flattened or exaggerated prosody in ASD this has yet to be studied experimentally. The present study aimed to extend research on prosodic processing in ASD by investigating the effect of prosodic contour manipulations on speech encoding and memory. The findings indicated that for both the typically developing and ASD groups recall ability was influenced by changes in prosodic contours, although there was no difference at the group level. Infant research shows that prosody is important for language acquisition and development and studies of adults with ASD have revealed links between prosodic, social and communication difficulties. Thus, the relationship between responses to prosodic manipulations, language abilities, as well as other aspects of ASD symptomatology in high-functioning adults will be explored and discussed.

INTRODUCTION

As previously suggested, the results from studies showing enhanced pitch processing in individuals with ASD have been considered in the context of "assets" in ASD, for example in facilitating preserved musical processing (Heaton, 2009). However, abnormalities in aspects of language involving pitch components appear to be universal in ASD and have been observed in children with enhanced pitch discrimination. For example, in Järvinen-Pasley, et al.'s (2008) study of high-functioning children and adolescents with ASD, participants with superior pitch discrimination were unable to use this knowledge in order to determine whether sentences were questions or statements. Speech has many constantly fluctuating perceptual components. In addition to pitch, it has tempo and timbre and these may interfere with an autistic individual's understanding of the linguistic aspects of speech, especially if these perceptual components are more salient than the semantic content.

In linguistics, prosody is defined as the suprasegmental features of speech that are important for modulating and enhancing meaning. These features include pitch, intonation, stress, loudness, rate, duration, rhythm and pausing (O'Connor, 2012). McCann and Peppé (2003) categorise prosodic function in speech into three subdomains: grammatical, pragmatic and affective. Grammatical prosody involves features such as pausing, stress and pitch contours to indicate syntactic information within sentences (Warren, 1996) and this will be discussed in more detail in chapter six. Pragmatic prosody also involves stress and pitch changes and often conveys the speaker's intentions or emphasises important information (Winner, 1989). On the other hand, affective prosody serves a more global function than either of the two other subdomains (Paul, Augustyn, Klin & Volkmar, 2005). Affective prosody involves many of the suprasegmental features of speech for a variety of social functions including conveying the speaker's feelings (Hargrove, 1997).

Abnormal prosody has been noted as a core feature of ASD since the original observations made by Kanner (1943). Prosodic abnormalities in ASD are generally noted in terms of expressive prosody and range from robotic, monotone intonation patterns, deficits in volume control and pitch and unusual stress patterns (Paul et al., 2005). Furthermore, unusual expressive prosody is reported across the spectrum, even within individuals with high-functioning autism and Asperger syndrome (Shriberg et al., 2001). However, these deficits are not universal with studies reporting abnormal prosody in between 47% (Paul et al., 2004) to 57% (Simmons & Baltaxe, 1975) of the ASD samples tested. Furthermore, despite improvement in other areas of language, unusual speech prosody appears to persist (DeMyer et al., 1973; Kanner, 1971; Rutter & Lockyer, 1967; Simmons & Baltaxe, 1975). This is particularly concerning considering that prosodic characteristics are significantly correlated with independent living in intellectually impaired adults (Shriberg & Widder, 1990) and findings by Paul et al. (2004) indicate that the level of social and communicative competence observed in individuals with ASD is significantly related to their prosodic difficulties.

Most of the research to date on abnormal prosody in individuals with ASD focuses on their expressive rather than receptive abilities (McCann & Peppé, 2003). Furthermore, most of the research into the perception of prosody examines affective prosody and utilises research paradigms in which participants are required to match emotionally expressive sentences to descriptor words. Rutherford, Baron-Cohen and Wheelwright (2002) compared the performance of adults with ASD to typically developing adults and found that ASD individuals had difficulty extracting mental state information from vocalisations. Furthermore, studies have found that children, adolescents and adults with ASD demonstrated impaired processing of more complex vocal expression such as embarrassment or pride (Golan, Baron-Cohen & Hill, 2006; Golan, Baron-Cohen, Hill & Rutherford, 2007; Kleinman, Marciano & Ault, 2001). Other studies have also examined individuals' ability to match vocal expressions to expressive faces and reported greater levels of difficulty within ASD groups (Hall, Szechtman & Nahmias, 2003; Hobson, Ouston & Lee, 1988). However, it is unclear whether these results are due to impaired perception of affective prosody or just indicative of difficulties integrating audio-visual stimuli. Researchers often interpret their findings within the context of the Theory of Mind (ToM) hypothesis and attribute impaired processing of affective prosody to difficulties making mental state attributions (O'Connor, 2012). Other studies examining ASD individuals' ability to perceive prosody have focused on components of linguistic prosody such as stress. McCann, Peppé, Gibbon, O'Hare & Rutherford (2007) found that all of a sample of 31 intellectually able children with ASD had difficulties with at least one aspect of receptive prosody, even after adjusting for mental age. Additionally, Paul et al. (2005) examined participants' productive and receptive prosodic abilities across the areas of stress, intonation and phrasing. The only area in which individuals with ASD were found to be impaired was on stress and this was consistent across pragmatic/affective and emphatic linguistic information. Although they did not find any significant deficits in the perception of intonation or phrasing prosodic information in the ASD group, the authors suggested that this could be due to ceiling performance on some of the tasks. Linguistic prosody is an under-researched area of prosody abnormalities in individuals with ASD.

Research has suggested a developmental link between prosody and language, indicating that prosody may play an important role in the language acquisition process. According to Price, Ostendorf, Shattuck-Hufnagel and Fong (1991) infants as young as four days old are able to distinguish a familiar from unfamiliar language on the basis of prosody alone. Furthermore, Cooper and Aslin (1990) found that infants prefer child-directed speech, suggesting that they are highly sensitive to linguistic prosody. However, as discussed in chapter one of this thesis, children with ASD often do not exhibit the same preference for motherese that is demonstrated in typically developing children (Klin, 1991, 1992). Additionally Kuhl, Coffey-Corina, Padden and Dawson (2005) found that autistic children who spent more time orienting to motherese speech also exhibited better receptive language skills, further underscoring the role that prosody plays in language acquisition. Morgan & Demuth (1995) put forth the 'prosodic bootstrapping hypothesis', which suggests that in order to segment the constant stream of speech they experience they need to be sensitive to subtle prosodic differences. Research has also shown links between infants' prosody preferences and developmental language disorders (Jusczyk et al., 1992; Jusczyk, Cutler & Redanz, 1993), as well as prosodic impairment and specific language impairment (SLI) (Gerken & McGregor, 1998). Whilst children with SLI demonstrate subtle prosodic problems, they rarely exhibit the overt prosodic difficulties seen in ASD. Thus, it is highly probably that the relationship between prosody and language abilities in children with SLI is also apparent, perhaps even to a greater degree, in individuals with ASD. However, few studies have examined the relationship between prosodic abilities and other aspects of language in ASD and those that have only looked at these abilities in children (McCann & Peppé, 2007).

An aspect of prosody that has yet to be investigated concerns the impact of abnormal perception of prosody on memory encoding and recall of speech stimuli. There are numerous anecdotal reports, from speech therapists, music therapists and others professionals, suggesting that speech comprehension improves when speech is flattened or the prosodic contours are exaggerated or sung. Whilst there are no current data addressing the question of why this might occur, it could be speculated that flattening speech contours serves to increase the salience of the semantic content for an individual with a strong interest in pitch information. Exaggerated prosody could enable listeners without a strong interest in pitch to segment the speech stream. Given that studies show that many individuals with ASD do not show enhanced processing of pitch it is plausible to suggest that different approaches to increasing speech comprehension will serve different functions.

In experiment one, reported in chapter three, enhanced pitch discrimination was not observed in the ASD group. This result was surprising given the large numbers of studies that have shown enhanced pitch in ASD (Bonnel et al., 2003, 2010; Heaton, 2003; Heaton, Davis, et al., 2008; Heaton et al., 1998, 1999; Heaton, Williams, et al., 2008; Jones et al., 2009; Järvinen-Pasley, Wallace, et al., 2008; Mottron et al., 2000). However, one explanation for this finding might be that experiment one was an explicit task in which participants were directly instructed to distinguish between stimuli varying in pitch. This may have served to increase pitch discrimination in the control group. It may then be the case that group differences will emerge in a study where the effects of enhanced pitch are tested implicitly, for example in a memory recall task.

In order to examine the effect of prosody on memory and encoding for speech in high-functioning adults with ASD, sentence repetition tasks were utilised in which participants were required to listen to prosodically manipulated sentences and then perform immediate verbatim recall. Sentences were presented in either monotone or exaggerated prosody to mimic the ‘flat’ and ‘singsong’ productive prosody styles often reported in individuals with ASD. Recall accuracy and speed on the two prosodically manipulated conditions were compared with baseline recall of sentences spoken in natural speech pitch in order to examine the extent that memory and encoding for speech is effected by prosody within individual participants.

EXPERIMENT 2 PILOT STUDY: TESTING ENCODING AND MEMORY OF PROSODICALLY MANIPULATED SPEECH

Aims

This pilot study aims to develop a set of stimuli with prosodic manipulations that can be utilised to increase our understanding of the effect of prosody on encoding and memory of speech in ASD and typically developing individuals with high and low levels of autistic traits.

Hypotheses

1. Individuals with ASD will have more difficulty encoding and recalling speech with an exaggerated pitch contour rather than monotone.
2. It is hypothesised that TD individuals with higher levels of autistic traits, as measured by the AQ, will be more affected by prosodic manipulations to speech in comparison to the rest of their cohort.

METHODS

Participants and Background Measures

Nine adults with ASD were recruited and participated in the pilot study. One participant was female and eight were male. All of the adults in the ASD group were recruited from local support and social groups. The participants all had a previous diagnosis of ASD performed by a clinician. 17 adults with typical development (controls) were recruited from the 1st year undergraduate psychology experiment credit scheme at Goldsmiths College. 12 of the TD participants were female and five were male. In order to assess continuum hypothesis of ASD, the control group was divided into two groups based on their self-reported levels of autistic traits as assessed by the Adult Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001). The cut-off score for the AQ is 32, therefore individuals who scored at or above the median of 16 were considered to have high levels of autistic traits (N= 8) and those who scored 15 and below were placed in the low autistic trait group (N= 9). In addition to the AQ, the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997), a test of receptive vocabulary with adult norms, was administered to all three groups.

Table 4-1. *Exp 2 pilot participant background data*

	ASD N= 9		HAQ N= 8		LAQ N= 9	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
CA (mos)	333.89 (101.01)	234-510	244.00 (17.26)	224-273	241.11 (31.30)	223-322
AQ [a]	21.67 (7.91)	7-31	19.00 (3.59)	16-27	10.56 (3.84)	5-14
PPVT[b]	86.89 (16.94)	66-120	96.00 (10.01)	81-109	109.44 (7.45)	103-119

Note: CA= chronological age, ASD= autism spectrum disorders, HAQ= high autistic traits, LAQ= low traits; [a]Adult Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001) [b]Peabody Picture Vocabulary Test (PPVT), standard score (L. M. Dunn & Dunn, 1997)

Experimental Methods

Experimental Stimuli

The pilot study for experiment two was designed to test the effect of pitch manipulations on word recall during sentence repetition. The paradigm for this pilot study was derived from a variation of the sentence repetition study developed by Tun, Wingfield, Stine & Mecsas (1992). Sentence stimuli consisted of 30, 15-word sentences randomly selected from the 60 sentences used by Tun et al. (1992) (Appendix I). The sentences were recorded by an adult British English speaking female and manipulated using PRAAT (Boersma, 2001) to generate three different prosody conditions: monotone speech, typical speech prosody and exaggerated speech prosody. Typical speech prosody acted as the control condition and was developed by adjusting the original sentences to the mean intensity (perceived volume) and a median pitch of 200Hz, which removed any inconsistencies that were artefacts from the recording process. The monotone condition was characterised by a reduction of speech prosody and was generated by adjusting the pitch range of the typical speech stimuli to 0, thus eliminating the pitch contour from the sentences. The final condition, exaggerated prosody, represented extreme speech prosody in which the pitch range of the typical speech stimuli was adjusted to 4, increasing the high pitch points or decreasing the low pitch points in the sentence by a factor of 4. An E-Prime programme was designed to randomly select and randomise the presentation of 10 sentences in each of the three conditions for every participant to adjust for any inherent differences in the sentences.

Procedure

Participants were administered three practice sentences, one under each condition and asked to perform a verbatim recall immediately following the end of the recorded sentence. The researcher informed participants to repeat as much of the sentence as they could remember, in the order that they heard it and to omit any words they could not recall. Following the practice trials, 30 experimental sentences were administered in the same format. Participants received one point for each correct word that was produced in the correct place within the recalled sentence. No points were awarded for words that were either incorrect or in the wrong order. Raw scores were calculated by counting the number of points each participant achieved with a maximum of 150 in each condition and 450 overall. Raw scores for each condition were converted to percentages for the analysis.

Analysis

A factorial analysis of variance (ANOVA) was used to analyse the data from the pilot study with the within-subjects factor of prosody condition (3 levels; monotone, typical speech prosody and exaggerated prosody) and between-subjects factor of group (3 levels; ASD, HAQ and LAQ). The dependent variable was the percentage of correct responses made by each participant across the 10 sentences in each prosody condition.

RESULTS

Accuracy Analysis

Means, standard deviations and ranges for the percentage correct scores across prosody manipulations are shown in table 4-2.

Table 4-2. *Exp 2 pilot mean percentage correct scores, standard deviations and ranges*

	ASD N= 9		HAQ N= 8		LAQ N= 9	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Mono	55.60 (18.27)	30.00-78.00	75.83 (10.07)	58.00-92.67	79.55 (8.18)	65.33-90.00
Normal	58.22 (20.27)	28.00-86.00	78.75 (11.31)	58.67-92.67	85.92 (6.87)	71.33-96.00
Exag.	57.26 (21.02)	32.67-96.67	74.92 (12.67)	48.00-88.00	80.44 (11.25)	61.33-96.67
Total	57.16 (19.26)	30.22-86.89	76.50 (10.81)	54.89-89.56	81.98 (6.51)	73.11-94.22

Note: Mean percentage correct scores (out of a maximum of 100)

A factorial analysis of variance (ANOVA) was performed on the data across the groups for this experiment. Mauchly's test of sphericity was not significant, $\chi^2(2)= 0.54$, $p= 0.764$, for the main effect of prosody, indicating that the assumption of sphericity had been met. Therefore, no F-value corrections were needed (Field, 2009).

The main effect of prosody on participants' sentence recall abilities was approaching significance, $F(2, 26)= 2.98$, $p= 0.061$ (Fig. 4-1) (M= 70.46, SD= 16.46 for monotone, M= 74.30, SD= 18.18 for normal and M= 70.87, SD= 18.21 for exaggerated prosody). In order to examine the a priori hypothesis that individuals with ASD would have more difficulty recalling speech with exaggerated prosody than monotone, pairwise comparisons were conducted. Further comparisons revealed that participants experienced more difficulty when recalling sentences that were spoken in monotone ($p<0.05$) or exaggerated ($p= 0.078$) speech prosody compared with normal speech prosody. However there was no significant difference between participants' performance on the moderate and exaggerated speech prosody conditions, $p= 0.808$. These results suggest that individuals experience more difficulty recalling sentences whenever pitch deviates from the norm.

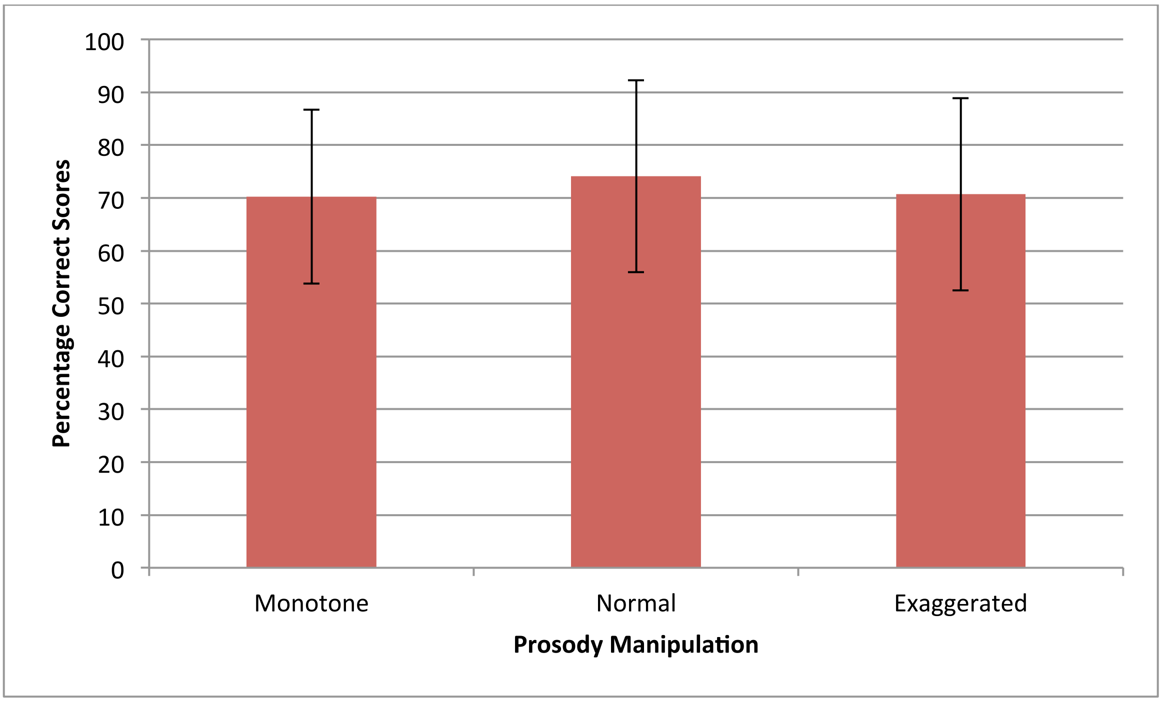

Figure 4-1. *Exp 2 pilot main effect of prosody*

There was also a highly significant main effect of group on the participants' sentence recall abilities, $F(1, 26)= 8.47$, $p<0.01$ (Fig. 4-2). The ASD group produced significantly fewer correct responses than both the HAQ group ($p<0.05$) and the LAQ group ($p<0.001$). However, there was no significant difference between the performance of typically developing individuals with high and low levels of autistic traits, $p= 0.409$ (M= 57.16, SD= 19.26 for ASD, M= 76.50, SD= 10.81 for HAQ and M= 81.97, SD= 6.51 for LAQ). This suggests that the ASD group had more difficulty recalling sentences overall than either of the two control groups, regardless of whether TD individuals had high or low levels of autistic traits. Furthermore, there was no significant pitch manipulation by group interaction, $F(4, 26)= 0.44$, $p= 0.778$.

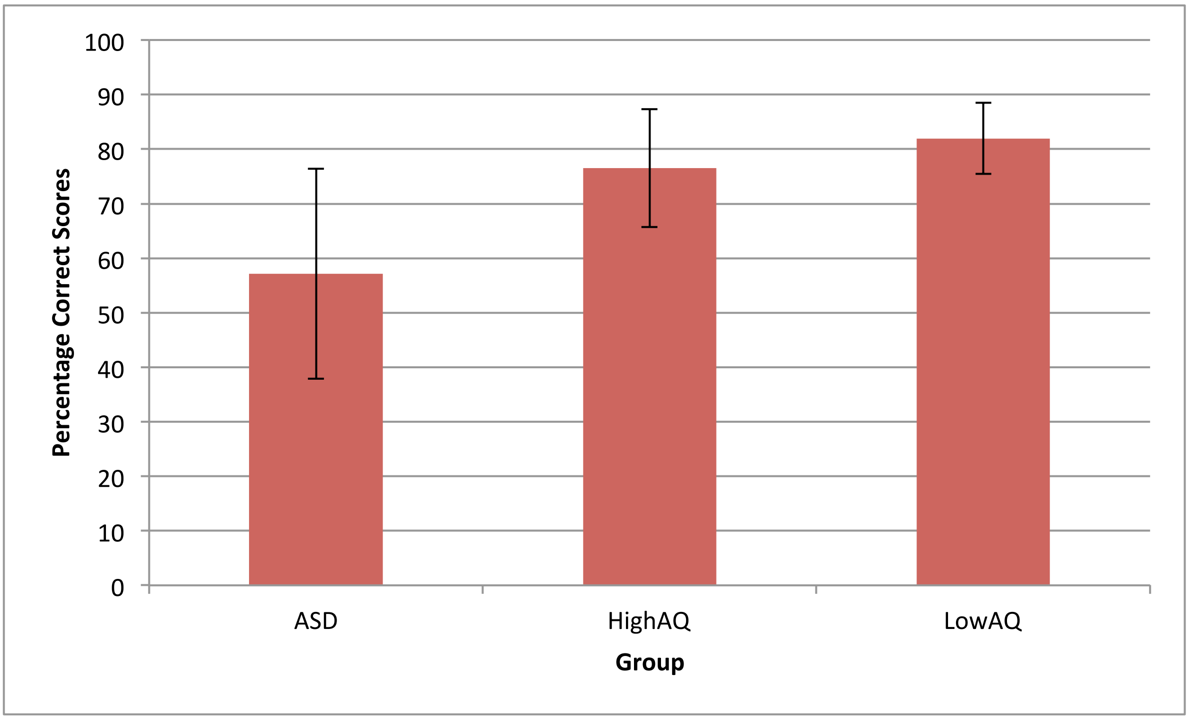

Figure 4-2. *Exp 2 pilot main effect of group*

BRIEF DISCUSSION

The aim of this pilot study was to generate a set of stimuli that could be used to assess encoding and recall of prosodic speech in individuals with ASD. The results suggest that prosodic manipulations made to the sentence stimuli were able to generate a different pattern of responses in which there was a trend towards individuals experiencing more difficulty on conditions in which linguistic prosody deviated from the norm. Furthermore, the ASD group experienced significantly more difficulty than either of the two control groups, which suggests that prosodic change strongly impacts on speech encoding and recall in this group. As the two control groups demonstrated a similar pattern of performance on the task, experiment two will recruit typically developing individuals with a range of autistic traits into one control group. Despite the small group sizes the results from the pilot study show that the paradigm and prosodic manipulations developed for experiment two are sensitive enough to pick up subtle effects of prosody and are suitable for examining processing differences distinguishing individuals with ASD and their typically developing peers.

EXPERIMENT 2: TESTING ENCODING AND MEMORY OF PROSODICALLY MANIPULATED SPEECH

Aims

The present study aims to increase our understanding of the effect of prosody on encoding and memory of speech in ASD using the paradigm and stimuli developed and tested in the pilot study previously discussed. In addition to analysing accuracy scores, the present study will also incorporate the use of recall times in order to examine some of the more subtle differences in the processing of linguistic prosody. In order to extend the findings from the previous chapter the relationship between sensitivity to small perceptual changes in linguistic stimuli and one's ability to encode and recall prosodic speech will be explored. This will allow for a discussion of the extent that encoding and memory of speech may be associated with increased perceptual processing in ASD.

Despite the fact that enhanced pitch processing abilities are often discussed in terms of "assets" in individuals with ASD, it is unclear what impact such abilities may have in other areas, especially speech processing. Heaton, Davis and Happé (2008) described a single case study (AC) in which an ASD individual begun to exhibit absolute pitch abilities by the age of three yet did not produce his first meaningful sentence until around six years of age. Whilst it is unclear whether there was a direct relationship between AC's absolute pitch skills and his delayed language acquisition, anecdotal reports of him asking his father "why when you call 'dinner is ready' (do) you make a D and mom makes an A?" (Heaton et al., 2008, p. 2096) are suggestive of the interaction between enhanced pitch and communication in his everyday life. Thus, another aim of the present study was to examine the relationship between any effects of enhanced pitch processing and other aspects of speech processing.

As previously discussed, research has suggested that prosody may play a role in language development. Studies have investigated prosodic preferences in infants and also examined the relationship between these early preferences and language disorders. However, the majority of these studies have been carried out with young children and the relationship between later language abilities and prosodic abnormalities is not well understood. Thus, another aim of experiment two is to explore the relationship between cognitive, behavioural and clinical correlates and abnormal receptive prosody.

Hypotheses

1. Individuals in both groups will experience more difficulty encoding and recalling prosodic speech that deviates from the norm.
2. Individuals with ASD will have more difficulty encoding and recalling speech with an exaggerated pitch contour rather than monotone.
3. Individuals who were better able to discriminate small pitch changes in linguistic stimuli will experience more perceptual capture when linguistic prosody deviates from the norm.
4. Individuals with ASD with increased language, sensory and communication abnormalities and ASD symptomatology will be more affected by prosodic manipulations made to speech.

5. It is hypothesised that TD individuals with higher levels of autistic traits, as measured by the AQ, will be more affected by prosodic manipulations to speech in comparison to the rest of their cohort.

METHODS

Participants

All 38 participants described in chapter two of this thesis participated in the present study.

Experimental Methods

Experimental Stimuli

The experimental stimuli for experiment two were the same as that described in the pilot study.

Procedure

The procedure for experiment two was carried out in the same manner as in the pilot study previously described. However, during the experimental trials, participants' responses were also timed and recorded for later analysis. Recall times were measured from the end of the last word in the sentence stimulus to the end of the participants' response.

Analysis

Discrepancy scores were generated for each participant in order to account for any individual differences in working memory, language comprehension, or speech rate that may have affected their performance. Participants' percentage correct scores and recall times on the perceptual manipulation conditions were subtracted from their scores on the normal speech (baseline) condition in order to calculate their individual levels of perceptual disturbance for accuracy and recall time analyses.

A factorial analysis of variance (ANOVA) was used to analyse the data from experiment two with the within-subjects factor of prosody condition (2 levels; monotone and exaggerated prosody) and between-subjects factor of group (2 levels; ASD and controls). The dependent variables for the accuracy analysis and recall time analysis were the discrepancy scores and recall times respectively for each participant across the 10 sentences in each prosody condition.

RESULTS

Accuracy Analysis

Means, standard deviations and ranges for the percentage correct scores across pitch manipulations are shown in table 4-3.

Table 4-3. *Exp 2 mean percentage correct scores, standard deviations and ranges*

	ASD		TD	
	Mean (SD)	Range	Mean (SD)	Range
Monotone	75.68 (17.47)	36.67-96.76	75.23 (12.79)	42.00-92.67
Normal Prosody	78.21 (14.39)	38.67-98.00	78.25 (13.26)	39.33-94.00
Exaggerated	76.10 (15.91)	47.33-97.33	74.88 (11.44)	50.00-90.00
Total	76.66 (15.21)	42.44-97.33	76.12 (11.74)	43.78-89.33

Note: Mean percentage correct scores (out of a maximum of 100)

Discrepancy score means, standard deviations and ranges for the discrepancy scores across pitch manipulations are shown in table 4-4.

Table 4-4. *Exp 2 discrepancy scores, standard deviations and ranges*

	ASD		TD	
	Mean (SD)	Range	Mean (SD)	Range
Monotone	2.52 (6.82)	-8.67-17.33	3.02 (7.13)	-12.00-18.67
Exaggerated	2.15 (9.74)	-14.67-17.33	3.37 (6.87)	-12.00-15.33

Note: Negative scores signify better performance on perceptual manipulation in comparison to baseline

A factorial analysis of variance (ANOVA) was performed on the data across the groups for this experiment. Mauchly's test of sphericity was not necessary for the main effects of group or stimulus types as these variables contained only two levels and thus the assumption of sphericity was automatically met.

There was no significant main effect of pitch manipulation on participants' sentence recall, $F(1, 38)= 0.001$, $p= 0.980$. Participants' performance indicated near identical levels of performance when recalling sentences spoken with an exaggerated prosody or monotone (M= 2.77, SD= 6.89 for monotone and M= 2.74, SD= 8.34 for exaggerated prosody) (Fig. 4-3). Therefore, individuals did not appear to experience different levels of perceptual disturbance when encoding and recalling speech that was spoken in monotone or exaggerated prosody. In order to examine whether participants experienced significantly more disturbance in the two conditions with prosodic manipulations than normal speech alone, a one-sample t-test was conducted. A mean value of 0 that would indicate identical accuracy when recalling perceptually manipulated speech and normal speech, was used. Results revealed a significant difference between discrepancy scores on the monotone, $t(37)= 2.48$, $p<0.05$ pitch condition and 0 and the exaggerated, $t(37)= 2.02$, $p<0.05$ condition and 0. Thus, the present results suggest that participants showed reduced recall in the two conditions with abnormal linguistic prosody in comparison to normal speech.

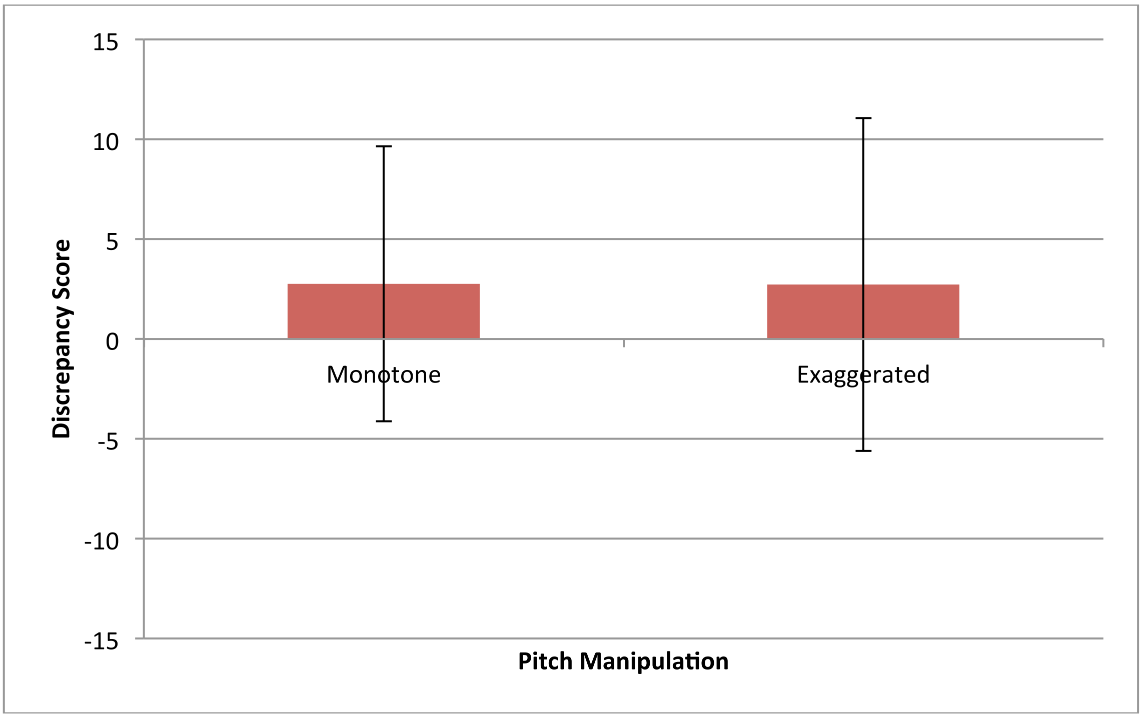

Figure 4-3. *Exp 2 main effect of pitch manipulation*
Note: Higher scores indicate increased perceptual disturbance from prosody

There was also no significant main effect of group on the participants' sentence recall abilities, $F(1, 38)= 0.17$, $p= 0.679$. However, results indicated that typically developing individuals experienced slightly more difficulty when encoding and recalling sentences with pitch manipulations in comparison to ASD participants (M= 2.32, SD= 7.25 for ASD and M= 3.19, SD= 5.59 for TD) (Fig. 4-4). Thus, individuals with ASD do not appear to experience more difficulty than typically developing individuals when recalling sentences with abnormal linguistic prosody. Furthermore, there was no significant pitch manipulation by group interaction, $F(1, 38)= 0.08$, $p= 0.781$.

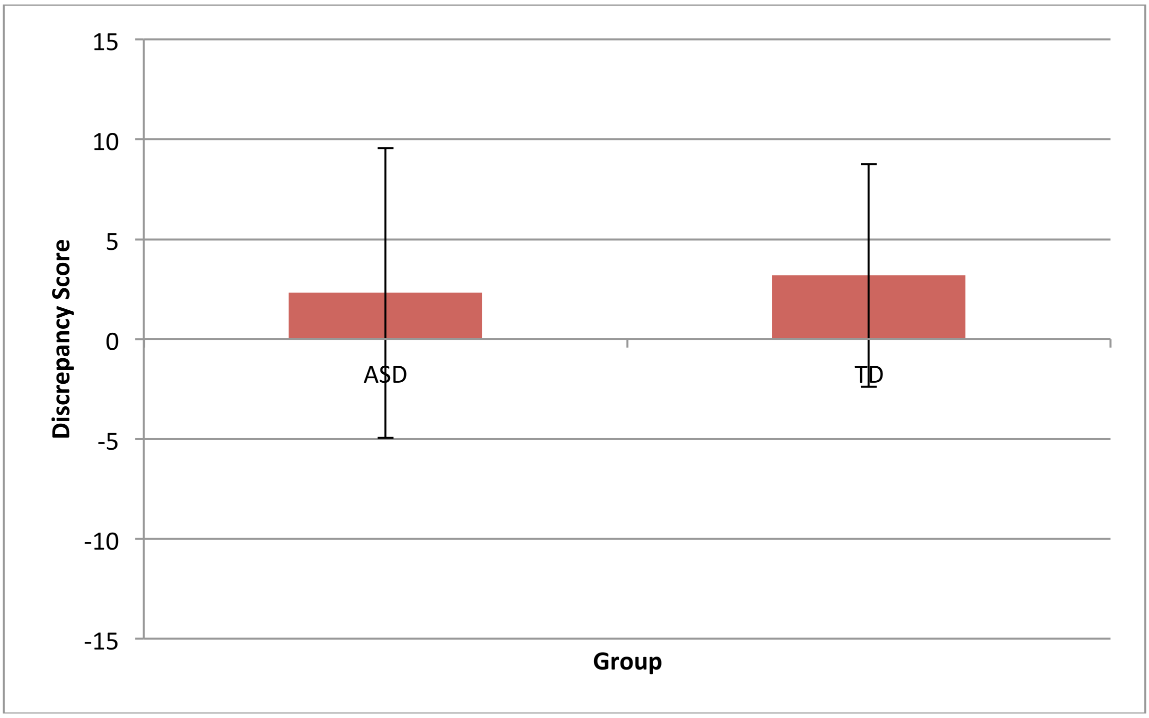

Figure 4-4. *Exp 2 main effect of group*
Note: Higher scores indicate increased perceptual disturbance from prosody

Recall Time Analysis

Percentage correct score means, standard deviations and ranges for the recall times across pitch manipulations are shown in table 4-5.

Table 4-5. *Exp 2 mean recall times, standard deviations and ranges*

	ASD		TD	
	Mean (SD)	Range	Mean (SD)	Range
Monotone	79.41 (22.91)	52.23-143.50	78.47 (17.56)	57.00-132.40
Normal Prosody	88.97 (36.93)	56.60-224.30	79.86 (11.99)	60.30-104.10
Exaggerated	78.96 (21.22)	47.90-121.20	83.67 (17.22)	65.00-118.50
Total	247.34 (67.08)	165.90-401.40	242.01 (41.67)	185-70-339.90

Discrepancy score means, standard deviations and ranges for the recall times across pitch manipulations are shown in table 4-6.

Table 4-6. *Exp 2 mean recall time discrepancy scores, standard deviations and ranges*

	ASD		TD	
	Mean (SD)	Range	Mean (SD)	Range
Monotone	9.56 (36.67)	-19.20-152.10	1.40 (15.28)	-43.40-29.70
Exaggerated	10.01 (29.51)	-24.50-119.40	-3.83 (11.08)	-29.50-13.90

Note: Negative scores indicate higher reaction times on perceptual manipulation in comparison to baseline

A factorial analysis of variance (ANOVA) was performed on the data across the groups for this experiment. Mauchly's test of sphericity was not necessary for the main effects of group or stimulus types as these variables contained only two levels and thus the assumption of sphericity was automatically met.

There was no significant main effect of pitch manipulation on participants' sentence recall speed, $F(1, 38)= 0.95$, $p= 0.337$. However, participants' performance demonstrated a slightly slower discrepancy recall speed when processing sentences spoken with an exaggerated prosody in comparison to monotone (M= 5.48, SD= 28.01 for monotone and M= 3.10, SD= 23.08 for exaggerated prosody) (Fig. 4-5). Thus, participants' recall times indicate that they were slightly faster at encoding and recalling monotone than exaggerated speech in comparison to normal speech prosody. As positive discrepancy recall times indicated reduced perceptual disturbance in prosodic conditions compared with normal speech, one-sample t-tests with a mean value of 0 were conducted to examine whether participants were experiencing less perceptual capture on conditions with prosodic manipulations. The was no significant difference between monotone, $t(37)= 1.20$, $p= 0.236$, recall times and 0 or exaggerated, $t(37)= 0.83$, $p= 0.414$ recall times and 0. Therefore, the results suggest that individuals' encoding and recall speeds on conditions involving abnormal linguistic prosody were not affected by prosodic manipulations.

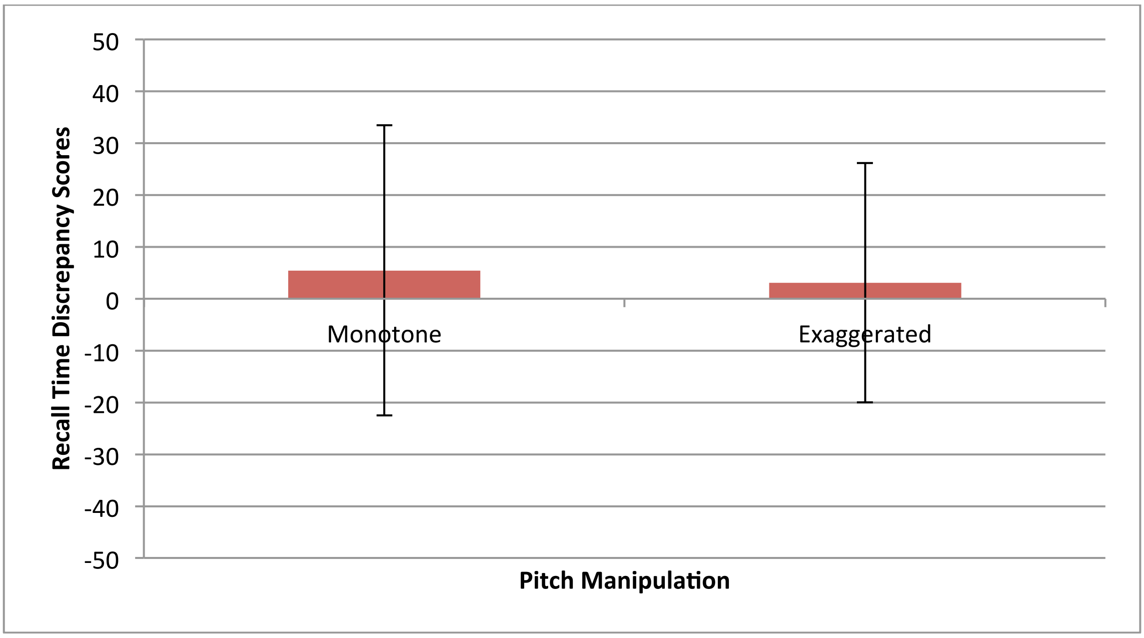

Figure 4-5. *Exp 2 main effect of pitch manipulation*
Note: Negative recall times indicate increased perceptual disturbance from prosody

There was also no significant main effect of group on the participants' sentence recall speed, $F(1, 38)= 1.96$, $p= 0.170$. Results indicated that typically developing individuals experienced slightly slower recall speeds when recalling sentences with pitch manipulations in comparison to ASD participants (M= 9.78, SD= 32.12 for ASD and M= -1.21, SD= 11.82 for TD) (Fig. 4-6). Thus, typically developing individuals experienced slightly more perceptual disturbance from prosodic manipulations than ASD individuals did. Furthermore, there was no significant pitch manipulation by group interaction, $F(1, 38)= 1.34$, $p= 0.254$.

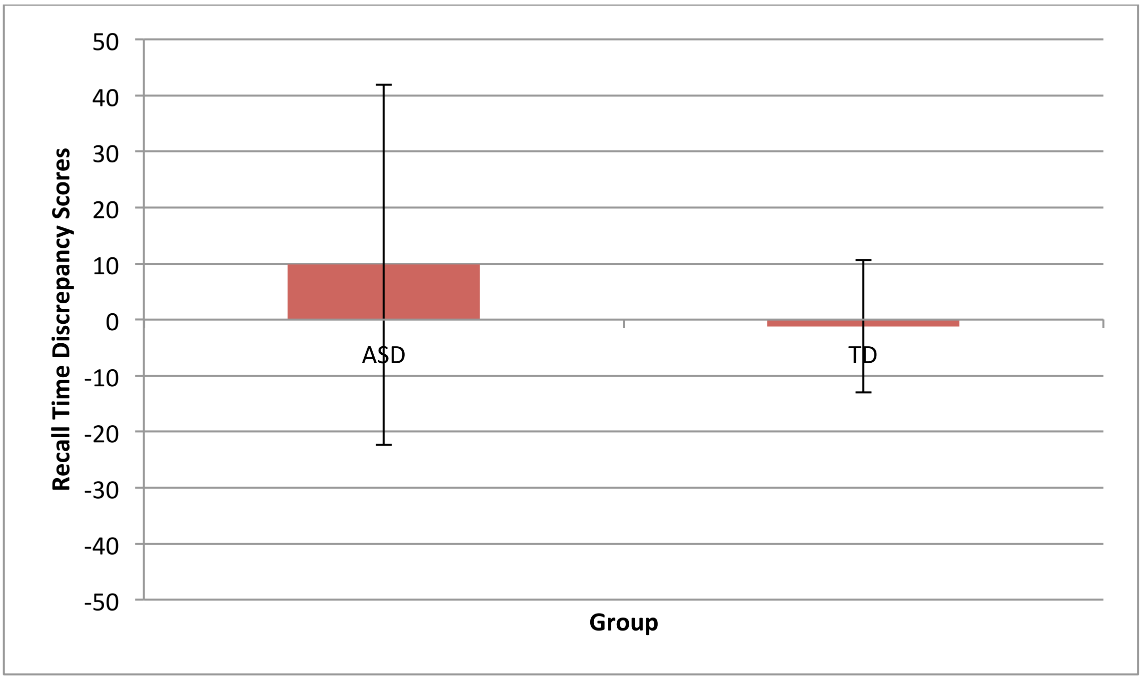

Figure 4-6. *Exp 2 main effect of group*
Note: Negative recall times indicate increased perceptual disturbance from prosody

Relationship Between Enhanced Pitch and Prosodic Speech Processing

Another aim of the present study was to examine what effect enhanced pitch processing abilities may have on encoding and recall of prosodic speech. In order to assess this question, a correlation analysis was performed. Participants' discrepancy scores across the two levels of prosodic manipulations in the current experiment along with participants' discrimination scores on the small intervals of the word stimuli in experiment 1 were used in the correlation.

There were no significant correlations between the performance of individuals with ASD or TD on the present experiment and their discrimination on experiment one (table 4-7). These results indicate that there is not a clear relationship between fine-grained pitch discrimination and one's ability to encode and recall sentences that are spoken in monotone or exaggerated pitch contours.

Table 4-7. *Exp 2 summary of correlations between discrepancy scores and pitch discrimination scores*

	ASD Small Word Interval		TD Small Word Interval	
	r	*p*	*r*	*p*
Monotone	-0.20	0.404	0.22	0.356
Exaggerated	-0.29	0.233	0.33	0.172

*Note: *p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

Correlation Analysis

Another aim of experiment two was to identify the cognitive, behavioural and clinical correlates of encoding and recall of prosodic speech. Whilst difficulties encoding and recalling prosodic speech were not observed at the group level in the ASD sample, the extent that variations in performance are associated with cognitive, behavioural and clinical factors remains an important question.

In order to assess the cognitive correlates of encoding and recall of prosodic speech, a correlation analysis was performed. Participants' accuracy discrepancy scores during the monotone and exaggerated prosody conditions along with participants' WASI Verbal, WASI Performance, WASI Full Scale, PPVT, WM forward, WM backward and WM total scores were used in the correlation.

There were no significant correlations between participants' discrepancy scores on the experimental task and their scores on the PPVT in either group. Within the ASD group, individuals' discrepancy scores on the monotone pitch condition were significantly negatively correlated with their verbal IQ (r= -0.59, p<0.01), performance IQ (r= -0.53, p<0.05) and full scale IQ (r= -0.59, p<0.01). These results indicate that higher IQ scores in ASD individuals' are related to lower levels of perceptual disturbance when recalling sentences that are spoken in a monotone pitch. However, there were no significant correlations between IQ and discrepancy scores on the exaggerated pitch condition in the ASD group or either pitch manipulation in typically developing adults. There were also no significant correlations between participants' working memory scores and their performance on the experimental task in either group.

In order to assess the behavioural correlates of encoding and recall of prosodic speech, a correlation analysis was performed. Participants' accuracy discrepancy scores during the monotone and exaggerated prosody conditions along with participants' Communication Checklist – Language Structure, Communication Checklist – Pragmatic Skills, Communication Checklist – Social Engagement and Communication Checklist – Total standard scores and their Sensory Profile – Low Registration, Sensory Profile – Sensation Seeking, Sensory Profile – Sensory Sensitivity, Sensory Profile – Sensation Avoiding and Sensory Profile – Total scores were used in the correlation.

Within the ASD group there was a significant positive correlation between participants' discrepancy scores on the exaggerated prosodic condition and their scores on the language structure ($r = 0.47$, $p < 0.05$) and social engagement ($r = 0.50$, $p < 0.05$) subscales as well as their total scores ($r = 0.50$, $p < 0.05$) on the Communication Checklist. There was also a significant positive correlation between participants' discrepancy scores on the monotone pitch condition and their scores on the language structure subscale, $r = 0.61$, $p < 0.01$. Thus, the more communication abnormalities ASD participants reported, especially in terms of language structure and social engagement, the more perceptual disturbance they experienced when recalling sentences with manipulated pitch contours. There were no significant correlations between participants' discrepancy scores on the experimental task and their scores on the Communication Checklist in the typically developing group. There were no significant correlations between ASD or TD participants' discrepancy scores on any of the levels of perceptual manipulation during the experimental task and their scores on the sensory profile and its subscales. Thus, sensory abnormalities, as measured by the Sensory Profile, do not appear to be associated with an individuals' ability to recall sentences with manipulated pitch contours.

In order to assess the clinical correlates of encoding and recall of prosodic speech, a correlation analysis was performed. Participants' accuracy discrepancy scores during the monotone and exaggerated prosody conditions along with participants' Autism Spectrum Quotient – Social Skills, Autism Spectrum Quotient – Attention Switching, Autism Spectrum Quotient – Attention to Detail, Autism Spectrum Quotient – Communication, Autism Spectrum Quotient – Imagination and Autism Spectrum Quotient – Total and ASD participants' ADOS – Communication, ADOS – Reciprocal Social Interaction, ADOS – Diagnostic, ADOS – Imagination and Creativity and ADOS – Stereotyped and Repetitive Behaviours scores were used in the correlation.

ASD participants' imagination AQ scores were significantly positively correlated with their discrepancy score on the exaggerated pitch condition, r= 0.57, p<0.05. Additionally, discrepancy scores on the monotone pitch condition were significantly negatively correlated with participants' scores on the attention to detail subscale of the AQ, r= -0.54, p<0.05. Therefore, as the ASD participants exhibited higher levels of self-reported autistic traits on the imagination or attention to detail subscales they experienced more perceptual disturbance from the exaggerated pitch manipulation and less disturbance from the monotone pitch manipulation respectively. However, there were no significant correlations between ASD participants' other subscale and total AQ scores and their performance on the experimental task. Unlike the ASD group, none of the control participants' subscale scores were correlated with performance on any levels of the experimental task. The correlations with total AQ scores also failed to reach significance in the typically developing group.

ASD participants' imagination and creativity ADOS scores were significantly negatively correlated with their discrepancy scores on the exaggerated pitch, $r = -0.524$, $p<0.05$ condition of the experimental task. Therefore, as the ASD participants' symptom severity on the imagination and creativity ADOS subscale increased, they experienced less perceptual disturbance from the exaggerated speech pitch manipulation. However, there were no significant correlations between ASD participants' other ADOS subscale scores and their discrepancy scores on the experimental task.

Given the interesting finding in experiment one that suggested there may be a different developmental trajectory of auditory processing in ASD and typically developing individuals, it was decided that an additional correlation analysis would be carried out. In order to assess the relationship between age and encoding and recall of prosodic speech, a correlation analysis was performed. Participants' accuracy discrepancy scores during the monotone and exaggerated prosody conditions along with participants' chronological ages were used in the correlations. Within the ASD group there was a significant positive correlation between chronological age and their discrepancy scores on the monotone, $r = 0.69$, $p<0.001$ and exaggerated, $r = 0.66$, $p<0.01$ pitch manipulations. Thus, older ASD individuals experience more perceptual disturbance when recalling sentences that have manipulated pitch contours. There was no significant correlation between age and performance on the experimental task in the typically developing group.

All significant correlations between participants' scores on all levels of the background measures and their performance on the monotone and exaggerated pitch conditions of the experimental stimuli are summarised below (table 4-8).

Table 4-8. *Exp 2 summary of sig. correlations between discrepancy scores and background measures*

ASD; TD	Monotone Prosody	Exaggerated Prosody
Cognitive Correlates		
WASI		
VIQ	-0.59**	NS
PIQ	-0.53*	NS
FSIQ	-0.59**	NS
Behavioural Correlates		
Communication Checklist		
Language Structure	0.61**	0.47*
Social Engagement	NS	0.50*
Total Score	NS	0.50*
Clinical Correlates		
AQ		
Attention to Detail	-0.54*	
Imagination	NS	0.57*
ADOS		
Imagination & Creativity	NS	-0.52*
Chronological Age	0.69***	0.66**

Note: Red= significant in ASD group; Blue= significant in TD group; NS= non-significant in both groups; **p*<0.05, ***p*<0.01, ****p*<0.001 (two-tailed)
Negative correlations indicate a relationship between higher scores on the background measure and reduced perceptual disturbance from prosody.

Regression Analysis

Monotone Prosody

In order to examine the extent that the significant cognitive, behavioural and clinical correlates in the table above accounted for the variance in encoding and recall of monotone speech in ASD and typically developing participants two multiple linear regressions were performed. The dependent variable was the accuracy discrepancy score for the monotone prosody condition. The predictor variables were individuals' verbal, performance and full-scale IQ scores on the WASI, scores on the language structure subscale of the Communication Checklist and scores on the attention to detail subscale of the AQ. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

The results revealed a significant linear relationship between ASD participants' accuracy discrepancy scores during the monotone condition and the predictor variables.

Table 4-9 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the predictor variables on the accuracy discrepancy scores during the monotone condition in the ASD group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.43, [$F(1,19) = 8.43$, $p<0.01$; adjusted $R^2 = 0.47$]. Thus, roughly 47% of the variability in ASD participants' accuracy discrimination scores during the monotone condition was predicted by their scores on the language structure subscale of the Communication Checklist and attention to detail subscale of the AQ. A closer look at the un-standardised regression coefficients indicates that higher levels of communication difficulties in the realm of language structure predicted an increase in an ASD individual's discrepancy scores indicating increased perceptual disturbance when encoding and recalling monotone speech. Furthermore, higher levels of autistic traits on the attention to detail subscale predicted a decrease in an ASD individual's discrepancy scores, indicating less perceptual disturbance when encoding and recalling monotone speech.

Table 4-9. *Exp 2 multiple regression of accuracy discrepancy score for ASD participants during monotone condition*

	B	SE *B*	β	*t*	*p*
CC-Language Structure	0.28	0.10	0.51	2.77	0.14**
AQ-Attention to Detail	-1.37	0.60	-0.41	-2.28	0.038*

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

The results also revealed that there was no significant linear relationship between TD participants' accuracy discrepancy scores during the monotone condition and the predictor variables with a multiple correlation of 0.28, [$F(1,19) = 1.46$, $p = 0.243$; adjusted $R^2 = 0.02$]. Thus, there did not appear to be a relationship between the predictor variables and encoding and memory of monotone speech in the typically developing population.

Exaggerated Prosody

In order to examine the extent that the significant cognitive, behavioural and clinical correlates in the table above accounted for the variance in encoding and recall of speech with exaggerated prosody in ASD and typically developing participants two multiple linear regressions were performed. The dependent variable was the accuracy discrepancy score for the exaggerated prosody condition. The predictor variables were individuals' scores on the language structure and social engagement subscales as well as total scores of the Communication Checklist, attention to detail subscale of the AQ and imagination subscale of the ADOS. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

The results revealed a significant linear relationship between ASD participants' accuracy discrepancy scores during the exaggerated condition and the predictor variables. Table 4-10 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the predictor variables on the accuracy discrepancy scores during the exaggerated condition in the ASD group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.67, [$F(1,19)= 6.18$, $p<0.01$; adjusted $R^2= 0.38$]. Thus, roughly 38% of the variability in ASD participants' accuracy discrimination scores during the exaggerated condition was predicted by their scores on the language structure subscale of the Communication Checklist and imagination subscale of the ADOS. A closer look at the un-standardised regression coefficients indicates that higher levels of communication difficulties in the realm of language structure predicted an increase in an ASD individual's discrepancy scores indicating increased perceptual disturbance when encoding and recalling speech with exaggerated prosody. Furthermore, higher levels of ASD symptomatology on the imagination subscale predicted a large decrease in an ASD individual's discrepancy scores, indicating much less difficulty encoding and recalling speech with exaggerated prosody.

Table 4-10. *Exp 2 multiple regression of accuracy discrepancy score for ASD participants during exaggerated condition*

	B	SE *B*	β	*t*	*p*
CC-Language Structure	0.34	0.15	0.42	2.20	0.044*
ADOS-Imagination	-6.62	2.66	-0.47	-2.41	0.029*

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

The results also revealed that there was no significant linear relationship between TD participants' accuracy discrepancy scores during the monotone condition and the predictor variables with a multiple correlation of 0.28, [$F(1,19)= 1.46$, $p= 0.243$; adjusted $R^2= 0.02$]. Thus, there did not appear to be a relationship between the predictor variables and encoding and memory of monotone speech in the typically developing population.

DISCUSSION

Overall, the findings from experiment two suggested that adults with ASD did not experience any more difficulty encoding and recalling speech with abnormal prosody than their typically developing peers. However, the accuracy analysis revealed that individuals in both groups experienced significantly more difficulty recalling speech that was either spoken in a monotone or exaggerated pitch in comparison to normal speech prosody. Whilst the accuracy and reaction time analyses didn't uncover any significant group differences, exploratory correlation and regression analyses suggested there may be different patterns of underlying mechanisms driving performance in the two groups. Most notably, IQ scores in individuals with ASD were related to higher levels of accuracy when encoding and recalling monotone speech and older age was related to increased difficulty encoding and recalling both monotone and exaggerated prosody.

One of the primary aims of experiment two was to increase our understanding of the effect of prosody on speech encoding and recall in individuals with ASD. Although no overall group differences emerged within either the accuracy or recall time analyses, this is not necessarily surprising given that both groups possessed higher than average levels of intelligence and were matched on IQ and working memory scores. Furthermore, there were no significant differences between accuracy or recall time discrepancy scores on the monotone and exaggerated prosody conditions. Accuracy, but not recall time results, did however indicate that individuals were experiencing significant levels of disturbance from both of the conditions with abnormal linguistic prosody in comparison to normal speech. This confirms the first hypothesis of experiment two and suggests that individuals across both groups did experience more difficulty encoding and recalling speech when the linguistic prosody deviated from the norm. However, as there was not a significant group by prosody interaction, the second hypothesis that individuals with ASD would have more difficulty with exaggerated than monotone speech prosody was not supported. Although the recall time analysis was designed to elicit a more sensitive measure of processing abnormalities, it is possible that this behavioural measure was not sensitive enough to identify atypical processing in high-functioning individuals with ASD. Indeed Paul et al. (2005) noted that whilst individuals with ASD and TD may achieve the same end goal they rely on different strategies. In the study by Paul et al., participants' pragmatic/affective prosodic processing was examined through a task in which participants were instructed to indicate whether the person speaking was 'excited' or 'calm'. Thus, in the present study, it is possible that individuals with ASD were able to achieve the same end goal (recall accuracy) as typically developing individuals, albeit via a different processing strategy. The marked difference in patterns of correlations between the dependent variables and the background measures were of relevance to this question and will be further discussed. Future studies utilising electrophysiological methodologies may be able to identify any possible subtle processing differences between participants with ASD and TD when encoding and recalling linguistic stimuli.

Another aim of the study was to examine the relationship between fine-grained pitch discrimination and speech encoding and recall. Although no group differences emerged in experiments one or two, large standard deviations were observed and it was plausible that the variance reflected possible subgroups characterised by levels of prosodic disturbance. Correlation analyses were conducted with individuals' percentage correct scores on the small pitch interval of the word pairs from experiment one and their monotone and exaggerated pitch discrepancy scores from experiment two. No significant correlations were found in either group, which suggests that there is not a clear relationship between sensitivity to small perceptual changes in word pitch tested in an explicit task and the extent that one's ability to encode and recall speech is influenced by changes in pitch contours. Therefore, the third hypothesis that individuals who were better able to discriminate small pitch changes in experiment one would experience more perceptual capture in experiment two was not supported.

The final aim of experiment two was to explore the cognitive, behavioural and clinical correlates of abnormal receptive prosody. Individuals with ASD demonstrated a very different profile of correlations between their task performance and scores on the background measures to that of typically developing controls where no relationship was found between task performance and any of the background measures investigated. Thus, the results from the present study did not confirm the final hypothesis that typically developing individuals with higher levels of autistic traits would be more affected by prosodic speech. Correlations revealed that higher verbal, performance and full-scale IQ scores were associated with reduced levels of perceptual disturbance from monotone speech prosody. This may explain why the trend towards group differences, observed in the pilot study carried out with intellectually lower functioning individuals with ASD, was not replicated in experiment two. Correlations also revealed a significant relationship between older age and increased perceptual disturbance in the ASD group but not the control group. This result perhaps indicates that individuals with ASD are more susceptible to age related processing effects such as cognitive slowing. Furthermore, on the self-reported measure assessing communication abnormalities, individuals with ASD who reported higher levels of difficulty on the language structure and social engagement subscales as well as on total scores experienced significantly higher levels of memory disruption in response to speech with abnormal prosody. Thus, the present study indicates that there is a relationship between language ability and prosodic processing in individuals with ASD, even for those on the very high-functioning end of the spectrum. This partially supports the fourth hypothesis that individuals with ASD with increased language, sensory and communication abnormalities would be more affected by prosodic manipulations to speech. Regression analyses further highlighted this relationship, indicating that higher levels of communication difficulties with language structure significantly predicted increased levels of perceptual disturbance when encoding and recalling speech spoken in either monotone or exaggerated prosody. Additionally, the regression analyses also highlighted a strong relationship between increased levels of autistic symptomatology as measured by the attention to detail subscale of the AQ and imagination subscale of the ADOS and significantly decreased perceptual disturbance when encoding and recalling monotone and exaggerated speech prosody respectively. Thus, the high-functioning ASD adults in the present study did not appear to have more difficulty with receptive prosody due to their specific clinical autistic symptomatology. Taken together this evidence suggests that the lack of group difference in the present study may very well be due to fact that only high-functioning individuals were included in the study. The correlation analyses revealed some associations between symptoms of ASD and recall, thus future research should examine whether this relationship also exists in intellectually lower-functioning individuals who demonstrate higher levels of language impairments. It would also be interesting to investigate the extent that this effect is present during earlier stages of development.

CHAPTER 5: TEMPORAL INFLUENCES ON SENTENCE RECALL

SUMMARY

Whilst experiments one and two were concerned with investigating responses to pitch manipulations in speech stimuli, experiment three investigated the impact of temporal changes, through increased rates of speech, on speech processing. Research with typically developing adults has observed significant declines in rates of memory recall with increasing speech rate. Impairments in temporal processing across multiple domains are often noted in individuals with ASD. The present study aimed to increase our understanding of the effect of temporal manipulations on encoding and recall of speech in adults with ASD. The findings indicated that individuals from both groups experienced more difficulty processing sentences that were spoken at faster speeds and this appeared to affect the ASD group more than controls. Research suggests that impairments in processing rapid auditory stimuli may well result in difficulties with verbal comprehension and impairments in verbal and language abilities. Thus, the relationship between language abilities and abnormal temporal processing of speech as well as other aspects of ASD symptomatology in high-functioning adults will be explored and discussed.

INTRODUCTION

In addition to pitch, another important component of prosody mentioned in the previous chapter is rate or speed of speech. Temporal aspects of auditory information carry important information. For example, Rosen (1992) proposed that temporal cues are the primary component upon which speech perception is based and studies have demonstrated that deficiencies in speech perception are often associated with deficits discriminating temporal auditory features (Kujala et al., 2000). Furthermore, changes to the temporal parameters of speech affect other perceptual components of the speech signal. Increasing the rate of natural speech also involves changes at the syllable, word and sentence levels to the relative timing of other speech units (Janse, 2004). Several studies have examined temporal perception of speech through rapid speed processing in typically developing individuals. Wingfield (1975) noted a systematic perceptual performance decline in typical young adults when available processing time was reduced. These findings have been further supported through sentence recall paradigms utilising time compressed speech, which have observed significant declines in rates of performance with increasing speech rate (Stine, Wingfield & Poon, 1986; Tun, Wingfield, Stine & Mecsas, 1992; Tun, 1998; Wingfield, Poon, Lombardi & Lowe, 1985).

Impairments in temporal processing, including auditory impairments, are often noted in individuals with ASD. A recent study by Kwakye and colleagues (2011) used temporal order judgment tasks to assess auditory and multisensory temporal processing in children with ASD. Their results provided evidence for impairments in both multisensory and auditory temporal processing in children with ASD in comparison to their typically developing peers. Their findings are consistent with other behavioural studies and electrophysiological findings of reduced mismatch negativity in response to duration changes in non-speech sounds (Lepistö et al., 2005, 2006). Taken together, these results indicate atypical responses to temporal aspects of auditory information in ASD. Kwakye et al. (2011) suggested that these impairments could be due in part to an extended temporal processing window in individuals with ASD that affects the rapid processing of sensory information. Furthermore, evidence from speech-in-noise paradigms has suggested that individuals with ASD also have difficulty using temporal dips to enhance the perception of speech amidst competing background noise. Oram Cardy and colleagues (2005) postulated that rapid temporal processing deficits may be linked to impaired language development through interference with acoustic information during speech perception. Their study provided neural evidence of impaired rapid temporal processing in children with ASD. However, as these results were only characteristic of a subset of their participants (44%) the authors suggest that these deficits could be a function of impaired language rather than ASD specifically.

Gepner & Féron (2009) put forth a tempo-spatial processing hypothesis to explain various degrees of disability often noted in individuals with ASD. Within the auditory domain, the authors noted evidence of impairments in speech flow perception and segmentation in children with ASD (Gepner & Massion, 2002) and increased phoneme categorization performance when phonemes were produced at reduced speeds (Tardif et al., 2002). Overall, their hypothesis suggests that rapid changes in the environment, acting on one or more sensory modalities are implicated in processing impairments in children and adults with ASD. Rapid processing impairments in the auditory domain may well result in difficulties with verbal comprehension and impairments in verbal and language abilities. This is particularly concerning due to the fact that the ability to integrate temporal information is hypothesised to be vital in the development of social functioning that are often impaired in individuals with ASD (Gepner & Tardif, 2006).

Speech processing involves the rapid decoding of a constantly changing signal that must occur in real time. Thus, it is not surprising that individuals who experience temporal processing difficulties overall would have more difficulty with rapid speech. Stine et al. (1986), Tun et al. (1992), Tun (1998) and Wingfield et al. (1985) found that elderly adults demonstrated steeper declines in rates of performance with increasing speech rate in comparison to younger individuals. Speech rate is normally under the control of the speaker rather than the listener and impairments in rapid speech processing could therefore have a direct impact on one's social communication abilities. Studies by Laine et al. (2008 & 2009) attempted to alleviate the effects of rapid processing impairments in individuals with ASD by slowing the auditory presentation of sentences. Their results suggested that verbal comprehension was enhanced during slow speech rates, especially in children with low-functioning autism. Thus, temporal manipulations to speech through increasing the rate of presentation may well uncover increased speech processing abnormalities in adults with ASD.

EXPERIMENT 3 PILOT STUDY: TESTING ENCODING AND MEMORY OF TEMPORALLY MANIPULATED SPEECH

Aims

This pilot study aimed to assess whether the set of stimuli with temporal manipulations developed by Tun et al. (1992) can be utilised to increase our understanding of the effect of temporal manipulations on speech processing in ASD and typically developing individuals with high and low levels of autistic traits.

Hypotheses

1. Individuals in both groups will experience more difficulty processing speech as the speed of speech increases.
2. TD individuals with higher levels of autistic traits, as measured by the AQ, will be more affected by increased rates of speech in comparison to the rest of their cohort.

METHODS

Participants and Background Measures

Nine adults with ASD were recruited and participated in the pilot study. One participant was female and eight were male. All of the adults in the ASD group were recruited from local support and social groups. The participants all had a previous diagnosis of ASD performed by a clinician. 17 adults with typical development (controls) were recruited from the 1st year undergraduate psychology experiment credit scheme at Goldsmiths College and participated in the experiment. 12 of the participants were female and 5 were male. In order to assess the continuum hypothesis of ASD, the control group was divided into two groups based on their self-reported levels of autistic traits as assessed by the Adult Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001). The cut-off score for the AQ is 32, therefore individuals who scored at or above the median of 16 were considered to have high levels of autistic traits (N= 8) and those who scored 15 and below were placed in the low autistic trait group (N= 9). In addition to the AQ, the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997), a test of receptive vocabulary with adult norms, was administered to all three groups (Table 5-1).

Table 5-1. *Exp 3 pilot participant background data*

	ASD N= 9		HAQ N= 8		LAQ N= 9	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
CA (mos)	333.89 (101.01)	234-510	244.00 (17.26)	224-273	241.11 (31.30)	223-322
AQ [a]	21.67 (7.91)	7-31	19.00 (3.59)	16-27	10.56 (3.84)	5-14
PPVT [b]	86.89 (16.94)	66-120	96.00 (10.01)	81-109	109.44 (7.45)	103-119

Note: CA= chronological age, ASD= autism spectrum disorders, HAQ= high autistic traits, LAQ= low traits; [a] Adult Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001); [b] Peabody Picture Vocabulary Test (PPVT), standard score (Dunn & Dunn, 1997)

Experimental Methods

Experimental Stimuli

The present pilot study was designed to test the effect of temporal processing during sentence repetition. Sentence stimuli consisted of 30, 15-word sentences randomly selected from the 60 sentences used by Tun et al. (1992) (Appendix II). The sentences were recorded by an adult British English speaking female and manipulated using PRAAT (Boersma, 2001) to generate three different speed conditions: normal speech (140 words per minute (wpm)), moderate speed (200 wpm) and fast speed (280 wpm). Normal speech acted as the control condition and was only manipulated by adjusting the original sentences to the mean intensity (perceived volume) and a median pitch of 200Hz, which removed any inconsistencies that were artefacts from the recording process. The moderate condition was generated using electronic time compression to reduce the normal speech sentences to 70% of their original length. The final condition, fast speed, compressed the normal speech sentences to 50% of their original length, creating a condition representing a doubled rate of speech. An E-Prime programme was designed to randomly select and randomise the presentation of 10 sentences in each of the three conditions for every participant to adjust for any inherent differences in the sentences.

Procedure

Participants were administered three practice sentences, one under each condition and asked to perform a verbatim recall immediately following the end of the recorded sentence. The researcher informed participants to repeat as much of the sentence as they could remember, in the order that they had heard it and to omit any words they could not recall. Following the practice trials, 30 experimental sentences were administered in the same format. During the experimental trials, participants' responses were timed and recorded for later analysis. Participants received one point for each correct word that was produced in the correct place within the recalled sentence. No points were awarded for words that were either incorrect or in the wrong order. Raw scores were calculated by counting the number of points each participant achieved with a maximum of 150 in each condition and 450 overall. Raw scores for each condition were converted to percentages for the analysis.

Analysis

A factorial analysis of variance (ANOVA) was used to analyse the data from experiment 3 with the within-subjects factor of prosody condition (3 levels; normal speech, moderate speed and fast speed) and between-subjects factor of group (3 levels; ASD, HAQ and LAQ). The dependent variable was the percentage of correct responses made by each participant across the 10 sentences in each speed condition.

RESULTS

Accuracy Analysis

Means, standard deviations and ranges for the percentage correct scores across speed manipulations are shown in table 5-2.

Table 5-2. *Exp 3 pilot mean percentage correct scores, standard deviations and ranges*

	ASD N= 9		HAQ N= 8		LAQ N= 9	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Norm.	62.59 (23.99)	32.67-93.33	81.75 (10.73)	61.33-94.00	84.30 (5.73)	77.33-94.67
Mod.	61.33 (17.67)	28.00-88.00	81.17 (7.91)	66.00-91.33	84.44 (6.53)	74.67-96.00
Fast	56.15 (21.17)	30.00-82.00	77.42 (9.14)	62.00-92.00	83.63 (6.43)	72.00-92.00
Total	60.02 (20.50)	30.22-87.78	80.11 (8.86)	63.11-91.78	84.12 (5.45)	76.22-92.22

Note: Mean percentage correct scores (out of a maximum of 100)

A factorial analysis of variance (ANOVA) was performed on the data across the groups for this experiment. Mauchly's test of sphericity was significant, $\chi^2(2)= 6.99$, $p= 0.030$, for the main effect of speed, indicating that the assumption of sphericity had been violated. Therefore, the F-values were corrected for the interaction term using the Greenhouse-Geisser corrected values of the degrees of freedom (Field, 2009).

There was a significant main effect of speed on participants' sentence recall, $F(1.57, 26)= 5.03$, $p<0.05$ (Fig. 5-1). In order to further examine the significant main effect of speed, a trend analysis was conducted. There was significant linear trend, $F(1, 26)= 16.57$, $p<0.001$, indicating that as speed of speech increased, sentence recall accuracy decreased proportionally (M= 76.21, SD= 18.08 for normal, M= 75.65, SD= 15.57 for moderate and M= 72.40, SD= 18.12 for fast speed). Further comparisons revealed that participants experienced significantly more difficulty when encoding and recalling sentences that were spoken at a fast speed compared with both normal speed ($p<0.001$) and moderate speed ($p<0.05$). However there was no significant difference between participants' performance on the normal and moderate speed conditions, $p= 0.718$. Thus, participants' ability to recall sentences was significantly impacted when the rate of speech was twice as fast as normal speech.

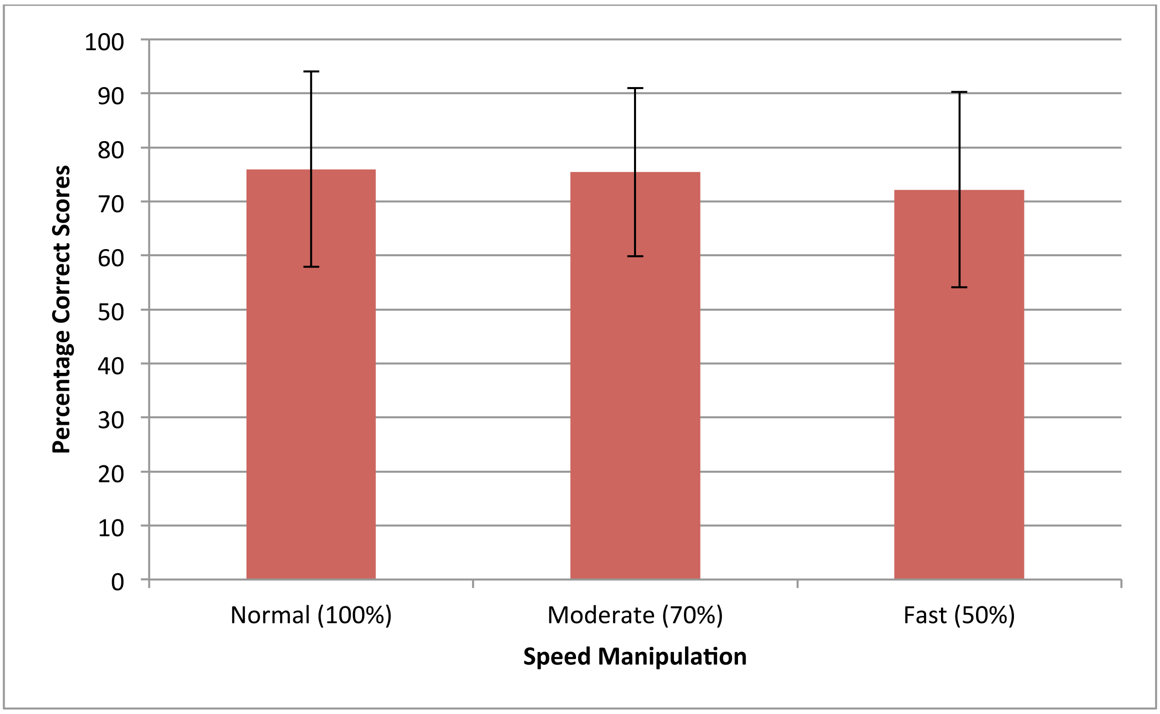

Figure 5-1. *Exp 3 pilot main effect of speed*

There was also a highly significant main effect of group on the participants' sentence recall abilities, $F(1, 26)= 8.24$, $p<0.01$ (Fig. 5-2). The ASD group produced significantly fewer correct responses than both the HAQ group ($p<0.05$) and the LAQ group ($p<0.001$). However, the there was no significant difference between the performance of typically developing individuals with high and low levels of autistic traits, $p= 0.545$ (M= 60.02, SD= 20.50 for ASD, M= 80.11, SD= 8.86 for HAQ and M= 84.12, SD= 5.54 for LAQ). This suggests that the ASD group had more difficulty recalling sentences overall than either of the two control groups, regardless of whether TD individuals had high or low levels of autistic traits. Furthermore, there was no significant speed manipulation by group interaction, $F(3.14, 26)= 0.96$, $p= 0.425$.

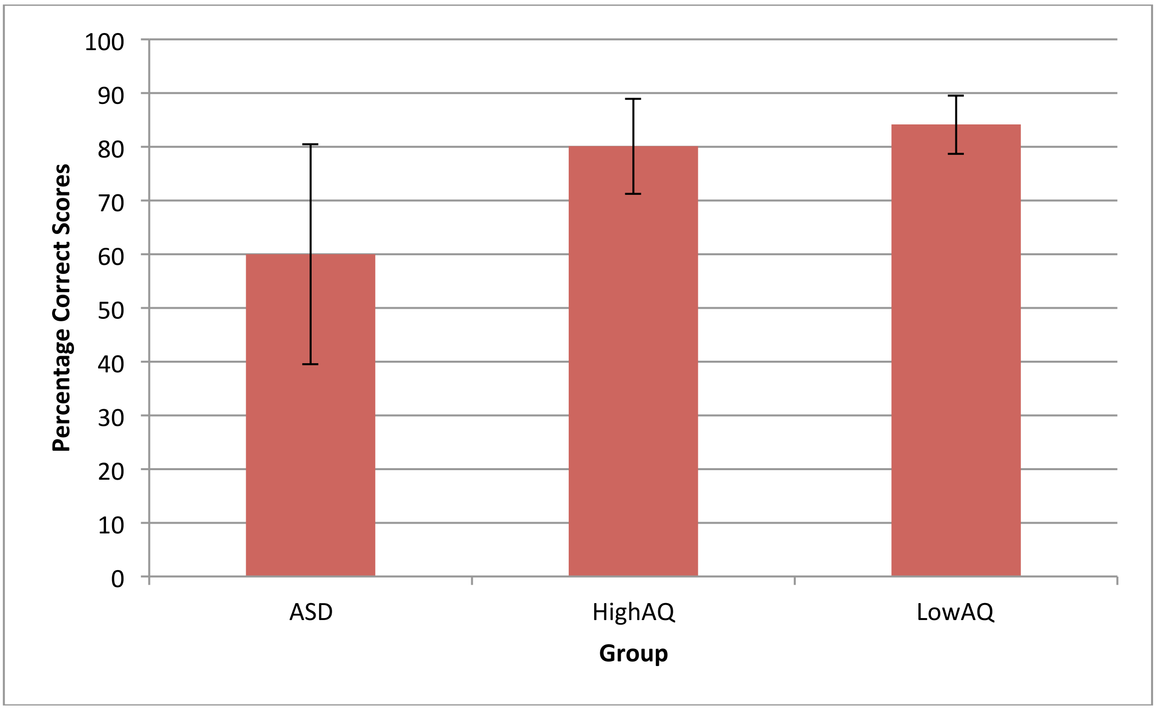

Figure 5-2. *Exp 3 pilot main effect of group*

BRIEF DISCUSSION

The primary aim of this pilot study was to assess whether the present set of stimuli could be used to assess temporal speech processing in individuals with ASD. The results suggest that temporal manipulations made to the sentence stimuli were able to generate a different pattern of responses with individuals experiencing significantly more difficulty on conditions in which the speed of speech was fast. Furthermore, the ASD group experienced significantly more difficulty on the fast speed condition than either of the two control groups that suggests a diminished ability to encode and recall fast speech in this group. However it should be noted that verbal scores were lower in the ASD group than either of the two TD groups and this may have contributed to the effect. As the two control groups performed at a similar level on the task, experiment 3 will recruit typically developing individuals with high and low levels of autistic traits into one control group and this will be carefully matched to the ASD participants for language IQ scores. Importantly, the pilot study established that the paradigm and temporal manipulations made on the sentences are sensitive enough to pick up subtle differences in temporal processing and are suitable for examining processing differences distinguishing individuals with ASD and their typically developing peers.

EXPERIMENT 3: TESTING ENCODING AND MEMORY OF TEMPORALLY MANIPULATED SPEECH

Aims

Whilst experiments one and two were concerned with investigating responses to changes in pitch in speech stimuli, experiment three aims to investigate the impact of temporal changes on encoding and recall of speech. Research carried out with typically developing adults has shown that word recall diminishes as the speed of speech increases and it is predicted that the magnitude of this effect will be far greater in those with ASD due to a pre-existing rapid temporal processing deficit. In addition to analysing accuracy scores, the present study will also incorporate the use of recall times in order to examine some of the more subtle differences in the processing of temporally manipulated speech.

The present study also aims to examine the relationship between language ability and rapid temporal processing deficits proposed by Oram Cardy et al. (2005). Furthermore, in an attempt to clarify whether this relationship is a function of impaired language rather than ASD specifically, correlations will be used to explore the relationship between cognitive, behavioural and clinical correlates and memory and recall for rapidly presented sentences. Whilst questions about age were not addressed in the pitch change study, there is strong evidence for age effects when processing temporal change so age data will be included in the analysis.

Hypotheses

1. Individuals in both groups will experience more difficulty processing speech as the speed of speech increases.
2. Individuals with ASD with more language difficulties and sensory and communication abnormalities will be more affected by increased rates of speech.
3. It is hypothesised that TD individuals with higher levels of autistic traits, as measured by the AQ, will be more affected by increased rates of speech in comparison to the rest of their cohort.

METHODS

Participants

All 38 participants described in chapter two of this thesis participated in the present study.

Experimental Methods

Experimental Stimuli

The experimental stimuli for experiment three were the same as that described in the pilot study.

Procedure

The procedure for experiment three was carried out in the same manner as in the pilot study previously described. However, during the experimental trials, participants' responses were also timed and recorded for later analysis. Recall times were measured from the end of the last word in the sentence stimulus to the end of the participants' response.

Analysis

Discrepancy scores were generated for each participant in order to account for any individual differences in working memory, language comprehension, or speech rate that may have affected their performance. Participants' percentage correct scores on the perceptual manipulation conditions were subtracted from their scores on the normal speech (baseline) condition in order to calculate their individual levels of change in response to speed manipulations.

A factorial analysis of variance (ANOVA) was used to analyse the data from experiment three with the within-subjects factor of speed condition (2 levels; moderate speed and fast speed) and between-subjects factor of group (2 levels; ASD and controls). The dependent variable was the percentage of correct responses made by each participant across the 10 sentences in each speed condition.

RESULTS

Accuracy Analysis

Means, standard deviations and ranges for the percentage correct scores across speed manipulations are shown in table 5-3.

Table 5-3. *Exp 3 mean percentage correct scores, standard deviations and ranges*

	ASD		TD	
	Mean (SD)	Range	Mean (SD)	Range
Normal	81.72 (15.77)	40.67-98.67	80.38 (12.26)	51.33-95.33
Moderate	80.63 (13.86)	50.00-97.33	82.42 (12.62)	40.67-93.33
Fast	77.16 (17.32)	34.67-96.00	78.07 (12.06)	50.67-90.67
Total	79.84 (14.94)	44.22-97.33	80.29 (11.45)	48.89-92.44

Note: Mean percentage correct scores (out of a maximum of 100)

Discrepancy score means, standard deviations and ranges for the discrepancy scores across speed manipulations are shown in table 5-4.

Table 5-4. *Exp 3 discrepancy scores, standard deviations and ranges*

	ASD		TD	
	Mean (SD)	Range	Mean (SD)	Range
Moderate	1.09 (9.12)	-16.67-18.00	-2.03 (7.23)	-18.67-10.67
Fast	2.56 (8.14)	-12.67-23.33	2.31 (8.56)	-12.00-26.67

Note: Negative scores signify better performance on perceptual manipulation in comparison to baseline

A factorial analysis of variance (ANOVA) was performed on the data across the groups for this experiment. Mauchly's test of sphericity was not necessary for the main effects of group or stimulus types as these variables contained only two levels and thus the assumption of sphericity was automatically met.

There was a highly significant main effect of speed manipulation on participants' sentence recall, $F(1, 38)= 9.29$, $p<0.01$. Participants' performance indicated a significantly higher level of difficulty when encoding and recalling speech spoken at a fast rate of speed in comparison to moderate speed (M= -0.47, SD= 8.27 for moderate and M= 3.44, SD= 8.32 for fast speech) (Fig. 5-3). In order to examine whether participants experienced significantly more difficulty in the two conditions with speed manipulations than normal speech alone, a one-sample t-test was conducted. A mean value of 0 that would indicate identical accuracy when recalling perceptually manipulated speech and normal speech was used. Results revealed a significant difference between discrepancy scores on the fast, $t(37)= 2.55$, $p<0.05$ speed condition and 0, but not on the moderate, $t(37)= -0.35$, p= 0.726 speed condition and 0. Thus, the present results suggest that individuals experienced significantly more difficulty during the fast condition in comparison to normal speech, but were equally able to encode and recall moderately fast and normal speeds of speech.

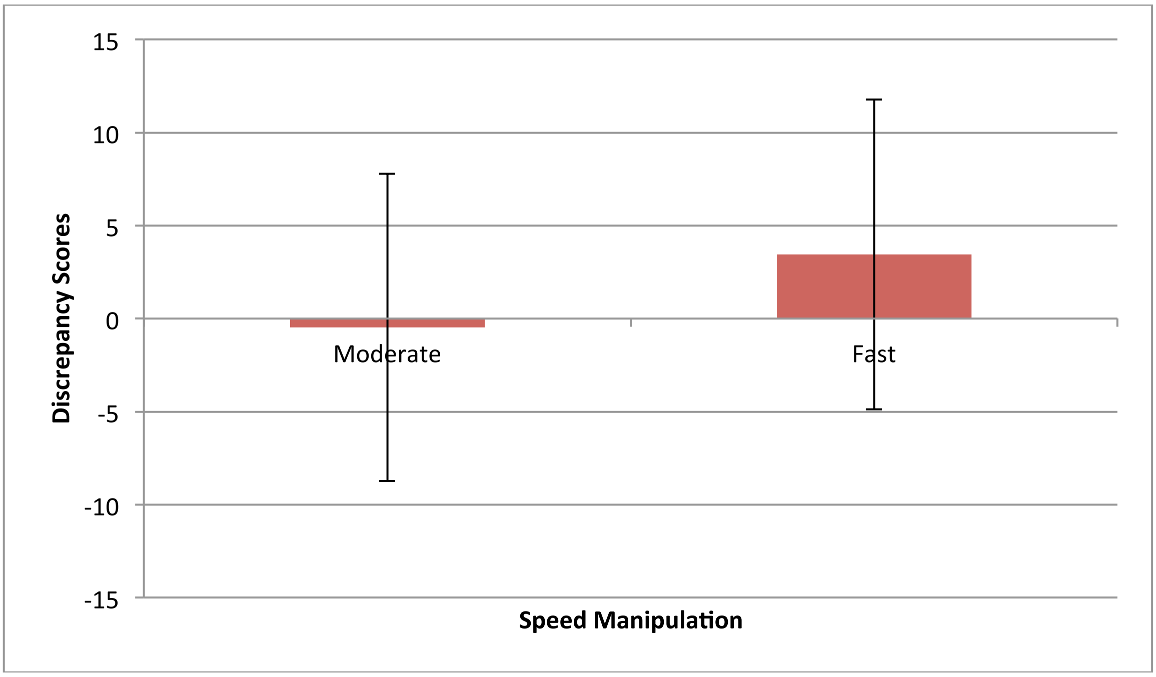

Figure 5-3. *Exp 3 main effect of speed manipulation*
Note: Higher scores indicate increased perceptual disturbance from speed

Results indicated that ASD individuals experienced slightly more difficulty when encoding and recalling sentences with speed manipulations in comparison to typically developing participants (M= 2.82, SD= 7.62 for ASD and M= 0.14, SD= 6.93 for TD) (Fig. 5-4) but this was not statistically significant $F(1, 38)= 1.29$, $p= 0.264$. Furthermore, there was no significant speed manipulation by group interaction, $F(1, 38)= 0.12$, $p= 0.735$.

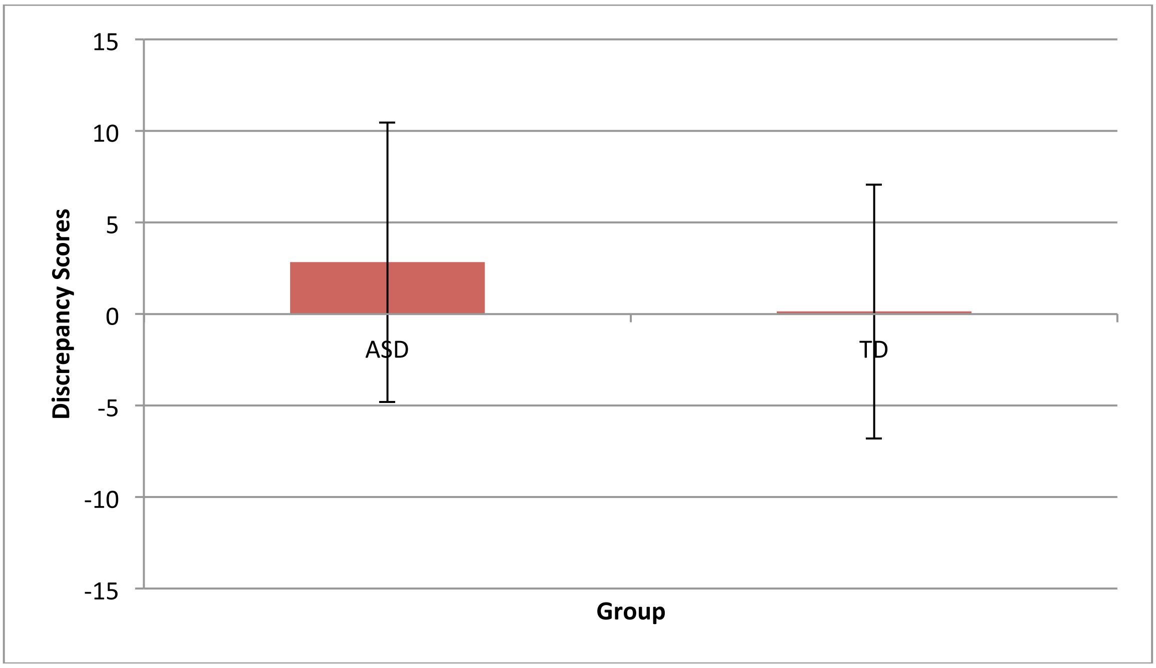

Figure 5-4. *Exp 3 main effect of group*
Note: Higher scores indicate increased perceptual disturbance from speed

Recall Time Analysis

Percentage correct score means, standard deviations and ranges for the recall times across speed manipulations are shown in table 5-5.

Table 5-5. *Exp 3 mean recall times, standard deviations and ranges*

	ASD		TD	
	Mean (SD)	Range	Mean (SD)	Range
Normal	77.35 (21.48)	51.50-142.70	75.52 (68.60)	47.10-111.10
Moderate	76.00 (25.30)	48.20-152.00	68.60 (10.55)	53.90-91.90
Fast	68.46 (21.41)	45.00-130.60	71.43 (10.87)	56.80-91.90
Total	221.81 (62.26)	151.40-353.40	215.55 (32.23)	166.00-274.80

Discrepancy score means, standard deviations and ranges for the recall times across speed manipulations are shown in table 5-6.

Table 5-6. *Exp 3 mean recall times, standard deviations and ranges*

	ASD		TD	
	Mean (SD)	Range	Mean (SD)	Range
Moderate	1.34 (17.92)	-54.50-35.50	6.92 (13.86)	-20.70-36.70
Fast	8.89 (14.59)	-23.30-50.70	4.09 (10.64)	-14.40-21.80

Note: Negative scores indicate higher reaction times on perceptual manipulation in comparison to baseline

A factorial analysis of variance (ANOVA) was performed on the data across the groups for this experiment. Mauchly's test of sphericity was not necessary for the main effects of group or stimulus types as these variables contained only two levels and thus the assumption of sphericity was automatically met.

There was no significant main effect of speed manipulation on participants' sentence recall speed, $F(1, 38)= 1.08$, $p= 0.305$. However, participants' performance indicated a slightly slower discrepancy recall speed when processing sentences spoken with a moderate speed in comparison to fast (M= 4.14, SD= 28.01 for moderate and M= 6.49, SD= 23.08 for fast speed) (Fig. 5-5). Thus, participants' recall times indicate that they were not significantly faster at encoding and recalling very fast than moderately fast speech in comparison to normal speech rates. As positive discrepancy recall times indicated faster recall speeds in moderate and fast speed conditions compared with normal speech, one-sample t-tests with a mean value of 0 were conducted to examine whether participants were experiencing faster encoding and recall times on conditions with speed manipulations. Results revealed a significant difference between discrepancy recall speeds on the fast, $t(37)= 3.12$, $p<0.01$ speed condition and 0, but not the moderate, $t(37)= 1.59$, $p= 0.121$ speed condition and 0. Thus, the present results suggest that individuals showed faster encoding and recall times during the fast condition in comparison to normal speech, but were encoding and recalling moderately fast and normal speeds of speech at equivalent rates.

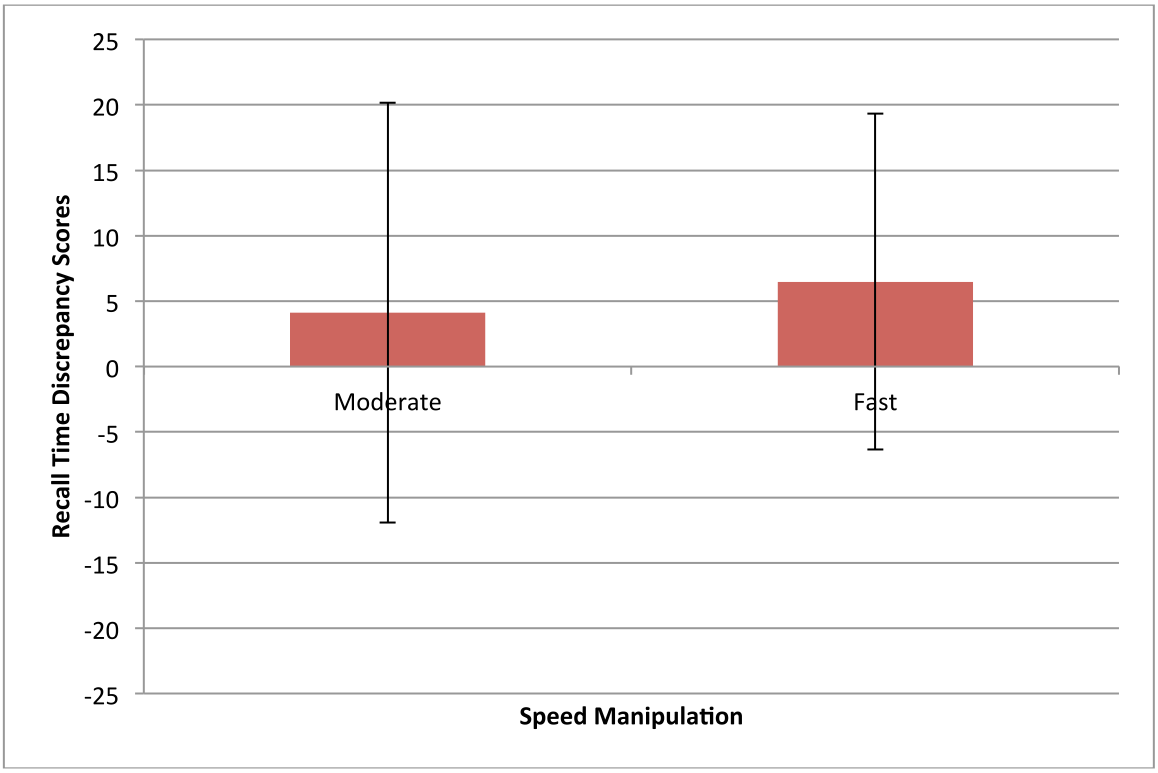

Figure 5-5. *Exp 3 main effect of speed manipulation*
Note: Negative recall times indicate increased perceptual disturbance from speed

There was also no significant main effect of group on the participants' sentence recall speed, $F(1, 38)= 0.01$, $p= 0.925$. However, results indicated that both groups were recalling the sentences faster during the speed manipulation conditions in comparison to their baseline recall speeds. (M= 5.12, SD= 14.13 for ASD and M= 5.50, SD= 11.07 for TD) (Fig. 5-6).

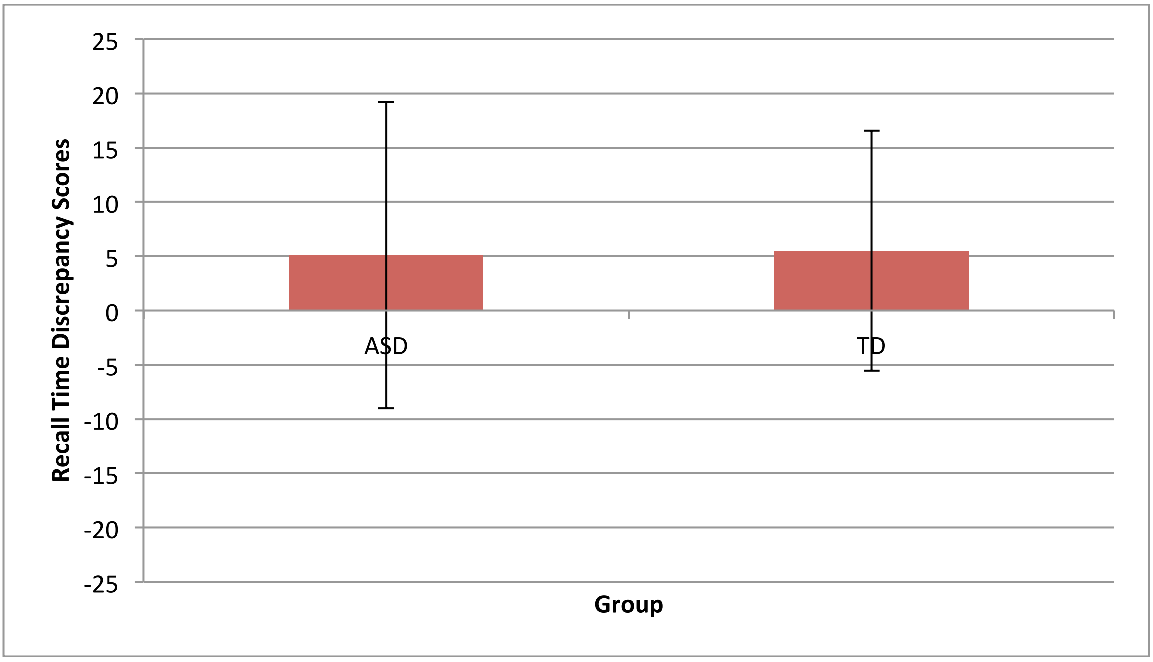

Figure 5-6. *Exp 3 main effect of group*
Note: Negative recall times indicate increased perceptual disturbance

There was however, a significant speed manipulation by group interaction, $F(1, 38) = 5.25$, $p<0.05$ (Fig. 5-7). In order to further examine the interaction and explore performance on the two experimental conditions within each group two post-hoc t-test were conducted. Results revealed a non-significant trend towards ASD participants recalling sentences slower during the moderate speed condition in comparison to the fast speech condition, $t(18) = -2.00$, $p = 0.060$. Typically developing participants, on the other hand, tended to recall sentences slower during the fast speech condition, although not significantly so, $t(18) = 1.12$, $p = 0.274$. The second group of post-hoc t-tests examined performance within each condition, across groups. No significant differences were found, however results indicated that the TD group experienced slightly slower recall speeds than the ASD group in the fast speed condition, $t(18) = 1.159$, $p = 0.254$, whereas the ASD group experienced slightly slower recall speeds than the TD group in the moderate speed condition, $t(18) = -1.073$, $p = 0.290$.

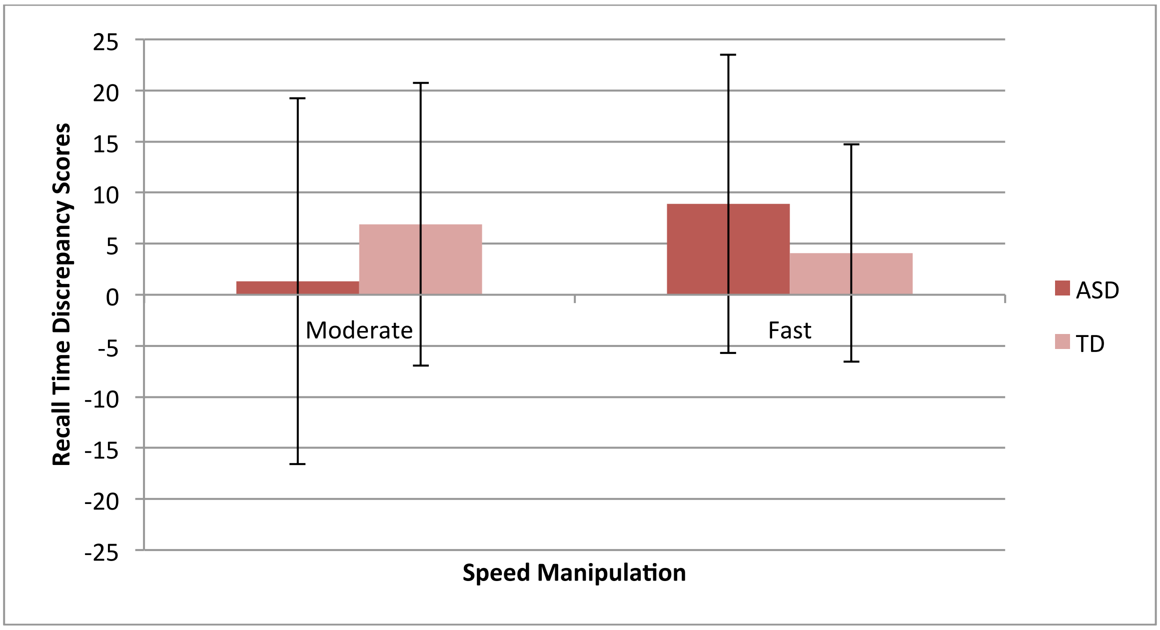

Figure 5-7. *Exp 3 group x speed manipulation interaction*
Note: Negative recall times indicate increased perceptual disturbance from speed

Correlation Analysis

Another aim of experiment three was to identify the cognitive, behavioural and clinical correlates of encoding and recall of fast speech. Whilst difficulties encoding and recalling fast speech were not observed at the group level in the ASD sample, correlations carried out on the data from experiment two had provided insights into the variance observed in the ASD group. Therefore the extent that variations in performance on the speed manipulation paradigm are associated with cognitive, behavioural and clinical factors remains an important question.

In order to assess the cognitive correlates of encoding and recall of fast speech, a correlation analysis was performed. Participants' accuracy discrepancy scores during the moderate and fast speed conditions along with participants' WASI Verbal, WASI Performance, WASI Full Scale, PPVT, WM forward, WM backward and WM total scores were used in the correlation.

ASD participants' performance IQ was significantly negatively correlated with their discrepancy scores on the fast speed condition of the experimental task, $r = -0.513$, $p < 0.05$. Therefore, as the ASD participants' performance IQ increased, their sentence recall abilities on fast speech in comparison to baseline sentence recall also increased. There were no significant correlations between ASD participants' discrepancy scores on the experimental task and their verbal IQ. These results indicate that ASD individuals' verbal IQ was not related to their abilities to recall sentences that had been manipulated by speed. There were no significant correlations between TD participants' discrepancy scores on the experimental task and their scores on the PPVT or WASI indicating that typically developing individuals' ability to recall sentences that are spoken at a faster than normal rate of speech was not effected by verbal or performance IQ scores. Furthermore, there were no significant correlations between participants' working memory scores and their performance on the experimental task in either group.

In order to assess the behavioural correlates of encoding and recall of fast speech, a correlation analysis was performed. Participants' accuracy discrepancy scores during the moderate and fast speed conditions along with participants' Communication Checklist Language Structure (CC-L), Communication Checklist Pragmatic Skills (CC-P), Communication g Social Engagement (CC-S) and Communication Checklist Total (CC-Tot) standard scores and their Sensory Profile Low Registration (SP-LR), Sensory Profile Sensation Seeking (SP-SSek), Sensory Profile Sensory Sensitivity (SP-SSen), Sensory Profile Sensation Avoiding (SP-SA) and Sensory Profile Total (SP-Tot) scores were used in the correlation.

Within the ASD group there was a significant positive correlation between participants' discrepancy scores on the fast speech condition and their scores on all subscales as well as their total communication checklist scores (Table 5-7). These results indicate that the more communication abnormalities ASD participants reported, across all areas assessed, the more difficulty they experienced when recalling sentences spoken at a very fast speed. Furthermore, there was also a significant positive correlation between ASD participants' discrepancy scores on the moderate speed condition and their scores on the social engagement subscale of the communication checklist. Thus the more communication abnormalities in the realm of social engagement that ASD participants reported, the more difficulty they experienced when recalling sentences spoken at even a moderately fast speed. In the TD group there was a significant positive correlation between participants' discrepancy scores on the moderate speed condition and their scores on the language structure subscale as well as their total communication checklist scores (Table 5-7). These results suggest that in instances where typically developing individual reported communication abnormalities, especially in the realm of language structure, they were more likely to experience perceptual disturbance from speed when recalling sentences spoken at a moderately faster as opposed to normal speed.

Table 5-7. *Exp 3 correlations between CC-SR and sentence recall discrepancy scores*

ASD	*CC-L* [a]	*CC-P* [b]	*CC-S* [c]	*CC-Tot* [d]
Moderate	0.13	0.23	0.48*	0.31
Fast	0.65**	0.48*	0.72**	0.67**
TD	*CC-L* [a]	*CC-P* [b]	*CC-S* [c]	*CC-Tot* [d]
Moderate	0.47*	0.39	0.37	0.48*
Fast	0.20	0.27	0.13	0.24

*Note: *p<0.05, **p<0.01, ***p<0.001 (two-tailed)*
[a] Language Structure Communication Checklist – Self Report (CC-SR) (Bishop et al., 2009); [b] Pragmatic Skills ; [c] Social Engagement ; [d] Total Score

Within the ASD group there was a significant negative correlation between participants' discrepancy scores on the moderate speed condition and their scores on the sensation seeking subscale of the sensory profile (Table 5-8). Thus, the more self-reported sensation seeking sensory abnormalities ASD participants experienced the less they were affected by the moderate speed manipulation. There was also a significant positive correlation between ASD participants' discrepancy scores on the fast speed condition and their scores on the low registration and sensory sensitivity subscales as well as their overall sensory profile scores (Table 5-8). These results indicate that the more self-reported sensory abnormalities, especially in the areas of low registration and sensation seeking, that ASD participant's reported, the more perceptual disturbance they experienced when recalling sentences spoken at a very fast speed. There were no significant correlations between TD participants' discrepancy scores on any of the other levels of perceptual manipulation during the experimental task and their scores on the subscales of the sensory profile.

Table 5-8. *Exp 3 correlations between Sensory Profile and sentence recall discrepancy scores*

ASD	*SP-LR*[a]	*SP-SSek*[b]	*SP-SSe* [c]	*SP-SA*[d]	*SP-Tot*[e]
Moderate	0.30	-0.53*	0.28	0.20	0.14
Fast	0.65**	-0.21	0.54*	0.38	0.54*
TD	*SP-LR*[a]	*SP-SSek*[b]	*SP-SSen*[c]	*SP-SA*[d]	*SP-Tot*[e]
Moderate	0.16	-0.01	0.35	0.30	0.23
Fast	0.12	0.13	0.38	0.20	0.25

*Note: *p<0.05, **p<0.01 (two-tailed)*
[a] Low Registration Subscale Adult/Adolescent Sensory Profile, standard score *(Brown & Dunn, 2002);* [b] Sensation Seeking; [c] Sensory Sensitivity; [d] Sensation Avoiding; [e] Total Score

In order to assess the clinical correlates of encoding and recall of fast speech, a correlation analysis was performed. Participants' accuracy discrepancy scores during the moderate and fast speed conditions along with participants' Autism Spectrum Quotient – Social Skills, Autism Spectrum Quotient – Attention Switching, Autism Spectrum Quotient – Attention to Detail, Autism Spectrum Quotient – Communication, Autism Spectrum Quotient – Imagination and Autism Spectrum Quotient – Total and ASD participants' ADOS – Communication, ADOS – Reciprocal Social Interaction, ADOS – Diagnostic, ADOS – Imagination and Creativity and ADOS – Stereotyped and Repetitive Behaviours scores were used in the correlation.

ASD participants' imagination AQ scores were significantly positively correlated with their discrepancy scores during both speed manipulations, $r = 0.62$, $p < 0.01$ (moderate), $r = 0.58$, $p < 0.05$ (fast). These results indicate that as ASD participants exhibited higher levels of autistic traits on the imagination subscale they experienced more perceptual disturbance from the both speed manipulations. There was also a significant positive correlation between ASD participants' social skills AQ scores and their discrepancy scores on the fast speech condition, $r = 0.48$, $p < 0.05$. Thus, as ASD participants reported higher levels of autistic traits on the social skills subscale, they also experienced more perceptual disturbance when recalling sentences spoken at a fast rate of speech. However, there were no significant correlations between ASD participants' other subscale and total AQ scores and their performance on the experimental task. Within the control group there was a significant positive correlation between participants' discrepancy scores on the moderately fast speech condition and their scores on the attention to detail subscale, $r = 0.46$, $p < 0.05$. Therefore, when typically developing individuals reported more autistic-like traits in terms of their attention to detail, they tended to experience a higher level of perceptual disturbance when recalling sentences spoken at a moderately fast rate of speech. There were no significant correlations between ASD participants' discrepancy scores on the experimental task and their scores on the ADOS. These results indicate that the individual participants' level of autistic symptom severity was not related to their ability to recall sentences that had been manipulated by speed.

In order to assess the relationship between age and encoding and recall of fast speech, a correlation analysis was performed. Participants' accuracy discrepancy scores during the moderate speed and fast speed conditions along with participants' chronological ages were used in the correlations. Within the ASD group there was a significant positive correlation between chronological age and their discrepancy scores on the fast, $r= 0.74$, $p<0.001$ speed manipulations. Thus, older ASD individuals experience more difficulty when recalling sentences that are spoken at a fast rate of speech. There was no significant correlation between age and performance on the experimental task in the typically developing group.

All significant correlations between participants' scores on all levels of the background measures and their performance on the moderate and fast speed conditions of the experimental stimuli are summarised below (table 5-9).

Table 5-9. *Exp 3 summary of sig. correlations between discrepancy scores and background measures*

ASD; **TD**	Moderate Speed	Fast Speed
Cognitive Correlates		
WASI		
PIQ	NS	-0.51*
Behavioural Correlates		
Communication Checklist		
Language Structure	0.47*	0.65**
Pragmatic Skills	NS	0.48*
Social Engagement	0.48*	0.72**
Total Score	0.48*	0.67**
Sensory Profile		
Low Registration	NS	0.65**
Sensation Seeking	-0.53*	NS
Sensory Sensitivity	NS	0.54*
Total Score	NS	0.54*
Clinical Correlates		
AQ		
Social Skills	NS	0.48*
Attention to Detail	0.46*	NS
Imagination	0.62**	0.58*
Chronological Age	-0.53*	0.74***

Note: Red= significant in ASD group; Blue= significant in TD group; NS= non-significant in both groups; **p<0.05, **p<0.01, ***p<0.001 (two-tailed)*
Negative correlations indicate a relationship between higher scores on the background measure and reduced perceptual disturbance from speed

Regression Analysis

Moderate Speed

In order to examine the extent that the significant cognitive, behavioural and clinical correlates in the table above accounted for the variance in encoding and recall of moderately fast speech in ASD and typically developing participants two multiple linear regressions were performed. The dependent variable was the accuracy discrepancy score for the moderate speed condition. The predictor variables were individuals' scores on the language structure and social engagement subscales as well as the total scores for the Communication Checklist, sensation seeking subscale of the Sensory Profile and scores on the attention to detail and imagination subscales of the AQ. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

The results revealed a significant linear relationship between ASD participants' accuracy discrepancy scores during the moderate speed condition and the predictor variables. Table 5-10 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t*) and significance (*p*) for the predictor variables on the accuracy discrepancy scores during the moderate speed condition in the ASD group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.80, [$F(1,19)= 13.82$, $p<0.001$; adjusted $R^2= 0.60$]. Thus, roughly 60% of the variability in ASD participants' accuracy discrimination scores during the moderate speed condition was predicted by their scores on the sensation seeking subscale of the Sensory Profile and imagination subscale of the AQ. A closer look at the un-standardised regression coefficients indicated that higher levels of sensory abnormalities in the realm of sensation seeking predicted a decrease in an ASD individual's discrepancy scores indicating decreased perceptual disturbance when encoding and recalling moderately fast speech. Furthermore, higher levels of autistic traits on the imagination subscale predicted an increase in an ASD individual's discrepancy scores, indicating increased perceptual disturbance when encoding and recalling moderately fast speech.

Table 5-10. *Exp 3 multiple regression of accuracy discrepancy score of ASD participants during moderate speed condition*

	B	SE *B*	β	*t*	*p*
SP-Sensation Seeking	-0.57	0.17	-0.52	-3.37	0.004**
AQ-Imagination	2.43	0.63	0.60	3.89	0.001***

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

The results also revealed a significant linear relationship between typically developing participants' accuracy discrepancy scores during the moderate speed condition and the predictor variables. Table 5-11 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the predictor variables on the accuracy discrepancy scores during the moderate speed condition in the ASD group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.47, [$F(1,19)= 4.34$, $p<0.05$; adjusted $R^2= 0.18$]. Thus, roughly 18% of the variability in TD participants' accuracy discrimination scores during the moderate speed condition was predicted by their scores on the language structure subscale of the Communication Checklist. A closer look at the un-standardised regression coefficients indicates that higher levels of communication difficulties in the realm of language structure predicted an increase in a TD individual's discrepancy scores, indicating increased perceptual disturbance when encoding and recalling moderately fast speech.

Table 5-11. *Exp 3 multiple regression of accuracy discrepancy score of TD participants during moderate speed condition*

	B	SE *B*	β	*t*	*p*
CC-Language Structure	0.86	0.39	0.47	2.20	0.042*

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

Fast Speed

In order to examine the extent that the significant cognitive, behavioural and clinical correlates in the table above accounted for the variance in encoding and recall of fast speech in ASD and typically developing participants two multiple linear regressions were performed. The dependent variable was the accuracy discrepancy score for the fast speed condition. The predictor variables were individuals' performance IQ scores on the WASI, scores on the language structure, pragmatic skills and social engagement subscales as well as total scores of the Communication Checklist, sensory sensitivity subscale of the Sensory Profile and social skills and imagination subscale of the AQ and imagination subscale of the ADOS. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

The results revealed a significant linear relationship between ASD participants' accuracy discrepancy scores during the fast speed condition and the predictor variables. Table 5-12 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the predictor variables on the accuracy discrepancy scores during the fast speed condition in the ASD group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.88, [$F(1,19)= 17.66$, $p<0.001$; adjusted $R^2= 0.75$]. Thus, roughly 75% of the variability in ASD participants' accuracy discrimination scores during the fast speed condition was predicted by their performance IQ scores and scores on the social skills and imagination subscales of the AQ. A closer look at the un-standardised regression coefficients indicates that higher levels of autistic traits in the realm of social skills and imagination predicted an increase in an ASD individual's discrepancy scores indicating increased perceptual disturbance when encoding and recalling speech spoken at a fast speed. Furthermore, higher performance IQ scores predicted a decrease in an ASD individual's discrepancy scores, indicating less difficulty encoding and recalling speech spoken at a fast speed.

Table 5-12. *Exp 3 multiple regression of accuracy discrepancy score of ASD participants during fast speed condition*

	B	SE *B*	β	*t*	*p*
WASI-Performance IQ	-0.43	0.08	-0.66	-5.15	0.000***
AQ- Social Skills	1.61	0.47	0.50	3.45	0.004**
AQ- Imagination	1.19	0.51	0.33	2.33	0.035*

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

The results also revealed that there was no significant linear relationship between TD participants' accuracy discrepancy scores during the fast condition and the predictor variables with a multiple correlation of 0.28, [F(1,19)= 1.46, p= 0.243; adjusted R^2= 0.02]. Thus, there did not appear to be a relationship between the predictor variables and encoding and memory of fast speech in the typically developing population.

DISCUSSION

Overall, similar to experiment two, the findings from experiment three suggested that adults with ASD did not experience any more difficulty encoding and recalling medium and fast rates of speech than their typically developing peers. However, the accuracy analysis revealed that individuals in both groups experienced significantly more difficulty recalling speech that was spoken at double speed in comparison to normal and moderately fast speech. Whilst the accuracy and reaction time analyses didn't uncover any significant group differences, exploratory correlation and regression analyses suggested there may be different patterns of underlying mechanisms driving performance in the two groups. In particular, increased communication difficulties and older age in ASD individuals were related to increased levels of difficulty encoding and recalling speed spoken at double the normal rate of speech.

One of the primary aims of experiment three was to increase our understanding of the effect of temporal manipulations on encoding and recall of speech in individuals with ASD. Behavioural and neuroimaging studies of participants with ASD had shown abnormalities in processing temporal aspects of auditory information and it had been hypothesised that this could be due to an extended temporal processing window that could affect the rapid processing of sensory information. Although no overall group differences emerged within either the accuracy or recall time analyses, this is not necessarily surprising given that both groups possessed higher than average levels of intelligence and good verbal skills. This result does not appear to reflect insensitivity in the paradigm as there were significant differences between accuracy but not recall time discrepancy scores on the moderate and fast speed manipulations. Thus, individuals within both groups recalled significantly fewer correct words when the speed of speech was twice as fast as normal, but not when sentences were produced at a moderately fast speed. Furthermore, accuracy results indicated that individuals were experiencing significant levels of perceptual disturbance from the fast temporal manipulation in comparison to normal speech. Thus confirming the first hypothesis that individuals across both groups would experience more difficulty encoding and recalling sentences when speed of speech increased. Recall time analyses also revealed a significant interaction between temporal manipulations and group. Trends suggested that ASD participants recalled sentences slower during the moderate speed condition in comparison to the fast speech condition, whilst typically developing individuals tended to recall sentences slower during the fast speech condition. It is unclear whether this result is a consequence of different auditory processing strategies in the two groups or indicative of subtle temporal processing abnormalities in individuals with ASD. Future studies utilising electrophysiological methodologies may be able to address this question.

Another aim of experiment three was to explore the cognitive, behavioural and clinical correlates associated with auditory temporal processing in typically developing and ASD individuals. Individuals with ASD demonstrated a very different profile of correlations between their performance on the task and scores on the background measures to that of typically developing controls where no relationship was found between task performance on the fast speed condition and any of the background measures investigated. Thus the final hypothesis that typically developing individuals with higher levels of autistic traits would be more affected by increased rates of speech was not confirmed. However, correlations revealed a significant relationship between older age and increased perceptual disturbance from fast speech in the ASD group but not the control group, despite the fact that the two groups were matched on mean age and range. This result perhaps indicates that individuals with ASD are more susceptible to age related processing effects such as cognitive slowing, than typically developing individuals. Although Wingfield et al. (1985, 1986), Tun et al. (1992) and Tun (1998) found that elderly typical adults demonstrated steeper declines in rates of performance with increasing speech rate in comparison to younger individuals, their elderly cohort extended far beyond the age range in the present study and it is unsurprising that the typically developing participants who completed experiment three did not show the declines reported in these studies. Furthermore, correlations showed that individuals with ASD who reported higher level of difficulty across all subscales of the communication checklist also experienced significantly higher levels of perceptual disturbance from speech spoken at double speed. Thus, the present study indicates that there is a relationship between language ability and temporal processing abnormalities in individuals with ASD that extends to those on the very high-functioning end of the spectrum. These results combined with the significant correlations between performance on the fast speed condition and sensory profile scores in the ASD group support the second hypothesis. However, the effects are relatively small and the nature of this relationship remains unclear. A similar relationship was also found between sensory processing abnormalities, autistic traits relating to social skills and imagination and accurate recall of sentences spoken at a fast speed. This finding was further supported by the regression analyses that indicated that higher levels of self-reported autistic traits on the imagination and social skills subscales of the AQ in individuals with ASD predicted a significant increase in perceptual disturbance when encoding and recalling moderate and fast speech. These results suggest that auditory processing deficits in ASD may not just be a function of language impairment, but rather indicative of an association with the sensory abnormalities and social and communication impairments characterising the disorder. Furthermore, the relationship between performance on the experimental task and performance IQ suggests that the absence of a group difference in the present study may very well be due to fact that only high-functioning individuals were included in the study. Future research should examine whether this relationship also exists in lower-functioning individuals who demonstrate higher level of language impairments and also to what extent this effect is present during earlier stages of development.

One limitation of the present study is that temporal manipulations to the sentence stimuli were artificial and thus the results may not be generalizable to real life situations. However, research has indicated that natural fast speech is actually more difficult to process than artificially time-compressed speech. Janse (2004) suggests this could be due to the fact that naturally fast speech does not just have temporal adjustments, it also contains more general prosodic changes as well as increased segmental overlap. Thus, it is plausible that the deficits reported in this study may be underestimating the difficulties that ASD individuals with high levels of communication abnormalities actually experience in their everyday lives. This underscores the importance of future research examining other indicators of abnormal temporal speech processing in individuals with ASD and the impact this may have on their vocational and psychosocial outcomes later in life.

The results from this study failed to demonstrate differences between ASD and TD groups and this suggests that abnormalities in these very high functioning individuals are either absent of difficult to isolate. One reason to suspect that abnormalities are present but difficult to isolate is that the regression analyses showed that disruption during encoding and recall of fast speech was associated with ASD symptomatology, especially in the realms of social skills and imagination. Unlike the stimuli used in experiments two and three, real speech involves change across both pitch and speed and it may be that ASD related deficits, hinted at in the results from the regression analyses carried out on the data from experiments two and three, provided the rationale for predicting that group differences would emerge on a more complex task. Therefore the following chapter will describe a study that integrates both temporal and prosodic change and also manipulate the level of grammatical complexity in the stimuli.

CHAPTER 6: PERCEPTUAL AND GRAMMATICAL COMPLEXITY INFLUENCES ON SENTENCE RECALL

SUMMARY

Adults with ASD and intelligence and age matched typically developing controls were tested to examine whether perceptual and grammatical manipulations effect speech encoding and recall. Sentences with either non-subordinate or subordinate clauses were utilized to assess the effect of grammatical complexity on sentence recall. In order to isolate perceptual as well as higher-order speech processing deficits, speed and pitch manipulations were also carried out on the stimuli. The results indicated that fast speech reduced sentence recall abilities in both groups and prosodic manipulations may further contribute to perceptual disturbance in the ASD group. There were also notable interactions between both perceptual manipulations and grammatical complexity for the ASD, but not the TD group. These results are discussed within the context of Samson et al.'s (2006) neural complexity hypothesis. Finally, correlational analyses were used to examine the extent that sensory processing abnormalities and scores on standardised measures of language and communication were associated with reduced performance in response to perceptual and higher-order changes in the experimental stimuli.

INTRODUCTION

The studies reported in chapters four and five (experiments two and three) of this thesis demonstrated that adults with ASD performed similarly to age and IQ matched typically developing adults on sentence repetition tasks. Findings from experiment three highlighted an overall deterioration in sentence recall abilities across both groups when the speed of speech increased whereas experiment two indicated that individuals from both the typically developing and ASD groups were susceptible to perceptual disturbance from abnormal speech prosody. Difficulties understanding the lower level paralinguistic aspects of speech, including prosodic and temporal information, have implications for processing the higher-level syntactic and semantic aspects of speech. Furthermore, investigating how individuals with ASD process speech at both lower and higher levels is critical to gaining a better understanding of their wider socio-communicative difficulties. Studies have shown that individuals with ASD, including highly verbal adults, experience deficits in pragmatic functioning (Baron-Cohen, 1997; Happé, 1993; Lord & Paul, 1997; Martin & McDonald, 2004; Tantam, Holmes & Cordess, 1993). However, most ASD research into pragmatic language has focused on high-level deficits whilst relatively few studies have examined encoding and recall in relation to grammatical abilities. In order to isolate perceptual as well as higher-order speech encoding and recall deficits in adults with ASD, speed, pitch and grammatical manipulations were carried out on sentence stimuli in an experimental study. The rationale for this experiment was drawn from the neural complexity hypothesis that postulates that deficits in auditory processing in ASD increase in line with increasing stimulus complexity (Samson et al., 2006). Thus one of the questions to be addressed in this chapter concerns whether the combined spectral and temporal characteristics of speech influence recall of grammatically simple and complex sentences.

Pitch is an important component of prosody and prosody enables listeners to access affective, pragmatic and syntactic aspects of language. However, in a recent behavioural study carried out with adolescents with ASD, Järvinen-Pasley, Pasley & Heaton (2008) observed increased sensitivity to the perceptual components of sentences (their pitch contours) that co-occurred with difficulties in determining whether changes in pitch contours denoted questions or statements. It appeared from these results that for these individuals the form of the stimuli has increased salience, but the function was not well appreciated. Findings have also highlighted a failure to exploit meaningful information from linguistic contexts in order to make global inferences (Jolliffe & Baron-Cohen, 2000). Using ERPs with typical populations, researchers have revealed that semantically inappropriate words (The cat eats the *tree*) are associated with a negative deflection peaking at 400ms (N400) (Kutas & Hillyard, 1980). By contrast prosody violations have elicited positivity at later time points (emotional prosody Kotz & Paulmann, 2007; phrasal prosody Steinhauer & Friederici, 2001). Recently, researchers also showed that people with AS demonstrated large N400 for both control and incongruent sentences suggesting that they are unable to integrate semantic information (Ring, Sharma, Wheelwright & Barrett, 2007).

The importance of the interaction between prosody and syntax has been demonstrated in several neurological studies of typical individuals. Although there is conflicting evidence, studies have generally shown that prosody plays a role in structural disambiguation (Marslen-Wilson, Tyler, Warren & Grenier, 1992; Schafer, Carlson, Clifton & Frazier, 2000; Speer, Warren & Schafer, 2003; Warren, Grabe & Nolan, 1995) and also in making chunking and phrasing decisions (Kjelgaard & Speer, 1999; Nagel, Shapiro, Tuller & Nawy, 1996; Speer, Kjelgaard & Dobroth, 1996; Steinhauer, Alter & Friederici, 1999). Thus, according to Eckstein and Friederici (2006) there is a consensus among neurophysiological studies that an interaction between syntax and prosody exists, especially during later stages of processing. Furthermore, in their own research with typically developing adults, Eckstein and Friederici (2006) used event related potentials with stimuli that either contained a prosodic or a syntactic violation or combined prosodic and syntactic violations. Prosodic and syntactic incongruences resulted in a negativity that was broad and focused in the left temporal region respectively, whilst syntactic violations led to an early negativity focused in the left temporal region as well as a late positivity. The combined prosodic and syntactic violations elicited a late positivity and more importantly an early temporal negativity. Their findings confirmed those from previous studies and demonstrated that the interaction between prosody and syntax also occurs at very early stages of processing, further underscoring the importance of these mechanisms. Additionally, their research suggests that different neural regions are utilized in syntactic processing (left hemisphere) and prosodic processing (right hemisphere).

As discussed in chapter four, prosodic deficits appear to exist at both the expressive and comprehension level in ASD. Furthermore, prosodic abnormalities are pervasive enough that they are included as part of the diagnostic criteria tested by the ADOS and ADI-R. It is interesting to note that within the ADOS it is not so much the type of expressive prosody that an individual is demonstrating that is important, but rather the inconsistency between the context of speech and the prosody used by the speaker (Diehl, Bennetto, Watson, Gunlogson & McDonough, 2008). The majority of prosody research in ASD has focused on affective rather than linguistic prosody. However, research into linguistic prosody, which is involved in syntactic and semantic processing, may provide insight into the communication difficulties that are a core component of autism. Research has shown the importance of prosodic comprehension in typically developing adults who demonstrated sensitivity to the interactions between sentence structure and prosody (Snedeker & Trueswell, 2003). Given the mismatch between productive prosody and speech context in ASD it is highly possible that similar abnormalities may exist during speech comprehension as well. Although this is an under-researched area, several recent studies have begun to examine the interaction between prosodic comprehension and syntax. Whilst adolescents with HFA were able to use prosodic clues to identify phrase structure to the same extent as typically developing controls, they did have difficulty using prosodic clues to identify stress differences in words (Paul et al., 2005). Another study with children partially replicated these results in showing that ASD and TD children did not differ in the use of prosody to perform linguistic decisions (Peppé, McCann, Gibbon, Ohare & Rutherford, 2006). Whilst no specific conclusions can be drawn from the studies carried out to date, it is clear that abnormalities in the integration of comprehension of linguistic prosody and grammatical syntax do exist to some extent in individuals with ASD.

Samson et al.'s (2006) neural complexity hypothesis (NCH), briefly introduced in chapter one of this thesis, is of particular importance when examining perceptual and higher-order manipulations to speech stimuli. According to the NCH, individuals with ASD should show superior performance compared with their typically developing peers on tasks involving pure tone discrimination. However, they should experience more difficulty than typical individuals when processing spectrally or temporally complex stimuli. Less complex, pure tone stimuli is processed within the primary auditory cortical area A1, which requires relatively little neuro-integrative processing. As stimuli become more complex, more extensive neural circuitry is involved (i.e. primary and associative auditory cortices, A1 and A2) and the NCH predicts that this results in poorer performance in individuals with ASD.

Behavioural evidence of enhanced processing of simple auditory stimuli in the ASD population was already presented and discussed in chapters four and five. These studies include findings of enhanced pitch sensitivity (Bonnel et al., 2003) and superior pitch discrimination and memory (Heaton, 2003, 2005; Heaton et al., 1998, 1999; Heaton, Hudry, et al., 2008; Heaton, Williams, et al., 2008; C. R. G. Jones et al., 2009; Mottron et al., 2000; O'Riordan & Passetti, 2006). There have also been numerous electrophysiological and neuroimaging studies, mostly testing perception of pitch change, that further support the suggestion that enhanced processing of low complexity auditory stimuli is superior in ASD. Earlier studies demonstrated that the cortical response evoked by an unexpected novel auditory stimulus among familiar sounds is smaller in children with autism than in controls (Courchesne et al., 1984; Lincoln et al., 1993). More recently, studies focusing on abnormal mismatch negativity (MMN) in ASD have observed larger amplitudes and earlier latencies in comparison to typically developing controls that provide further evidence for superior performance on low-level auditory tasks. Children with autism have been shown to elicit larger MMN amplitudes in response to changes in vowel pitch (Lepistö et al., 2005, 2008), tonal stimuli (Lepistö et al., 2005) and pure tone stimuli (Ferri et al., 2003). Similar studies carried out on individuals with Asperger syndrome (AS), the highest functioning ASD subgroup characterised by relatively intact language abilities, have observed larger MMN amplitudes in children with this disorder relative to age matched controls (Kujala et al., 2007, 2010; Lepistö et al., 2006). Abnormal MMNs in response to non-speech pitch changes have also been observed in children with autism who showed a shorter latency (Gomot et al., 2011, 2002). These results indicated that children with low-functioning autism detected the pitch changes faster than their typically developing peers matched on age and gender. Thus, individuals with ASD, including those on the lower functioning end of the spectrum, have higher levels of neurological reactivity to pitch deviance. The pattern of findings demonstrated in the behavioural and neurological studies support the NCH's assertion that individuals with ASD outperform their typically developing peers on simple auditory tasks.

Studies also support the NCH's suggestion that individuals with ASD perform poorly on auditory tasks involving more complex stimuli. A combination of behavioural (Alcántara et al., 2004; Groen et al., 2008), electrophysiological (Ceponiene et al., 2003; Kujala et al., 2005) and brain imaging (Boddaert et al., 2003, 2004; Gervais et al., 2004) research demonstrates that as auditory information becomes more complex (spectrally and/or temporally) it results in diminished performance and reduced functional brain activity in ASD participant groups. At the behavioural level Alcántara et al. (2004) found a reduced ability to perceive speech in noise in individuals with HFA and AS. The authors developed a paradigm that measured speech reception thresholds under 5 different background noise conditions that contained either spectral, temporal, combined spectral and temporal dips or no dips at all. The ASD group performed significantly worse than IQ and age matched typically developing controls on the conditions where temporal or combined temporal and spectral dips were present, however when there were only spectral dips or no dips at all the groups performed similarly. The author's interpreted these findings as indicative of a reduced ability to integrate information gained during glimpses present in temporal dips in noise in individuals with ASD. However, due to their use of sentence stimuli, it is unclear whether their results are due to peripheral or central processing deficits. Groen et al. (2008) aimed to replicate Alcántara et al.'s findings using two-syllable words embedded in spectral (pink noise and moving ripple) and temporal (amplitude modulated pink noise and amplitude modulated moving ripple) background noises. Whilst there were no significant group differences, adolescents with

HFA gained significantly less from conditions with temporal dips than IQ, age and gender matched controls suggesting that individuals with ASD are less able to integrate information gained from temporal dips in background noise. Thus, the two studies provide evidence for diminished neuro-integrative functioning during temporal integration and support the NCH's prediction of poorer performance on tasks involving complex auditory stimuli.

Evidence from electrophysiological studies further support difficulties processing spectro-temporally complex stimuli in individuals with ASD. Several MMN studies found that children with AS show longer MMN latencies relative to controls in response to infrequent changes to consonant and vowel stimuli (Jansson-Verkasalo et al., 2003; Lepistö et al., 2006). Research with AS adults also demonstrated similar findings of delayed MMN latencies and smaller amplitudes relative to typically developing adults on tasks involving changes in vocal prosody (Kujala et al., 2005). Impaired processing of auditory stimuli has also been found using more complex oddball paradigms (Dunn et al., 2008; Kujala et al., 2010; Lepistö et al., 2009). These results are further supported by ERP studies examining the P3a subcomponent that indicates attention switching. Ceponiene et al. (2003) failed to identify the P3a component when listening to vowel stimuli during an oddball task in children with ASD compared with their age-matched peers. Furthermore, Lepistö et al. (2006) observed smaller P3a amplitudes when listening to vowel, but not non-speech stimuli in children with AS relative to typically developing controls. These findings suggest that some of the difficulties processing spectro-temporally complex stimuli may occur at the attentional rather than the sensory level and this provides further support for the NCH.

Finally, evidence from brain imaging studies suggests that diminished auditory processing of complex stimuli may stem from atypical or reduced activation of the left frontal temporal regions (Boddaert et al., 2003, 2004). Gervais et al. (2004) found that brain regions that are typically activated in response to vocal stimuli in typically developing individuals are not activated to the same extent in adults with ASD, suggesting that autistic individuals may process spectro-temporally complex stimuli in an atypical fashion. Boddaert et al. (2003, 2004) suggested that this abnormality may be more prominent when processing the temporal aspects of complex auditory stimuli due to findings of right rather than left patterns of cortical activation during the processing of temporally complex speech-like stimuli. Overall, findings from behavioural, electrophysiological and neurological studies of auditory processing among individuals with ASD support the notion that auditory stimuli that are spectrally, temporally, or spectro-temporally complex seem to be associated with poorer auditory processing among this group. Combined with evidence for enhanced processing of simple auditory stimuli, these findings provide preliminary support for the NCH's assertion that levels of performance on auditory tasks are inversely related to stimulus complexity among ASD individuals.

EXPERIMENT 4: TESTING THE EFFECT OF COMBINED PROSODIC AND TEMPORAL MANIPULATIONS ON ENCODING AND MEMORY OF SPEECH

Aims

The primary aims of experiment four are to further investigate the findings of experiments two and three of this thesis and to test Samson et al.'s (2006) account of auditory processing utilizing stimuli with varying levels of grammatical and perceptual complexity. Experiment three demonstrated that participants experienced more difficulty recalling sentences that were spoken at a very fast rate of speech compared with a normal or moderately fast pace. Whilst experiment two did not indicate a reduced ability to recall sentences with pitch deviations in ASD at the group level, Samson et al.'s complexity hypothesis would predict that changes to both prosodic and temporal parameters of speech would degrade speech encoding and recall in the ASD group more than in a TD control group.

Another aim of the present study is to examine the extent that cognitive, behavioural and clinical correlates are associated with performance in response to perceptual and higher-order changes in the experimental stimuli in both typically developing adults and those with ASD. In the ASD sample, the relationship between sensory and communication abnormalities, symptom severity and performance on the experimental task may provide insights into the heterogeneity characterising the disorder and confirm whether all individuals diagnosed with ASD will show the difficulties described by Samson's theory.

Hypotheses

1. The added level of difficulty created by combining both prosodic and speed manipulations will cause greater interference than exhibited with either manipulation alone in both groups.
2. In line with Samson et al.'s (2006) complexity hypothesis, the ASD group will show a greater decrease than controls in sentence recall accuracy in conditions where the stimuli are more grammatically complex, whereas the TD group will not show the same effect.
3. Within the ASD group, individuals who experience higher levels of sensory abnormalities and communication deficits will demonstrate increased interference from perceptually and grammatically complex speech stimuli.
4. It is hypothesised that TD individuals with higher levels of autistic traits, as measured by the AQ, will show more increased interference from perceptually and grammatically complex speech in comparison to the rest of their cohort.

METHODS

Participants

All 38 participants outlined in chapter two participated in this study.

Experimental Methods

Experimental Stimuli

Data obtained from experiments two and three indicated that temporal but not prosodic manipulations impaired speech encoding and recall. Experiment four aimed to investigate whether an accumulated effect would also be observed. This paradigm further tested Samson et al.'s (2006) speech complexity hypothesis by including simultaneous prosodic and speed manipulations as well as varying levels of grammatical complexity in an implicit sentence repetition paradigm. The sentence stimuli utilised for experiments two and three had previously been used by Tun et al. (1992) to examine the age effects of rapid speech processing in TD individuals and thus provided the best opportunity for replication. Whilst the stimuli used by Tun et al. were matched for numbers of words and provided a high cognitive load, other linguistic factors that can affect speech encoding and recall such as number of syllables and word frequency were not controlled. The present study therefore aimed to take a more rigorous linguistic approach by taking these additional factors into account. In order to reduce the variability within the sentences used by Tun et al. more stringent matching criteria were utilised when selecting new linguistic stimuli. The sentence stimuli for experiment four were derived from Hasson, Nusbaum and Small (2006), which matched the sentences on average number of words, syllables and word frequency (table 6-1). In order to test Samson et al.'s complexity hypothesis more directly the linguistic content of the sentences also represented two levels of grammatical complexity (subordinate and non-subordinate clauses).

Table 6-1. *Exp 4 sentence matching (mean value for each sentence type)*

	Number of Words	Syllables	Word Frequency [a]
Subordinate Clause	10.1 (1.85)	14.9 (2.51)	97.6
Non-Subordinate Clause	10.1 (1.62)	13.7 (2.8)	93.6

[a] *Kucera & Francis (1967)*

Experiment four was designed to test the combined effect of temporal and spectral processing during sentence repetition of grammatically simple and complex sentences. Sentence stimuli consisted of 50 sentences randomly selected from the 84 sentences used by Hasson et al. (2006) (Appendix III). 25 of the 50 sentences contained a subordinate clause and represented a high level of grammatical complexity while the other 25 were non-subordinate clause sentences and represented low grammatical complexity. The sentences were recorded by an adult British English speaking female and manipulated using PRATT (Boersma, 2001) to generate two different prosody conditions: monotone and exaggerated speech prosody, two speed conditions: moderate speed (200 wpm) and fast speed (280 wpm) and one control condition in which neither the speed nor the prosody of the sentences had been manipulated. The normal speech control condition was only manipulated by adjusting the original sentences to the mean intensity (perceived volume) and a median pitch of 200Hz, in order to remove any inconsistencies that were artefacts from the recording process. The sentence stimuli were then manipulated to the two prosody conditions with the same procedure used for experiment two in chapter four of this thesis followed by a manipulation to their rate of speech using the same procedure as experiment three described in chapter five. An E-Prime programme was designed to randomly select and randomise the presentation of five sentences in each of the five conditions during each block for every participant to adjust for any inherent differences in the sentences, fatigue and practise effects.

Procedure

Participants were administered five practice sentences, one under each condition and asked to perform a verbatim recall immediately following the end of the recorded sentence. The researcher informed participants that they should repeat as much of the sentence as they could remember, in the order that they had heard it and to omit any words they could not recall. Following the practice trials, 50 experimental sentences were administered in the same format, split into two blocks of 25 by level of complexity. To avoid practise effects and fatigue the order of presentation of the two tasks was counterbalanced across sessions. During the experimental trials, participants' responses were timed and accuracy was recorded manually for later analysis. Overall response times were measured from the end of the recorded sentence stimuli to the end of the participant's response. Participants received one point for each correct word that was produced in the correct place within the recalled sentence. Words that were either incorrect or in the wrong order were not awarded any points. Raw scores were calculated by counting the number of points each participant achieved within each level of complexity and across all five conditions. Raw scores were then converted to percentages for the analysis.

Analysis

Discrepancy scores were generated for each participant in order to account for any individual differences in working memory, language comprehension, or speech rate that may have affected their performance. Participants' percentage correct scores on the perceptual manipulation conditions were subtracted from their scores on the normal speech (baseline) condition in order to calculate their individual levels of perceptual disturbance.

A factorial analysis of variance (ANOVA) was used to analyse the discrepancy data from experiment 4 with within-subjects factors of perceptual manipulation (4 levels; monotone pitch/moderate speed, exaggerated pitch/moderate speed, monotone pitch/fast speed and exaggerated pitch/fast speed) and level of grammatical complexity (2 levels; subordinate clause sentences and non-subordinate clause sentences) and between-subjects factor of group (2 levels; ASD and TD). The dependent variable was the discrepancy scores for each participant across the five trials at each perceptual manipulation in each of the two complexity levels.

RESULTS

Accuracy Analysis

Means, standard deviations and ranges for the percentage correct scores across grammatical complexity and perceptual manipulation conditions are shown in table 6-2.

Table 6-2. *Exp 4 mean percentage correct scores, standard deviations and ranges*

ASD	Non-Subordinate Clause		Subordinate Clause	
Speech Cond.	Mean (SD)	Range	Mean (SD)	Range
Normal	92.76 (9.98)	60.38-100.00	96.73 (4.78)	84.91-100.00
Mono/Mod	87.82 (15.26)	44.64-100.00	96.17 (4.06)	89.09-100.00
Mono/Fast	85.24 (10.47)	63.46-98.11	84.42 (13.59)	54.55-100.00
Exag/Mod	90.87 (9.21)	69.23-100.00	93.95 (6.21)	73.33-100.00
Exag/Fast	80.96 (12.55)	53.57-100.00	84.59 (15.64)	45.10-100.00
Total	87.46 (9.67)	65.90-98.47	91.14 (7.13)	72.69-100.00
TD	Non-Subordinate Clause		Subordinate Clause	
Speech Cond.	Mean (SD)	Range	Mean (SD)	Range
Normal	94.69 (6.36)	82.00-100.00	97.30 (4.75)	84.21-100.00
Mono/Mod	90.57 (9.27)	64.81-100.00	96.73 (4.08)	85.71-100.00
Mono/Fast	84.92 (15.16)	46.30-100.00	87.62 (9.62)	63.64-100.00
Exag/Mod	91.70 (7.38)	72.55-100.00	96.63 (3.97)	85.45-100.00
Exag/Fast	86.53 (9.17)	67.31-98.08	90.35 (8.33)	72.73-100.00
Total	89.65 (7.39)	75.48-98.08	93.70 (4.77)	80.81-99.26

Note: Mean percentage correct scores (out of a maximum of 100)

Discrepancy score means, standard deviations and ranges for the discrepancy scores across grammatical complexity and perceptual manipulation conditions are shown in table 6-3.

Table 6-3. *Exp 4 mean discrepancy scores, standard deviations and ranges*

ASD	Non-Subordinate Clause		Subordinate Clause	
Speech Cond.	Mean (SD)	Range	Mean (SD)	Range
Mono/Mod	4.94 (11.19)	-15.38-36.84	0.56 (3.37)	-5.17-7.34
Mono/Fast	7.52 (8.11)	-7.62-26.73	12.31 (11.61)	0.00-45.45
Exag/Mod	1.89 (7.32)	-13.74-12.25	2.78 (5.51)	-10.55-12.73
Exag/Fast	11.80 (13.05)	-14.17-42.51	12.13 (12.61)	-1.82-39.81
TD	Non-Subordinate Clause		Subordinate Clause	
Speech Cond.	Mean (SD)	Range	Mean (SD)	Range
Mono/Mod	3.71 (7.24)	-8.38-17.19	0.44 (4.97)	-10.02-14.29
Mono/Fast	9.87 (13.45)	-9.22-47.58	9.35 (9.54)	-10.33-27.78
Exag/Mod	2.95 (7.28)	-16.04-16.31	0.73 (5.19)	-12.09-12.07
Exag/Fast	8.60 (7.61)	-2.07-25.00	6.86 (8.54)	-10.13-27.27

Note: Negative scores signify better performance on perceptual manipulation in comparison to baseline

A factorial analysis of variance (ANOVA) was performed on the data across the groups for this experiment. Mauchly's test of sphericity was not significant, $\chi^2(5)= 7.79$, $p= 0.168$, for the main effect of perceptual manipulation and for the interaction between grammatical complexity and perceptual manipulation, $\chi^2(5)= 8.88$, $p= 0.114$, indicating that the assumption of sphericity had not been violated. Therefore, no F-value corrections for the interaction term were necessary (Field, 2009). No correction was needed for the main effect of stimulus type as this variable contained only two levels and thus the assumption of sphericity was automatically met.

The analysis showed that whilst the overall mean discrepancy scores in response to perceptual and grammatical manipulations were greater, indicating increased disturbance in response to manipulations for the ASD group compared with the typically developing participants (M= 6.76, SD= 5.30 for ASD and M= 5.34, SD= 4.82 for TD) (Fig. 6-1) this difference was not statistically significant, $F(1, 38)= 0.76$, $p= 0.388$.

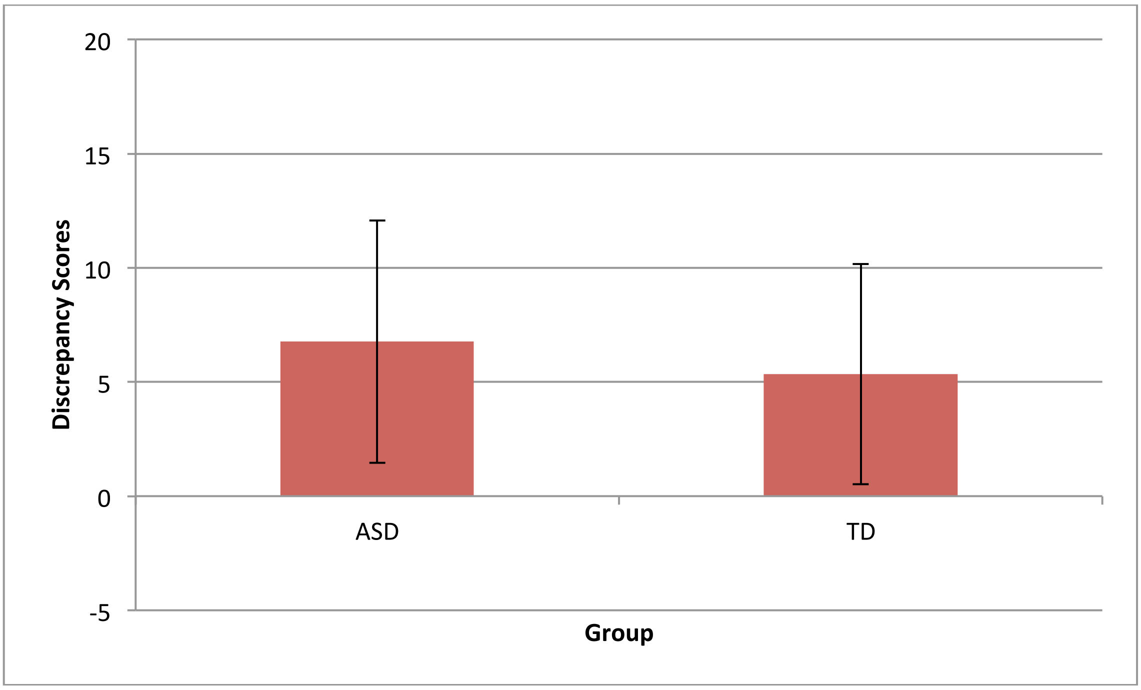

Figure 6-1. *Exp 4 main effect of group*
Note: Higher scores indicate increased perceptual disturbance

There was a highly significant main effect of perceptual manipulation on the participants' ability to successfully recall the sentences, $F(3, 38) = 27.39$, $p<0.001$. Comparisons confirmed the findings from experiment three, suggesting that participants experience more difficulty encoding and recalling speech as the speed of speech increases regardless of whether the speech contains monotone or exaggerated prosody ($ps<0.001$) (Table 6-4) (Fig. 6-2). Furthermore, in order to examine whether participants experienced significantly more difficulty in the conditions with speech manipulations than normal speech alone, a one-sample t-test was conducted. A mean value of 0 that would indicate identical accuracy when recalling perceptually manipulated speech and normal speech, was used. Results revealed a significant difference between discrepancy scores and 0 on all of the perceptual manipulation conditions (mono/mod, $t(37) = 3.08$, $p<0.01$; mono/fast, $t(37) = 6.91$, $p<0.001$; exag/mod, $t(37) = 2.62$, $p<0.01$; exag/fast, $t(37) = 8.02$, $p<0.001$). Thus, the present results suggest that individuals were experiencing significantly more difficulty during all of the perceptual manipulation conditions in comparison to normal speech.

Table 6-4. *Exp 4 pairwise comparisons of perceptual manipulation main effect*

Pitch Interval	Mean Difference	*t*	*p*
Mono/Mod vs. Mono/Fast	-7.39	-5.95	0.000*
Mono/Mod vs. Exag/Mod	0.30	0.35	0.727
Mono/Mod vs. Exag/Fast	-7.46	-6.52	0.000*
Mono/Fast vs. Exag/Mod	7.70	6.01	0.000*
Mono/Fast vs. Exag/Fast	-0.06	-0.05	0.963
Exag/Mod vs. Exag/Fast	-7.76	-6.85	0.000*

*Note: *p<0.008 (Bonferroni correction for multiple tests at p<0.05)*

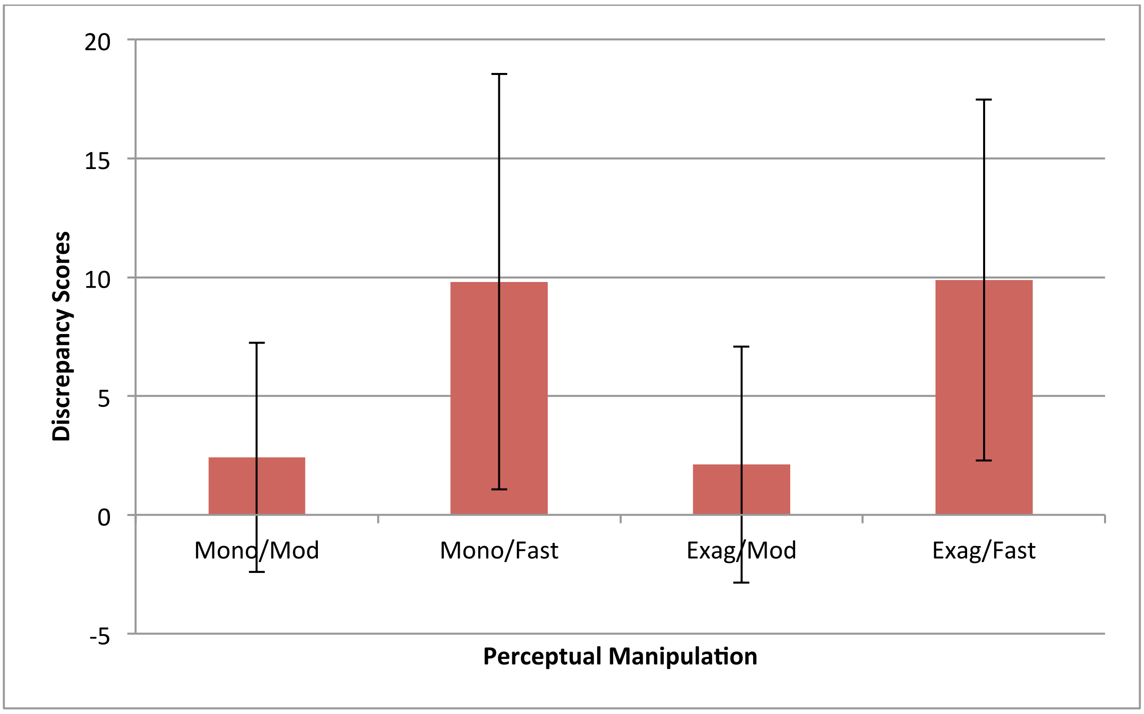

Figure 6-2. *Exp 4 main effect of perceptual manipulation*
Note: Higher scores indicate increased perceptual disturbance

Furthermore, there was no significant interaction between group and perceptual manipulation, $F(3, 38)= 1.27$, $p= 0.289$ (Fig. 6-3). However, there was a non-significant trend towards the ASD group experiencing more perceptual disturbance than the TD group in the exaggerated/fast condition, $t(36)= 1.78$, $p= 0.083$ (M= 12.01, SD= 8.61 for ASD and M= 7.74, SD= 5.88 for TD). Thus this suggested that the ASD group tended to experience more difficulty than the TD group when the fast speech stimuli became more complex with the addition of an exaggerated pitch contour.

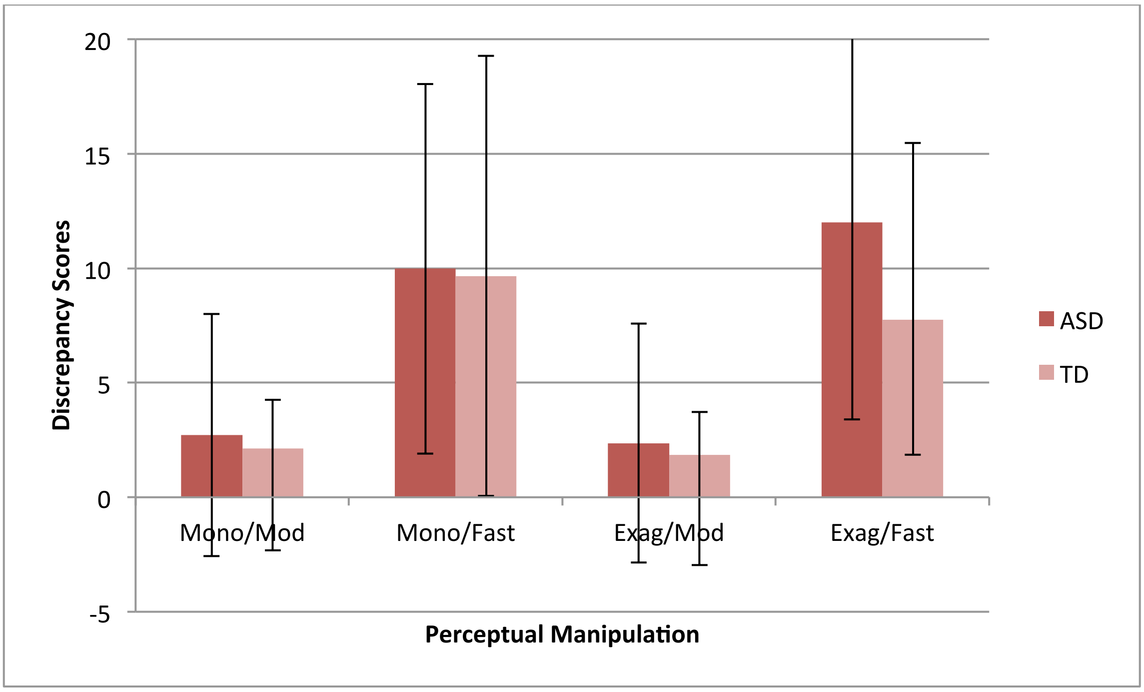

Figure 6-3. *Exp 4 group x perceptual manipulation interaction*
Note: Higher scores indicate increased perceptual disturbance

There was no significant main effect of grammatical complexity on participants' sentence recall, $F(1, 38)= 0.37$, $p= 0.544$. The analysis also showed that whilst the mean discrepancy scores for both grammatical conditions were poorer for the ASD group compared with the TD participants the group by grammatical complexity interaction was not significant, $F(1, 38)= 0.87$, $p= 0.357$, (Fig. 6-4).

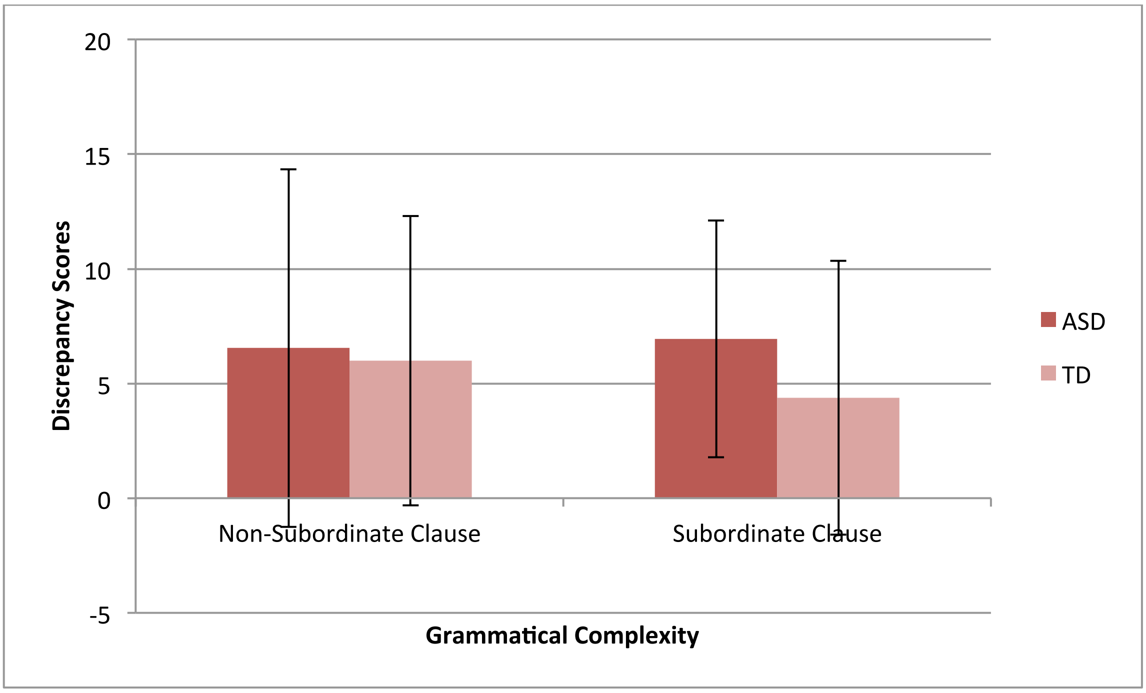

Figure 6-4. *Exp 4 group x grammatical complexity interaction*
Note: Higher scores indicate increased perceptual disturbance

Finally, there was no significant complexity by manipulation interaction, $F(3, 38)= 1.94$, $p= 0.127$ (Fig. 6-5); or complexity by manipulation by group interaction, $F(3, 38)= 0.58$, $p= 0.626$.

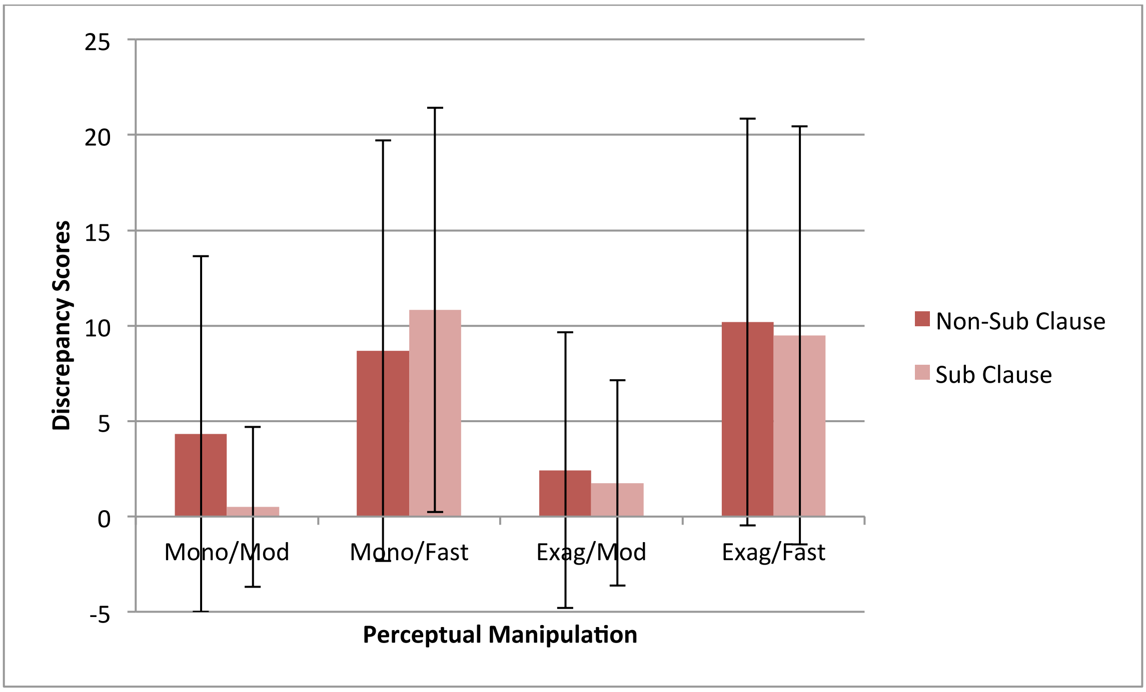

Figure 6-5. *Exp 4 perceptual manipulation x grammatical complexity interaction*
Note: Higher scores indicate increased perceptual disturbance

Recall Time Analysis

Means, standard deviations and ranges for the recall times across grammatical complexity and perceptual manipulation conditions are shown in table 6-5.

Table 6-5. *Exp 4 mean recall times, standard deviations and ranges*

ASD	Non-Subordinate Clause		Subordinate Clause	
	Mean (SD)	Range	Mean (SD)	Range
Normal	23.80 (6.51)	15.10-42.00	21.16 (5.12)	13.90-32.20
Mono/Mod	23.81 (6.30)	14.50-38.40	19.45 (4.32)	13.00-27.30
Mono/Fast	23.61 (7.44)	14.70-40.90	21.79 (5.97)	13.00-37.20
Exag/Mod	23.21 (6.06)	14.40-39.40	20.36 (6.52)	14.30-42.20
Exag/Fast	22.33 (6.72)	14.30-42.50	22.87 (8.80)	14,10-43.80
Total	23.35 (5.68)	14.76-36.46	21.13 (4.91)	14.70-34.34
TD	Non-Subordinate Clause		Subordinate Clause	
	Mean (SD)	Range	Mean (SD)	Range
Normal	19.68 (4.39)	13.10-30.70	17.34 (3.97)	12.20-25.90
Mono/Mod	21.69 (7.11)	12.60-42.90	17.27 (2.84)	11.70-23.40
Mono/Fast	23.16 (6.81)	14.00-41.90	21.06 (4.69)	14.80-29.70
Exag/Mod	19.92 (2.99)	15.90-24.50	18.44 (4.37)	11.30-26.10
Exag/Fast	21.21 (4.41)	14.50-29.10	19.01 (4.87)	12.70-32.20
Total	21.13 (4.15)	15.80-32.80	18.62 (2.56)	15.38-24.72

Discrepancy score means, standard deviations and ranges for the recall times across grammatical complexity and perceptual manipulation conditions are shown in table 6-6.

Table 6-6. *Exp 4 mean recall time discrepancy scores, standard deviations and ranges*

ASD	Non-Subordinate Clause		Subordinate Clause	
	Mean (SD)	Range	Mean (SD)	Range
Mono/Mod	-0.01 (4.48)	-8.80-12.60	1.71 (4.41)	-6.60-12.20
Mono/Fast	0.19 (4.57)	-8.50-7.80	-0.63 (6.29)	-14.10-8.80
Exag/Mod	0.59 (5.43)	-8.40-11.40	0.80 (6.17)	-11.40-10.60
Exag/Fast	1.48 (4.23)	-5.60-9.10	-1.71 (6.75)	-17.00-11.80
TD	Non-Subordinate Clause		Subordinate Clause	
	Mean (SD)	Range	Mean (SD)	Range
Mono/Mod	-2.01 (4.84)	-16.30-6.50	0.07 (4.43)	-9.40-8.00
Mono/Fast	-3.48 (6.31)	-15.30-6.20	-3.72 (5.67)	-15.70-5.50
Exag/Mod	-0.24 (4.30)	-6.90-7.60	-1.10 (6.03)	-13.90-8.50
Exag/Fast	-1.53 (5.23)	-8.90-6.90	-1.67 (5.15)	-13.70-7.10

Note: Negative scores indicate higher recall times on perceptual manipulation in comparison to baseline

A factorial analysis of variance (ANOVA) was performed on the data across the groups for this experiment. Mauchly's test of sphericity was not significant, $\chi^2(5)= 4.17$, $p= 0.524$, for the main effect of perceptual manipulation and for the interaction between grammatical complexity and perceptual manipulation, $\chi^2(5)= 7.47$, $p= 0.188$, indicating that the assumption of sphericity had not been violated. Therefore, no F-value corrections for the interaction term were necessary (Field, 2009). No correction was needed for the main effect of stimulus type as this variable contained only 2 levels and thus the assumption of sphericity was automatically met.

There was a significant main effect of group on participants' sentence recall, $F(1, 38)= 4.53$, $p<0.05$. Participants in the ASD group experienced significantly higher recall time discrepancy scores in comparison to the TD group (M= 0.30, SD= 2.84 for ASD group and M= -1.71, SD= 4.12 for TD group) (Fig. 6-6). Thus, ASD participants recalled sentences with perceptual manipulations faster than baseline sentences, whereas TD participants experienced more perceptual interference as demonstrated by slower recall of perceptually manipulated sentences in comparison to baseline recall.

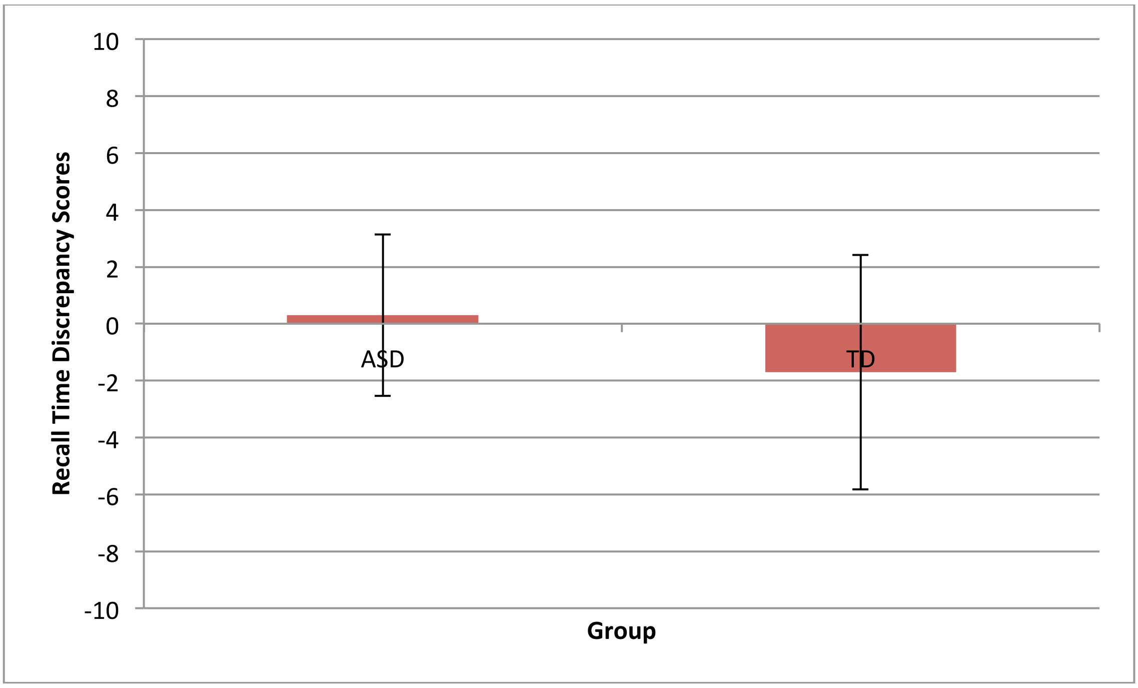

Figure 6-6. *Exp 4 main effect of group*
Note: Negative recall times indicate increased perceptual disturbance

There was also a significant main effect of perceptual manipulation on the participants' speed when recalling the sentences, $F(3, 38)= 3.32$, $p<0.05$. Comparisons confirmed the findings from experiment three, suggesting that participants experience slower speech encoding and recall as the speed of speech increases regardless of whether the speech contains monotone or exaggerated prosody (*ps*<0.05) (Table 6-7) (Fig. 6-7). As positive discrepancy recall times indicated faster recall speeds in perceptual manipulation conditions compared with normal speech, one-sample t-tests with a mean value of 0 were conducted to examine whether participants were experiencing faster processing times on conditions with perceptual manipulations. Results revealed a significant difference between discrepancy recall speeds on the mono/fast, $t(37)= -2.33$, $p<0.05$ condition and 0, but none of the other perceptual manipulation conditions and 0 (mono/mod, $t(37)= -0.24$, $p= 0.810$; exag/mod, $t(37)= -0.25$, $p= 0.804$; exag/fast, $t(37)= -1.45$, $p= 0.155$). Thus, the present results suggest that individuals were experiencing slower encoding and recall times during the monotone pitch fast speed condition in comparison to normal speech, but were encoding and recalling monotone/moderate, exaggerated/moderate, exaggerated/fast and normal speech at equivalent rates.

Table 6-7. *Exp 4 pairwise comparisons of perceptual manipulation main effect*

Pitch Interval	Mean Difference	Std. Error	*p*
Mono/Mod vs. Mono/Fast	1.85	0.68	0.010**
Mono/Mod vs. Exag/Mod	-0.07	0.74	0.924
Mono/Mod vs. Exag/Fast	0.80	0.73	0.281
Mono/Fast vs. Exag/Mod	-1.92	0.75	0.015*
Mono/Fast vs. Exag/Fast	-1.05	0.67	0.124
Exag/Mod vs. Exag/Fast	0.87	0.59	0.150

*Note: *p<0.05; **p<0.01; ***p<0.001*

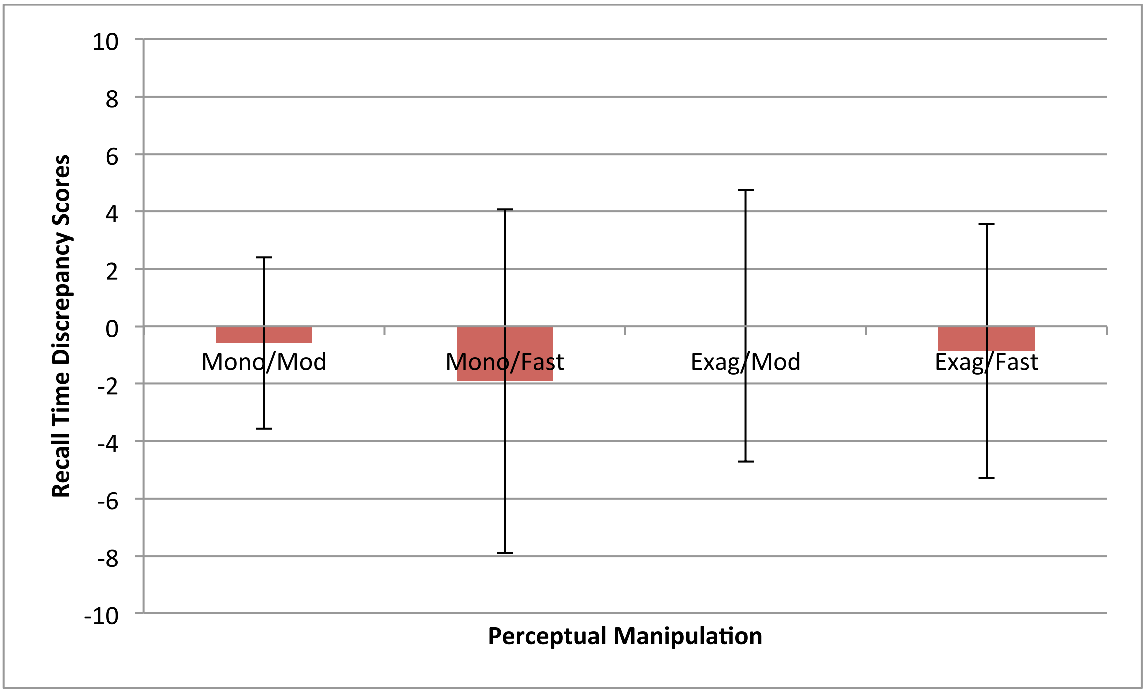

Figure 6-7. *Exp 4 main effect of perceptual manipulation*
Note: Negative recall times indicate increased perceptual disturbance

There was no significant main effect of grammatical complexity on participants' sentence recall times, $F(1, 38)= 0.03$, $p= 0.861$. Furthermore, there was no significant group by complexity interaction, $F(1, 38)= 0.18$, $p= 0.678$; group by manipulation interaction, $F(3, 38)= 0.90$, $p= 0.446$; complexity by manipulation interaction, $F(3, 38)= 2.78$, $p= 0.061$; or complexity by manipulation by group interaction, $F(3, 38)= 0.91$, $p= 0.438$.

Grammatical Complexity Analysis

In order to more directly test the second hypothesis that in line with Samson et al.'s (2006) complexity hypothesis, the ASD group would show a decrease in sentence recall accuracy in conditions where the stimuli are more grammatically complex whilst the TD group would not, four additional ANOVA's were conducted. Firstly to assess whether grammatical complexity interacted with prosodic complexity during auditory perception, a 2 x 2 ANOVA was conducted with within-subjects factors of prosodic manipulation (2 levels; monotone pitch/moderate speed and exaggerated pitch/moderate speed) and level of grammatical complexity (2 levels; subordinate clause sentences and non-subordinate clause sentences) for the ASD group and a parallel ANOVA was conducted with the TD group. The dependent variable was the discrepancy scores for each participant.

Within the ASD group, as expected from the results of the previous ANOVA, there was no significant main effect of prosodic manipulation, $F(1, 19)= 0.153$, $p= 0.700$ or grammatical complexity $F(1, 19)= 0.801$, $p= 0.383$. However, there was a strong trend towards significance on the interaction between prosodic manipulation and grammatical complexity, $F(1, 19)= 3.782$, $p= 0.068$ (Fig. 6-8). The interaction trend suggests an inverse relationship between grammatical and prosodic complexity whereby individuals with ASD are experiencing more perceptual disturbance from monotone speech when encoding and recalling grammatically simple but not complex sentences and from exaggerated speech prosody when encoding and recalling grammatically complex but not simple sentences.

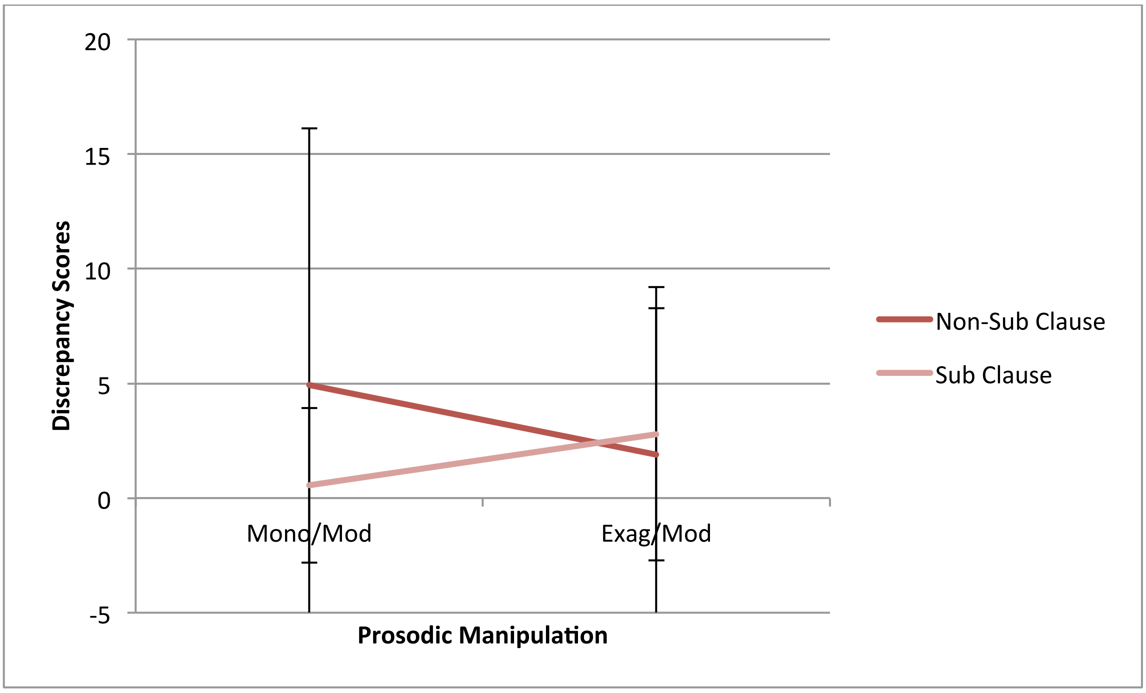

Figure 6-8. *Exp 4 ASD group prosodic manipulation x grammatical complexity interaction*
Note: Higher scores indicate increased perceptual disturbance

Within the TD group there was no significant main effect of prosodic manipulation, $F(1, 19)= 0.028$, $p= 0.868$, however there was a strong trend towards a significant main effect of grammatical complexity $F(1, 19)= 3.798$, $p= 0.067$. Participants' performance indicated that they experienced more perceptual disturbance during the non-subordinate clause sentences compared with the subordinate clause sentences (M= 3.33, SD= 4.87 for non-subordinate and M= 0.58, SD= 4.36 for subordinate). Unlike the ASD group, there was no trend towards significance on the interaction between prosodic manipulation and grammatical complexity, $F(1, 19)= 0.150$, $p= 0.703$ (Fig. 6-9), which suggests that there was no effect of grammatical complexity on typically developing adults abilities to encode and recall sentences manipulated by prosody.

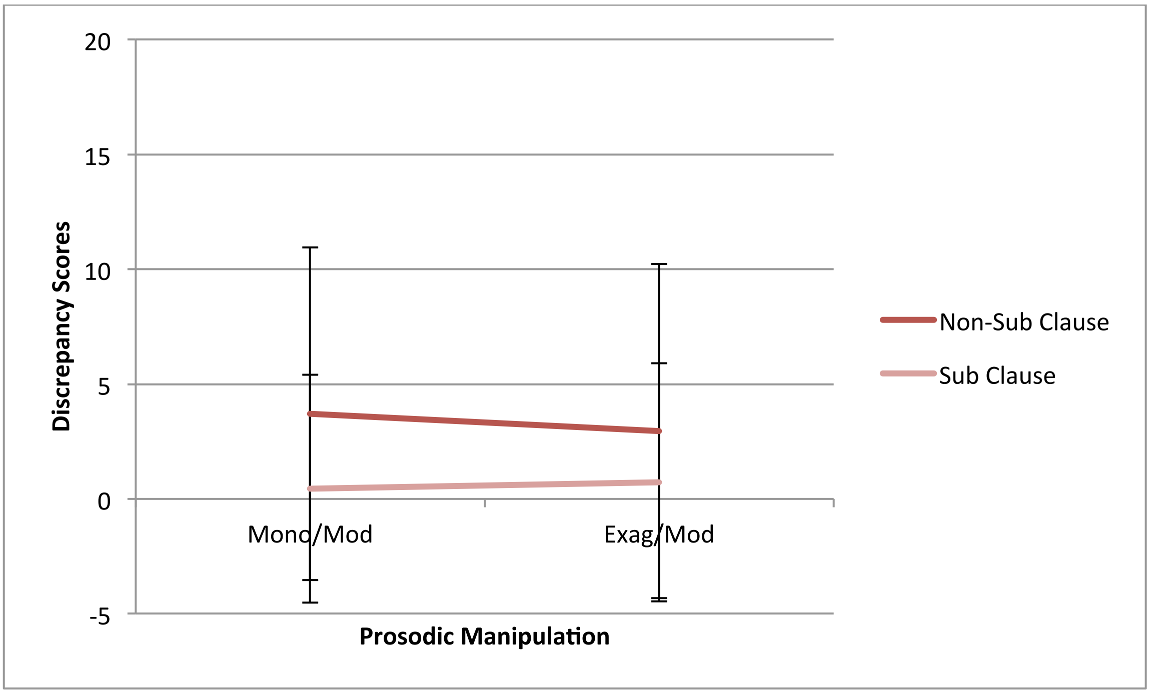

Figure 6-9. *Exp 4 TD group prosodic manipulation x grammatical complexity interaction*
Note: Higher scores indicate increased perceptual disturbance

Secondly, in order to assess whether grammatical complexity interacted with temporal complexity during auditory perception within the ASD group, a 2 x 2 ANOVA was conducted with within-subjects factors of speed manipulation (2 levels; monotone pitch/moderate speed and monotone pitch/fast speed) and level of grammatical complexity (2 levels; subordinate clause sentences and non-subordinate clause sentences) for the ASD group and a parallel ANOVA was conducted with the TD group. The dependent variable was the discrepancy scores for each participant.

In the ASD group, as expected from the results of the previous ANOVA, there was a highly significant main effect of speed manipulation, $F(1, 19)= 16.36$, $p<0.001$. Participants' performance indicated a significantly higher level of perceptual disturbance when encoding and recalling sentences spoken at a fast rate of speech in comparison to moderate speed (M= 2.75, SD= 5.31 for moderate and M= 9.93, SD= 7.99 for fast speech). In contrast, there was no significant main effect of grammatical complexity $F(1, 19)= 0.01$, $p= 0.918$. Of particular interest is the significant interaction between speed manipulation and grammatical complexity, *F*(1, 19)= 4.81, *p*= 0.042 (Fig. 6-10). Comparisons revealed that participants experienced significantly less perceptual disturbance during subordinate clause sentences with the monotone pitch/moderate speed manipulation than either subordinate or non-subordinate clause sentences with the monotone pitch/fast speed manipulation (*ps*<0.001) (Table 6-8) (Fig. 6-10).

Table 6-8. *Exp 4 pairwise comparisons of speed x grammatical complexity interaction*

Pitch Interval	Mean Difference	*t*	*p*
NSCMM vs. NSCMF	-2.58	-0.96	0.352
NSCMM vs. SCMM	4.38	1.51	0.149
NSCMM vs. SCMF	-7.37	-2.22	0.039
NSCMF vs. SCMM	6.96	4.25	0.000*
NSCMF vs. SCMF	-4.78	-1.73	0.101
SCMM vs. SCMF	-11.75	-4.23	0.001*

*Note: *p<0.008 (Bonferroni correction for multiple tests at p<0.05)*

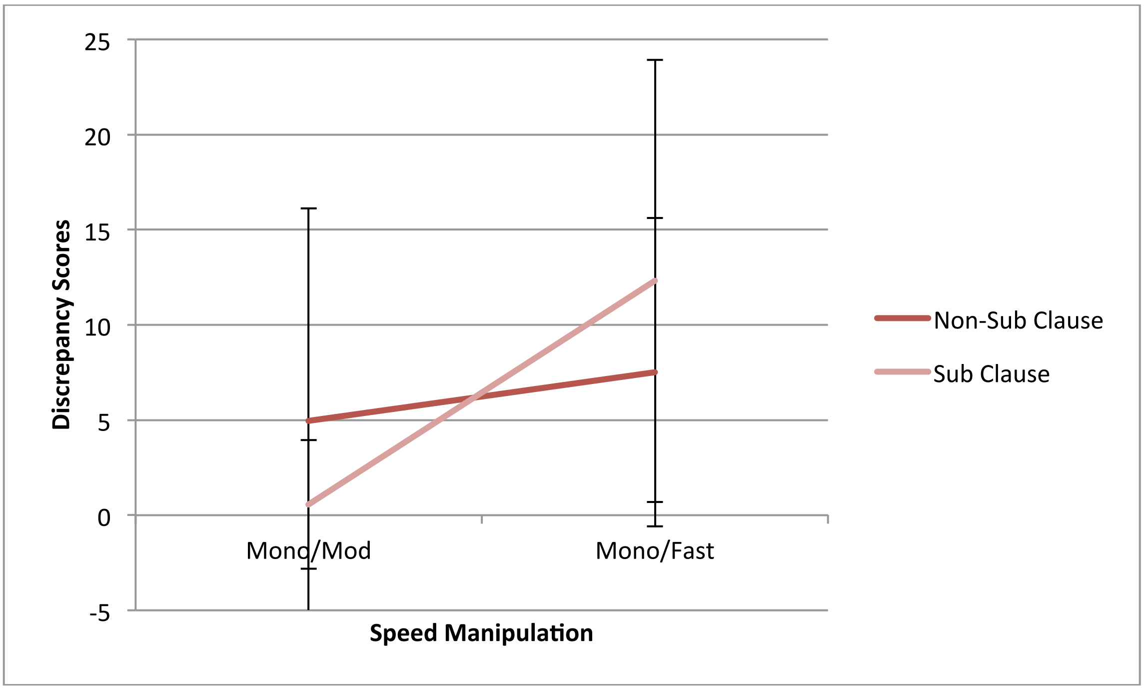

Figure 6-10. *Exp 4 ASD group speed manipulation x grammatical complexity interaction*
Note: Higher scores indicate increased perceptual disturbance

In the TD group there was also a highly significant main effect of speed manipulation, *F*(1, 19)= 17.93, *p*<0.001. Similar to the ASD group, participants' performance indicated a significantly higher level of perceptual disturbance when recalling sentences spoken at a fast rate of speech in comparison to moderate speed (M=

2.07, SD= 4.32 for moderate and M= 9.61, SD= 9.55 for fast speech). In contrast, there was no significant main effect of grammatical complexity $F(1, 19)= 0.64$, $p= 0.434$. However, unlike the ASD group, there was no significant interaction between speed manipulation and grammatical complexity, $F(1, 19)= 1.54$, $p= 0.231$ (Fig. 6-11), which suggests that there was no effect of grammatical complexity on typically developing adults abilities to encode and recall sentences manipulated by speed.

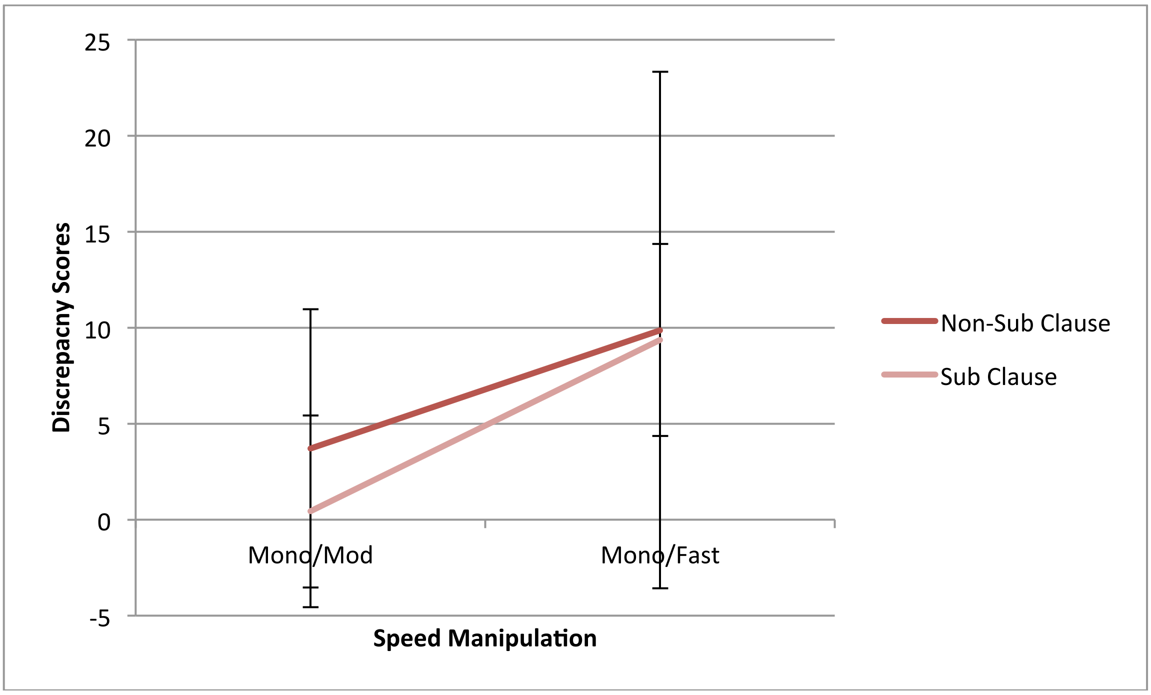

Figure 6-11. *Exp 4 TD group speed manipulation x grammatical complexity interaction*
Note: Higher scores indicate increased perceptual disturbance

Correlation Analysis

Another aim of experiment four was to identify the extent that cognitive, behavioural and clinical correlates are associated with reduced performance in response to perceptual and higher-order changes in the experimental stimuli. Although no overall group differences were found in the initial analysis, results replicated the findings from experiment three showing that fast speech significantly reduced sentence recall accuracy in both ASD and typically developing individuals. Additionally, there was a trend in the ASD group for reduced recall in the exaggerated pitch/fast speed condition, suggesting that prosodic manipulations in conjunction with increased speed caused more perceptual disturbance for individuals with ASD. Importantly, the results of the grammatical complexity analyses indicated that as the stimuli became more perceptually complex (either exaggerated pitch or fast speed) individuals with ASD were experiencing more perceptual disturbance when encoding and recalling more grammatically complex speech. Both types of complexity (perceptual and grammatical) increased hierarchically. Across the four perceptual manipulations monotone pitch/moderate speed was the least perceptually complex and exaggerated pitch/fast speed was the most perceptually complex. The same was true of the grammar manipulations with the non-subordinate clause sentence representing low grammatical complexity and the subordinate clause sentences representing high grammatical complexity. Of particular interest is the extent that variations in performance on the least complex and most complex perceptual and grammar manipulations are associated with cognitive, behavioural and clinical factors. Thus the following correlation analyses will examine the 4 DVs (monotone/moderate, exaggerated/fast, non-subordinate clause and subordinate clause) that represent each end of the complexity spectrum within the perceptual and grammar manipulations.

In order to assess the cognitive correlates of encoding and recall of complex perceptually manipulated speech, a correlation analysis was performed. Participants' accuracy discrepancy scores across the two levels of perceptual manipulations and the two levels of grammatical complexity during the experimental task along with participants' WASI Verbal, WASI Performance, WASI Full Scale, PPVT, WM forward, WM backward, WM total scores and chronological age were used in the correlation.

ASD participants' verbal IQ, performance IQ and full scale IQ were all significantly negatively correlated with their discrepancy scores on the exaggerated pitch/fast speed condition and of the experimental task as well as the more grammatically complex sentences (Table 6-6). This shows that ASD participants with higher IQ scores showed better sentence recall abilities of perceptually manipulated speech in comparison to baseline and experience less disturbance on grammatically complex sentences. Unlike the ASD group, only the monotone pitch/moderate speed condition was correlated with control participants' performance and full scale IQ and furthermore, their performance on the subordinate clause sentences was correlated with their verbal and full-scale IQ (Table 6-9). The positive correlation indicated that TD individuals with higher IQ scores experienced more perceptual disturbance from the monotone/moderate perceptual manipulation and had more difficulty on sentences with a higher level of grammatical complexity.

Table 6-9. *Exp 4 correlations between IQ and sentence recall discrepancy scores across groups*

ASD	*PPVT*[a]	*WASI Verb*[b]	*WASI Perf*[c]	*WASI Full*[d]
Mono/Mod	-0.11	-0.36	-0.04	-0.24
Exag/Fast	-0.30	-0.64**	-0.52*	-0.63**
Non-Sub.	0.19	-0.11	0.09	-0.03
Subordinate	-0.44	-0.62**	-0.48*	-0.59**
TD	*PPVT*[a]	*WASI Verb*[b]	*WASI Perf*[c]	*WASI Full*[d]
Mono/Mod	0.30	0.36	0.66**	0.61**
Exag/Fast	-0.05	0.23	0.11	0.19
Non-Sub.	-0.33	0.01	0.16	0.09
Subordinate	0.21	0.56*	0.28	0.51*

*Note: *p<0.05, **p<0.01 (two-tailed)*
Negative correlations indicate a relationship between higher scores on the background measure and reduced perceptual disturbance.
[a] Peabody Picture Vocabulary Test (PPVT), standard score (Dunn & Dunn, 1997)
[b] Verbal Subscale Weschler Abbreviated Scales of Intelligence (WASI), standard score (Wechsler, 1999)
[c] Performance Subscale Weschler Abbreviated Scales of Intelligence (WASI), standard score (Wechsler, 1999)
[d] Full-Scale Weschler Abbreviated Scales of Intelligence (WASI), standard score (Wechsler, 1999)

Within the ASD group, participants' backward digit span scores were significantly negatively correlated with their sentence recall abilities on conditions with subordinate clauses, r= -0.456, p<0.05. Thus, the better backward digit span ASD participants had the less disturbance they experienced from grammatically complex sentences. In contrast, TD participants' backward digit span scores were significantly positively correlated with their discrepancy scores on the exaggerated pitch/fast speed condition of the experimental task, $r = 0.50$, $p < 0.05$. This indicates that typically developing adults with higher backward digit spans experienced more perceptual disturbance from exaggerated pitch/fast speed perceptual manipulations.

In order to assess the behavioural correlates of encoding and recall of complex perceptually manipulated speech, a correlation analysis was performed. Participants' accuracy discrepancy scores across the two levels of perceptual manipulations and the two levels of grammatical complexity during the experimental task along with participants' Communication Checklist – Language Structure, Communication Checklist – Pragmatic Skills, Communication Checklist – Social Engagement and Communication Checklist – Total standard scores and their Sensory Profile – Low Registration, Sensory Profile – Sensation Seeking, Sensory Profile – Sensory Sensitivity, Sensory Profile – Sensation Avoiding and Sensory Profile – Total scores were used in the correlation.

There was a significant negative correlation between TD participants' performance on the monotone pitch/moderate speed condition and their score on the low registration subscale of the sensory profile, $r = -0.56$, $p < 0.05$. Thus as participants reported higher levels of low registration behaviours, they experienced less perceptual disturbance from the monotone/moderate manipulation. However, there were no other significant correlations between ASD or TD participants' discrepancy scores on any of the other levels of perceptual manipulation during the experimental task and their scores on the other subscales of the Sensory Profile or the Communication Checklist subscales.

In order to assess the clinical correlates of encoding and recall of complex perceptually manipulated speech, a correlation analysis was performed. Participants' accuracy discrepancy scores during across the two levels of perceptual manipulations and the two levels of grammatical complexity during the experimental task along with participants' Autism Spectrum Quotient – Social Skills, Autism Spectrum Quotient – Attention Switching, Autism Spectrum Quotient – Attention to Detail, Autism Spectrum Quotient – Communication, Autism Spectrum Quotient – Imagination and Autism Spectrum Quotient – Total and ASD participants' ADOS – Communication, ADOS – Reciprocal Social Interaction, ADOS – Diagnostic, ADOS – Imagination and Creativity and ADOS – Stereotyped and Repetitive Behaviours scores were used in the correlation.

ASD participants' attention to detail AQ scores were significantly negatively correlated with their discrepancy score on the exaggerated pitch/fast speed condition, $r= -0.74$, $p<0.001$ and subordinate clause sentences, $r= -0.59$, $p<0.05$. Therefore, as the ASD participants exhibited higher levels of autistic traits on the attention to detail subscale they experienced less perceptual disturbance from the exaggerated/fast manipulation and grammatically complex sentences. However, there were no significant correlations between ASD participants' other AQ scores and their performance on the experimental task. There were also no significant correlations between TD participants' AQ scores and their performance on the experimental task. ASD participants' stereotyped and repetitive behaviours ADOS scores were significantly negatively correlated with their discrepancy scores on the monotone pitch/moderate speed condition of the experimental task, $r= -0.55$, $p<0.05$. Therefore, as the ASD participants experienced higher levels of symptom severity on the two ADOS subscales, they experienced less perceptual disturbance from the moderate speed manipulation. However, there were no significant correlations between ASD participants' other ADOS subscale scores and their discrepancy scores on the experimental task.

In order to assess the relationship between age and encoding and recall of complex perceptually manipulated speech, a correlation analysis was performed.

Participants' accuracy discrepancy scores during across the two levels of perceptual manipulations and the two levels of grammatical complexity during the experimental task along with participants' chronological ages were used in the correlations. There was a significant positive correlation between ASD individuals' age and their discrepancy scores on the exaggerated pitch/fast speed condition and of the experimental task, r= 0.484, p<0.05. Thus, older ASD participants experienced more perceptual disturbance when processing sentences that were spoken at a fast rate in an exaggerated pitch contour. There were no significant correlations between chronological age and task performance in the typically developing group.

All significant correlations between participants' scores on all levels of the background measures and their performance on the perceptual and grammatical conditions of the experimental stimuli are summarised below (table 6-10 and 6-11).

Table 6-10. *Exp 4 summary of sig. correlations between perceptual complexity and background measures*

ASD; **TD**	Monotone/Moderate	Exaggerated/Fast
Cognitive Correlates		
WASI		
VIQ	NS	-0.64**
PIQ	0.66**	-0.52*
FSIQ	0.61**	-0.63**
Working Mem.		
Back Digit Span	NS	0.50*
Age	NS	0.48*
Behavioural Correlates		
Sensory Profile		
Low Registation	-0.56*	NS
Clinical Correlates		
AQ		
Attention Detail	NS	-0.74***
Imagination	0.49*	NS
ADOS		
Repetitive Behaviours	-0.55*	NS
Chrological Age	NS	0.48*

Note: Red= significant in ASD group; Blue= significant in TD group; NS= non-significant in both groups; **p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

Negative correlations indicate a relationship between higher scores on the background measure and reduced perceptual disturbance.

Table 6-11. *Exp 4 summary of sig correlations between grammatical complexity and background measures*

ASD; TD	Non-Subordinate Clause	Subordinate Clause
Cognitive Correlates		
WASI		
VIQ	NS	-0.62** 0.56*
PIQ	NS	-0.48*
FSIQ	NS	-0.59** 0.51*
Working Mem.		
Back Dig. Span	NS	-0.46*
Clinical Correlates		
AQ		
Atten. Detail	NS	-0.59*
Imagination	0.51*	NS

Note: Red= significant in ASD group; Blue= significant in TD group; NS= non-significant in both groups; **p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

Negative correlations indicate a relationship between higher scores on the background measure and reduced perceptual disturbance.

Regression Analysis

Whilst the correlation analyses uncovered a number of interesting correlations during the perceptual manipulations, the current experimental design does not allow for the complicated teasing apart of the complex relationships between the cognitive, behavioural and clinical correlates and the combined prosodic and temporal manipulations. As the relationship between the correlates and prosodic and temporal manipulations were examined separately in chapters four and five respectively, the following regression analyses will focus on the relationship between the correlates and encoding and recall of grammatically simple and complex speech.

Non-Subordinate Clause

In order to examine the extent that the significant cognitive, behavioural and clinical correlates in the table above accounted for the variance in encoding and recall of grammatically simple speech in ASD and typically developing participants two multiple linear regressions were performed. The dependent variable was the accuracy discrepancy scores for each group during the non-subordinate clause conditions. The predictor variable was individuals' scores on the imagination subscale of the AQ. Due to the exploratory nature of this analysis a backwards stepwise entry method was employed.

The results revealed that there was a trend towards a significant linear relationship between ASD participants' accuracy discrepancy scores during the non-subordinate clause condition and the predictor variables with a multiple correlation of 0.42, [$F(1,19)= 3.52$, $p= 0.079$; adjusted $R^2= 0.13$]. A closer look at the un-standardised regression coefficients indicates that higher levels of autistic traits in the realm of imagination suggested an increase in an ASD individual's discrepancy scores, indicating increased disturbance when encoding and recalling speech characterised by low levels of grammatical complexity.

Table 6-12. *Exp 4 multiple regression of accuracy discrepancy score of ASD participants during non-subordinate clause condition*

	B	SE *B*	β	*t*	*p*
AQ-Imagination	1.41	0.75	0.42	1.88	0.079

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

The results also revealed a significant linear relationship between typically developing participants' accuracy discrepancy scores during the non-subordinate clause condition and the predictor variables. Table 6-13 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the predictor variables on the accuracy discrepancy scores during the non-subordinate clause condition in the TD group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.51, [$F(1,19)= 6.08$, $p<0.05$; adjusted $R^2= 0.22$]. Thus, roughly 22% of the variability in TD participants' accuracy discrimination scores during the non-subordinate clause condition was predicted by their scores on the imagination subscale of the AQ. A closer look at the un-standardised regression coefficients indicates that higher levels of autistic traits in the realm of imagination predicted an increase in a TD individual's discrepancy scores, indicating increased disturbance when encoding and recalling grammatically simple speech.

Table 6-13. *Exp 4 multiple regression of accuracy discrepancy score of TD participants during non-subordinate clause condition*

	B	SE *B*	β	*t*	*p*
AQ-Imagination	1.63	0.66	0.51	2.47	0.025*

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

Subordinate Clause

In order to examine the extent that the significant cognitive, behavioural and clinical correlates in the table above accounted for the variance in encoding and recall of grammatically complex speech in ASD and typically developing participants two multiple linear regressions were performed. The dependent variable was the accuracy discrepancy scores for each group during the subordinate clause conditions. The predictor variables were individuals' verbal, performance and full-scale IQ scores and scores on the backward digit span working memory measure and the attention to detail subscale of the AQ. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

The results revealed a significant linear relationship between ASD participants' accuracy discrepancy scores during the subordinate clause condition and the predictor variables. Table 6-14 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the predictor variables on the accuracy discrepancy scores during the subordinate clause condition in the ASD group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.61, [$F(1,19)= 9.63$, $p<0.01$; adjusted $R^2= 0.34$]. Thus, roughly 34% of the variability in ASD participants' accuracy discrimination scores during the subordinate clause condition was predicted by their full-scale IQ scores. A closer look at the un-standardised regression coefficients indicated that higher full-scale IQ scores predicted a decrease in an ASD individual's discrepancy scores indicating decreased disturbance when encoding and recalling grammatically complex speech.

Table 6-14. *Exp 4 multiple regression of accuracy discrepancy score of ASD participants during subordinate clause condition*

	B	SE *B*	β	*t*	*p*
WASI-Full Scale	-0.22	0.07	-0.61	-3.10	0.007**

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

The results also revealed a significant linear relationship between typically developing participants' accuracy discrepancy scores during the subordinate clause condition and the predictor variables. Table 6-15 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t*) and significance (*p*) for the predictor variables on the accuracy discrepancy scores during the subordinate clause condition in the TD group. The results revealed a significant model for the predictor variables with a multiple correlation of 0.56, [$F(1,19)= 7.86$, $p<0.01$; adjusted $R^2= 0.28$]. Thus, roughly 28% of the variability in TD participants' accuracy discrimination scores during the subordinate clause condition was predicted by their verbal IQ scores on the WASI. A closer look at the un-standardised regression coefficients indicates that higher verbal IQ scores predicted an increase in a TD individual's discrepancy scores, indicating increased disturbance when encoding and recalling perceptually grammatically complex speech.

Table 6-15. *Exp 4 multiple regression of accuracy discrepancy score of TD participants during subordinate clause condition*

	B	SE *B*	β	*t*	*p*
WASI-Verbal IQ	0.029	0.10	0.56	2.80	0.010**

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

DISCUSSION

Overall, the findings from experiment four suggested that fast speech reduced sentence recall across both groups, confirming the results from experiment 3. However, patterns of performance suggested that prosodic manipulations may further contribute to perceptual disturbance in the ASD group. Furthermore, grammatical complexity analyses revealed that as stimuli became more auditorally complex (either with exaggerated pitch or fast speech) individuals with ASD experienced more perceptual disturbance when recalling sentences that were more grammatically complex. Whilst the preliminary accuracy and reaction time analyses didn't uncover any clear group differences, exploratory correlation and regression analyses suggested there may be different patterns of underlying mechanisms driving performance in the two groups. Similar to the findings from experiment two, increased IQ in individuals with ASD was related to higher levels of accuracy when encoding and recalling speech that was more perceptually or grammatically complex.

One of the primary aims of experiment four was to test Samson et al.'s neural complexity hypothesis in a study that combined changes to the prosodic and temporal parameters of speech at different levels of grammatical complexity. Although no overall group differences emerged within the initial analysis, this is unsurprising given the results from the previous studies showing that intelligence in the ASD group was associated with reduced difficulties in response to perceptual manipulations. Results replicated the finding from experiment three showing that fast speech significantly reduces sentence recall accuracy in both ASD and typically developing individuals. Furthermore, the results revealed a non-significant trend in the ASD group for reduced recall in the exaggerated/fast condition, suggesting that prosodic manipulations, in conjunction with increased speed caused more perceptual disturbance in the ASD group than in the TD group. Considered within the context of the NCH and Johnson et al.'s (2005) suggestion that one neural stream processes complex components of the speech signal, whilst the other processes relatively sustained pitch information, it is not surprising that the combination of fast and extremely prosodic speech would generate more difficulty for individuals with ASD because a much greater level of neuro-integrative processing would have been required. In general the first experimental hypothesis stating that the added level of difficulty created by combining both prosodic and speed manipulations would cause greater interference than that exhibited with either manipulation alone was not confirmed by the present study. However, the trend towards the ASD group experiencing more difficulty than the TD group when the fast speech stimuli became more complex with the addition of an exaggerated pitch contour suggests that perhaps more refined measures may uncover a more subtle processing deficit. It is also likely that group differences would have emerged on the study if a cognitively lower functioning ASD group had been tested.

Another key aim of experiment four was to examine Samson et al.'s (2006) account of auditory processing utilizing stimuli with varying levels of grammatical complexity. As discussed in the introduction to this chapter, there is a clear and important interaction that exists between syntax and prosody and whilst few studies have probed this interaction in ASD, it appears that abnormalities in the integration of comprehension of linguistic prosody and grammatical syntax do exist to some extent in individuals with ASD. The results of the grammatical complexity analyses in the ASD group revealed a strong trend towards a significant interaction between prosody and grammar and a similar significant interaction between speed manipulations and grammar complexity, thus providing support for the second hypothesis. In both analyses individuals with ASD experienced more perceptual disturbance when recalling sentences that were grammatically complex compared with those that were simple when perceptual complexity was manipulated. However, this interaction effect with grammatical complexity was stronger for fast speed than exaggerated pitch. It is not surprising that a stronger interaction effect was found for speed when considered within the context of Alcántara et al.'s (2004) and Groen et al.'s (2008) findings that individuals with ASD are less able to integrate information gained from temporal dips in background noise compared with spectral dips. Taken together, the research suggests that individuals with ASD may have more difficulty processing and utilizing temporal auditory information than spectral. Conversely, no such effect was found with either analysis in the typically developing group. Thus the results support the second experimental hypothesis that in line with Samson et al.’s (2006) complexity hypothesis, the ASD group showed a decrease in sentence recall accuracy in conditions where the stimuli were more grammatically complex, whereas the TD group did not show the same effect.

Another aim of experiment four was to examine how cognitive, behavioural and clinical correlates are associated with performance in response to perceptual and higher-order changes in the experimental stimuli in both typically developing adults and those with ASD. The correlational analyses revealed a pattern of results indicating that higher IQ and attention to detail in the ASD group are related to a reduced perceptual disturbance from the conditions with fast speech and exaggerated pitch contours and better recall of grammatically complex sentences. It is possible that whilst some individuals with ASD experience perceptual disturbance during speech encoding and recall, higher levels of intelligence may allow them to deal with a higher cognitive load and thus not become quite so distracted by the more perceptually complex stimuli. Better working memory abilities were also associated with decreased perceptual disturbance during grammatically complex sentences. Interestingly, higher levels of intelligence seem to be having an inverse relationship with perceptual disturbance in typically developing adults whose IQ scores are related to higher levels of perceptual disturbance when sentences are spoken at a moderate speed in monotone pitch or when recalling grammatically complex sentences. Thus, it appears that different mechanisms, at least in terms of intelligence, are underlying the performance of typically developing and ASD adults. Furthermore, within the ASD group, higher scores on the ADOS in the areas of reciprocal social interaction and stereotyped and repetitive behaviours were associated with decreased perceptual disturbance on the exaggerated pitch/moderate speed and monotone pitch/moderate speed experimental manipulations respectively. This suggests that higher levels of autistic symptomatology may be associated with decreased levels of perceptual capture and disturbance even when processing more complex auditory stimuli. It was hypothesised that within the ASD group, individuals who experienced higher levels of sensory abnormalities and communication deficits would demonstrate increased interference from perceptual manipulations to speech stimuli. The present study did not find any relationship between self-reported communication difficulties and perceptual disturbance or grammatical complexity in either of the two groups. Within the ASD group there was a relationship between higher levels of sensory abnormalities on the low registration quadrant of the sensory profile and increased perceptual disturbance on sentences that were spoken in monotone pitch at a very fast speed. However, no other correlations were found between self-reported sensory processing abnormalities and performance on the experimental manipulations for either group. Thus the present study did not support the final hypothesis as it appears as though other mechanisms besides sensory abnormalities and communication deficits are related to speech encoding and memory under the conditions tested in experiment four. The findings from experiment four will be discussed in the context of the results from other experiments in this thesis in the final chapter. The aim of this will be to further characterise any atypicalities in speech processing and associated phenotypes observed within this particular group of adults with ASD.

CHAPTER 7: EXAMINING PERCEPTUAL AND SEMANTIC PROCESSING BIASES IN AUDITORY STROOP PARADIGMS

SUMMARY

A large body of evidence indicates that typically developing individuals show a semantic bias when processing speech information. In contrast, some studies of individuals with Autism Spectrum Disorder (ASD) suggest this bias is weakened and that perceptual information may have increased salience. One class of perceptual information widely examined in ASD individuals is pitch and numerous studies have demonstrated enhanced pitch discrimination for pure and complex tone stimuli. In contrast, perception of timbre, another important component in speech appears to be similar to that of typically developing individuals. The present studies investigated perceptual and semantic processing biases utilizing newly developed auditory Stroop tasks in which participants were cued to the semantic or perceptual components (pitch/timbre) of stimuli presented in blocks of congruent and incongruent trials. Drawing on previous research showing that ASD represents a continuum of traits that are also evident in the non-clinical population, the present study also investigated the extent that levels of autistic traits impacted participants' interference effects. In a final exploratory study

high-functioning adults with ASD also completed the experimental task and their data were assessed in the context of results from standardised measures of social and communication skills, sensory abnormalities and intelligence described in chapter two. The extent that the experimental findings provide evidence of a weakened semantic processing bias in ASD, or increased attention to perceptual information was the primary focus of this study.

INTRODUCTION

Two of the most salient perceptual aspects of speech, are pitch and timbre. The function of pitch contours in speech is very well understood and has been shown to enrich the informational content of the spoken word. For example research has shown that statements are characterised by a terminal fall in pitch whereas questions are characterised by a terminal rise in pitch (Hadding & Studdert-Kennedy, 1974; Leitman, Sehatpour, Shpaner, Foxe & Javitt, 2009). Additionally, pitch can contribute to one's understanding of how another feels; happiness is characterised by a wide low to high range of pitch whereas sadness has a much narrower range (Patel, 2007). Whilst pitch may be considered one of the more significant aspects of auditory information, timbre is also extremely important. Timbre is often referred to as the quality of sound that allows individuals to differentiate between different voices, when they do not differ on pitch and/or loudness (Plack, 2005). However, whilst we know that timbre is an important component of all speech signals it has proved notoriously difficult to define. McAdams and Bregman (1979) suggested that timbre could be considered to be "the psychoacoustician's multidimensional wastebasket category for everything that cannot be qualified as pitch or loudness." The general consensus is that timbre is a psychoacoustically complex phenomenon that is far more difficult to define than other auditory components. Importantly however, researchers have suggested that timbre might provide a more general representation of sound that is independent of other perceptual features such as pitch and loudness that may prove invaluable in future speech perception and recognition research (Terasawa, Slaney, Berger & Jose, 2005).

As discussed previously, perceptual aspects of speech, such as pitch and timbre, play an important role in linguistics. However, from an early age children are taught the importance of processing speech for meaning (Manzo & Manzo, 1995). Indeed there may be an innate tendency to focus on meaning that predisposes an ability to screen out perceptual information (e.g. pitch and timbre) that is not directly linked to communicative intention. Thus it is not surprising that a wealth of research demonstrates a semantic processing bias, defined as a tendency to preferentially attend to the informational content of speech, in typically developing individuals. Indeed, previous research has shown that when both intonation and semantic content are present in auditory stimuli, typically developing participants consistently respond to semantic content alone (Schreibman et al., 1986). Furthermore, semantic biases have been shown to hinder performance of perceptual processing in typically developing individuals. In a study by Järvinen-Pasley, Wallace, Ramus, Happé and Heaton (2008), typically developing children showed significantly better identification of temporal patterning when there was no competing semantic information compared with when there was. This was further supported in a study by Järvinen-Pasley & Heaton (2007) in which typically developing children and children with autism showed similarly good levels of perceptual discrimination when asked to make same/different judgments about the pitch contours of two pieces of music. However, unlike children with autism, discrimination scores for the typically developing children were significantly poorer when they were required to make similar judgments about the pitch contours of short sentences.

Further results from Järvinen-Pasley, Pasley and Heaton (2008) identified a weakened semantic interference effect in children with ASD when presented with stimuli that included conflicting perceptual information. These results suggested that semantic information processing inhibits perceptual information processing to a lesser degree in ASD than in typical development. Researchers have suggested that the weakened semantic processing bias may have a negative impact on more functional areas of speech perception. One study that looked at both enhanced perceptual and reduced semantic processing in adolescents revealed superior performance when matching pitch contours to their visual analogues in ASD participants compared with controls. However, when those same individuals were required to determine whether a sentence was a question or statement using the available pitch cues, they were outperformed by their typically developing peers (Järvinen-Pasley, Pasley, et al., 2008). Furthermore, superior speech pitch discrimination has also been described in one adult with autism (Heaton, Davis, et al., 2008), although it is possible that this is simply the result of absolute pitch ability in that individual. The results presented in chapter three failed to identify superior pitch discrimination or a pitch processing bias in adults with ASD although this appeared to be driven by developmental increases in speech pitch perception in non-autistic individuals. Moreover, correlations and regression analyses carried out on the data from the studies presented in the previous chapters suggest that aspects of ASD symptomatology were associated with atypical auditory processing in the ASD group. It may be that a reduced semantic bias in children with ASD becomes gradually remediated when they have a higher IQ.

As discussed in chapter one of this thesis, research has increasingly embraced the idea that as a spectrum disorder, ASD lies on a continuum that extends into the typically developing population. Thus, autistic traits are exhibited by typically developing individuals, albeit at lesser levels. Given this assertion, it is possible that some of the behaviours observed in experimental studies of individuals with ASD may also be evident to a lesser extent in typically developing individuals who possess higher levels of autistic traits. Previous research discussed in chapter one identified relationships between higher levels of autistic traits in typically developing populations and factors often associated with ASD, including reduced left hemisphere dominance (Lindell & Withers, 2008). Gomot et al. (2008) conducted a more in-depth analysis in which the association between specific areas of autistic traits and auditory novelty detection was examined. Their results indicated that greater impairments in communication, socialisation and adaptation to the environment were associated with stronger brain activation during novelty detection. Additionally, similar correlations were found within the ASD and control groups, further supporting the continuum conceptualisation of ASD.

The current experiments expand on the previous studies in this thesis by examining the effects of perceptual manipulations on speech processing. Whilst the early studies have shown significant differences across the experimental conditions, they have largely failed to discriminate ASD and TD at the group level. Although the results presented in chapter three provide tentative evidence for a different pitch processing trajectory in ASD and TD controls, it is clear that group difference in adulthood are less marked and it may be the case that reduced attention to the perceptual components of speech correlates with an increased semantic bias, particularly in high-functioning individuals. In the studies presented in this chapter, auditory Stroop paradigms are used to tap into lower-level auditory processing. The classic Stroop task was used to assess interference between competing word stimuli and colour stimuli. A Stroop effect is determined to be present when mean reaction times are significantly longer when naming the colour of a word that is incongruent with the colour ink it was written in (e.g. word blue written in green ink) compared with when it was congruent (Stroop, 1935). Auditory Stroop tasks have been implemented previously and have uncovered strong Stroop effects for identifying pitch (Cohen & Martin, 1975; Hamers & Lambert, 1972) and gender (Green & Barber, 1981). In the pitch Stroop tasks the words 'high' and 'low' were spoken in either a high or a low pitch, whereas in the gender tasks the words 'man' and 'girl' were spoken by either a male or female speaker.

In order to examine whether individuals can inhibit their semantic processing, pitch and timbre Stroop tasks were utilised in studies of typical participants and participants with ASD. Participants were required to identify the perceptual component of the stimuli amid either complementary or competing semantic information. In addition, in order to assess whether individuals can inhibit their perceptual processing, pitch and timbre reverse Stroop tasks required participants to identify the semantic component of the stimuli amid either complementary or competing perceptual information. Experiment 5a examined the effects of pitch using Stroop tasks that consisted of the words 'high' and 'low' spoken in high and low pitches, mimicking previous auditory Stroop tasks that have assessed pitch. According to Pernet and Belin (2012) gender perception in speech has been shown to rely on timbre perception. Thus, in order to assess the possible effect of timbre in experiment 5b, Stroop tasks consisted of the words 'him' and 'her' spoken by male and female speakers, similar to the stimuli in previous auditory Stroop research assessing gender identification.

EXPERIMENT 5A: TESTING SEMANTIC AND PERCPETUAL PROCESSING BIASES IN TYPICAL POPULATIONS USING AN AUDITORY PITCH STROOP PARADIGM

Aims

The present study aims to examine the extent that typically developing adults can suppress their semantic or perceptual processing amid competing information during auditory processing. Previous findings by Järvinen-Pasley, Pasley, et al. (2008) revealed a semantic processing bias in typically developing children and adolescents and this impaired their ability to process perceptual auditory information. Thus, auditory pitch Stroop tasks will be used to examine perceptual and semantic processing using a more fine-grained approach. In order to replicate Järvinen-Pasley, Pasley, et al.'s (2008) finding of a semantic processing bias participants will be asked to identify perceptual (pitch) components of the stimuli amid congruent or competing semantic information. Furthermore, to examine whether participants also demonstrate a perceptual processing bias they will be asked to identify semantic components of the stimuli amid complementary or competing perceptual (pitch) information.

Drawing on previous assertions that Autism Spectrum Disorders (ASD) represent a continuum of traits that are also evident in the typically developing population, a main aim of experiment 5a is to investigate the extent that levels of autistic traits impact on the level of interference participants experience when processing competing semantic and perceptual auditory information. The Autism Spectrum Quotient will be used to assess the levels of autistic traits experienced by the typically developing participants and regression analyses will be employed during an exploratory analysis of the potential relationship between atypical auditory processing and autistic traits.

Hypotheses

1. Typically developing individuals will demonstrate a semantic processing bias, identifying perceptual components more slowly than semantic components amid competing auditory information.
2. Typically developing individuals with higher levels of autistic traits, as measured by the AQ, will experience less of an interference effect from competing semantic information.

METHODS

Participants and Background Measures

40 typically developing adults were recruited from the Goldsmith College, University of London 1st year undergraduate psychology experiment credit scheme. 31 of the participants were female and 9 were male. Their chronological ages ranged between 18 years 2 months and 43 years 4 months. All of the participants completed the AQ and their scores ranged from 4 to 30. As this is below the cut-off score of 32 proposed by Baron-Cohen et al. (2001) (Table 7-1) the possibility that individuals with ASD were included in the cohort could be ruled out. Participants were required to be first language British English speakers and have no known hearing difficulties.

Table 7-1. *Exp 5a participant background data*

	Mean	Standard Deviation	Range
Age (months)	275.50	74.99	218-521
AQ-Total[a]	15.10	5.52	4-30
AQ-Social Skills	1.40	1.58	0-7
AQ-Attention Switching	4.57	2.11	0-10
AQ-Attention to Detail	5.12	2.43	0-6
AQ-Communication	1.60	1.41	0-5
AQ-Imagination	14.72	5.03	4-24

[a]Adult Autism Spectrum Quotient (AQ) Total (Baron-Cohen et al., 2001)

Experimental Methods

Experimental Stimuli

Experiment 5a aimed to examine the extent that typically developing adults suppress their semantic and/or perceptual processing when auditory stimuli are comprised of competing information. The perceptual component in experiment 5a introduced competing information in the form of a pitch manipulation that was either congruent or incongruent with the semantic content of the spoken word.

The perceptual component was designed to assess the effect of pitch manipulations on semantic and perceptual processing of speech. The stimuli consisted of the words ‘high’ and ‘low’ recorded in both high and low pitches by an adult British English speaking female. The original word stimuli were processed and analysed using PRAAT software (Boersma, 2001) to equalise volume and remove any inconsistencies that were artefacts from the recording process. The fundamental frequencies for the resulting single word stimuli are reported in table 7-2. In each of two conditions, thirty of each of the two types of stimuli were presented to each participant in a computer generated random order using C++. This resulted in a total 120 trials, 60 that were congruent (e.g. word ‘high’ spoken in a high pitch & the word ‘low’ spoken at a low pitch) and 60 that were incongruent (e.g. word ‘low’ spoken in a high pitch and the word ‘high’ spoken at a low pitch). In one condition (containing 120 trials) participants were instructed to respond to the semantic content (i.e. what was the word?) of the stimuli and in the other condition participants were required to respond to the perceptual content (i.e. what was the pitch?).

Table 7-2. *Exp 5a fundamental frequency of experimental stimuli*

Semantic	'High'		'Low'	
Perceptual	High	Low	High	Low
F_0 (Hz)	257.31	167.02	260.15	171.81

Note: F_0= Fundamental Frequency (pitch)

Experiment 5a therefore consisted of two conditions each of which included 120 trials. In the first condition, participants were instructed to respond to the semantic content (i.e. what was the word?) of the stimuli and in the other task participants were required to respond to the perceptual content (i.e. what was the pitch?). In order to indicate which word they had heard, participants needed to suppress their perceptual processing, whereas in order to indicate what perceptual component they had heard they needed to suppress their semantic processing. In order to ensure accuracy of response, a block of 40 practice trials preceded the experimental trials. The 120 trials in the experimental phase were divided into three blocks of 40 trials each, in order to avoid fatigue. Within each condition participants were responding to combinations of either congruent perceptual and semantic information or incongruent perceptual and semantic information. Trials within each condition were randomised using C++ software.

Procedure

All of the participants completed the initial 40 practice trials in which they were either instructed to respond to the semantic content (i.e. what was the word?) of the stimuli and in the other condition participants were required to respond to the perceptual content (i.e. what was the pitch?). In the semantic cuing condition participants were told that in each trial they would hear one of two words, ‘high’ or ‘low’ and they were instructed to indicate which word they had heard by either pressing the letter ‘Q’ for ‘high’ or ‘P’ for ‘low’ on the keyboard. Each of the keys was covered with a standardised sticker with the words ‘high’ and ‘low’ on them. For the perceptual cuing condition participants were told that in each trial they would hear a word spoken in either a high or a low pitch and they were instructed to indicate what the pitch was by either pressing the letter ‘Q’ for high pitch or ‘P’ for low pitch on the keyboard. Each of the keys was covered with a standardised sticker with the symbol ↑ for high pitch or ↓ for low pitch on them. Participants were always instructed to respond as quickly and accurately as possible.

Following the relevant instructions, participants were administered 40 practice trials, with feedback after each trial indicating whether or not they had answered correctly. Following the practice trials, 120 experimental trials were administered in the same format, but without feedback. In order to avoid practise effects and fatigue the order of presentation of the conditions was counterbalanced across sessions. Participation took place across two sessions on separate days and participants were always administered either a semantic cuing or a perceptual cuing condition in each session. The experimenter sat with the participant offering encouragement regardless of their performance on the task. A Toshiba laptop was used to run the experiment and the stimuli were delivered via a set of Sennheiser HD202 headphones. Throughout the course of the experiment the screen was black with a white fixation cross appearing in the middle of the screen in between trials. Accuracy scores and reaction times for each trial were recorded by C++ for later analysis.

Analysis

A factorial analysis of variance (ANOVA) was used to analyse the data from experiment 5a with within-subjects factors of condition (2 levels; semantic and perceptual cuing) and congruency (2 levels; congruent and incongruent). The dependent variable was the mean reaction time for each participant across the 60 trials at each congruency in each of the two conditions. In order to examine the relationship between AQ scores and performance on the pitch Stroop task, a regression analysis will also be performed.

RESULTS

Data Cleaning

Experiment 5a was designed to generate predominately correct responses due to the training and feedback participants received during the practice trials for each condition. Thus, all incorrect responses were removed from the analysis. In order to remove the noise often reported in reaction time tasks, a bi-participant trim was conducted for each of the two conditions. Z-scores were generated for the individual responses for each participant. All responses that were three standard deviations above or below an individual's mean reaction time for each condition were removed as anomalies in the data (e.g. fatigue or a repeated response due to an unrecorded initial response). The resulting case summaries from the data cleaning are described in table 7-3.

Table 7-3. *Exp 5a data cleaning case summary*

	Semantic Condition	Perceptual Condition
Before Data Cleaning	4800	4800
After Incorrect Responses Removed	4783	4654
After 3 SD Bi-Participant Trim	4687	4534

Reaction Time Analysis

In order to assess the hypothesis that participants would show a semantic but not perceptual processing bias, a factorial analysis of variance (ANOVA) was performed. Means and standard deviations for the reaction times for each of the conditions are shown in table 7-4.

Table 7-4. *Exp 5a means and standard deviations for reaction time data*

	Semantic Condition		Perceptual Condition	
	Congruent	Incongruent	Congruent	Incongruent
Mean	247.55	247.58	299.18	340.49
SD	100.72	98.35	122.69	140.27

The results revealed a highly significant main effect of condition on participants' reaction times, $F(1, 40)= 25.23$, $p<0.001$ (Fig. 7-1), with participants responding slower when asked to identify the perceptual (pitch) component in comparison to the semantic component of the stimuli (M= 319.84, SD= 128.76 for perceptual and M= 247.57, SD= 95.96 for semantic). Thus, participants were more able to suppress their perceptual processing to focus on the semantic component of the stimuli than suppress their semantic processing to focus on the perceptual aspects of speech.

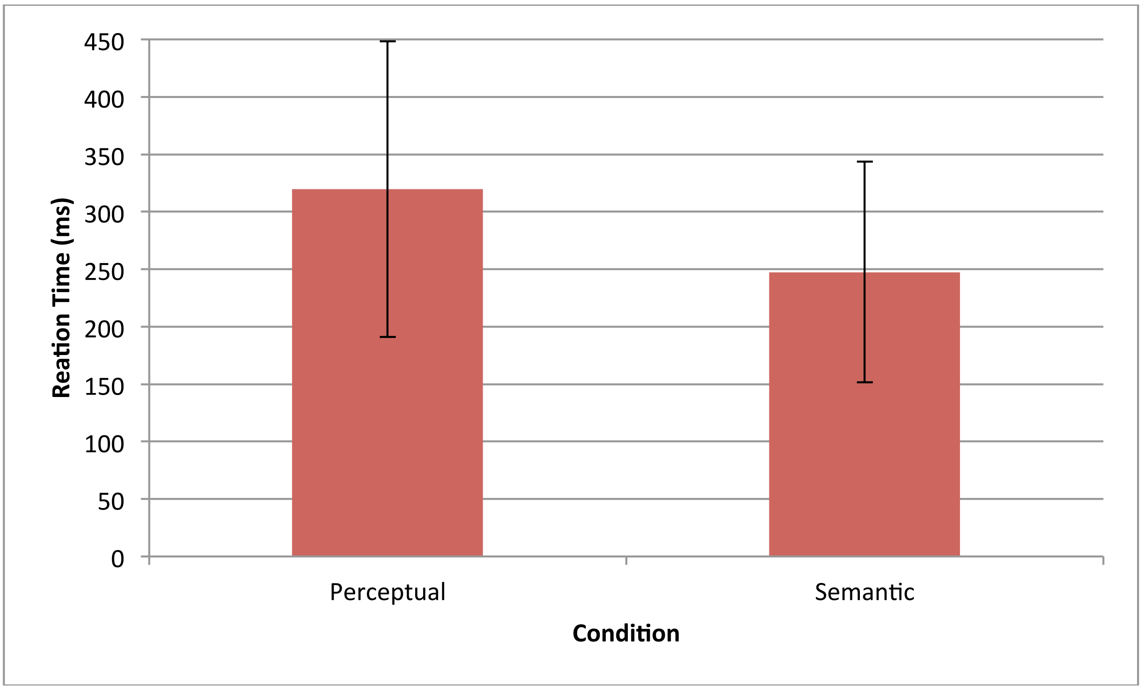

Figure 7-1. *Exp 5a main effect of condition*

There was also a highly significant main effect of congruency on participants' reaction times, $F(1, 40)= 9.75$, $p<0.01$ (Fig. 7-2), with participants responding more slowly during incongruent than congruent trials (M= 294.04, SD= 108.53 for incongruent and M= 273.37, SD= 103.35 for congruent). As hypothesised, participants were slower at identifying either the perceptual or semantic component of the stimuli when there was competing information.

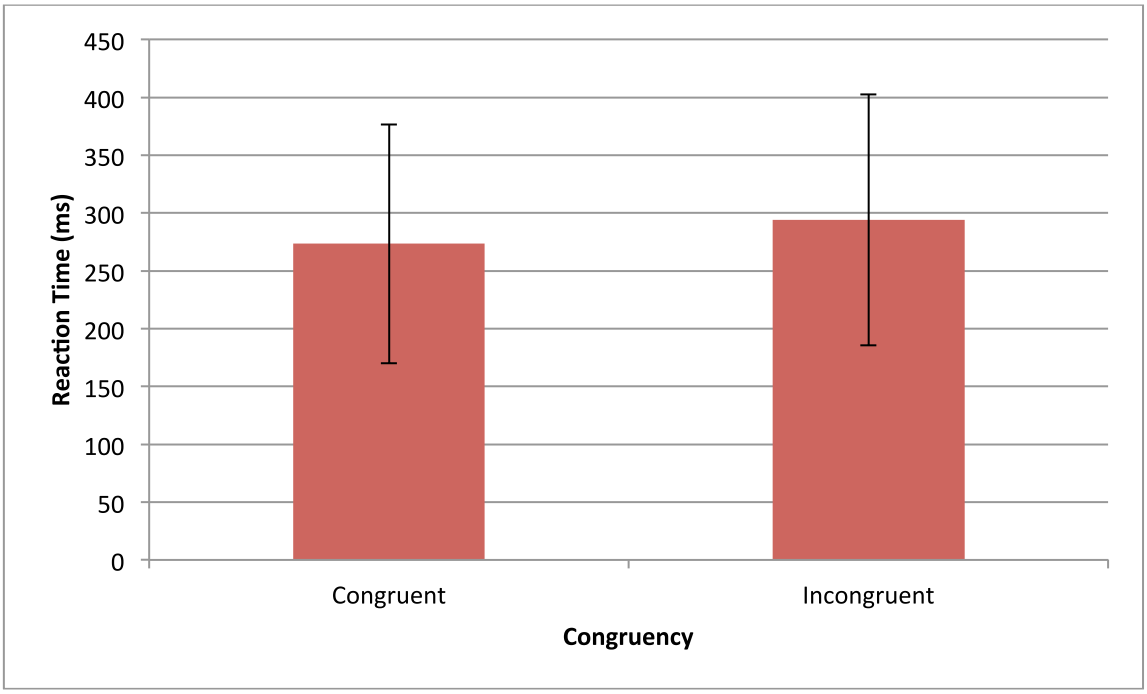

Figure 7-2. *Exp 5a main effect of congruency*

Finally, there was a highly significant interaction between condition and congruency, $F(1, 40) = 13.99$, $p<0.001$ (Fig. 7-3). This interaction suggests that participants were experiencing different levels of interference when asked to isolate semantic content amid competing perceptual information compared with when asked to isolate perceptual content amid competing semantic information. Post hoc pairwise comparisons (N.B. with a Bonferroni corrected p threshold of 0.025) revealed that participants responses were not significantly slowed by incongruent trials when asked to identify the semantic content of the stimulus, $t(39) = 0.01$, $p = 0.990$, but were experiencing a Stroop effect when asked to identify the perceptual content of the stimulus, $t(39) = 4.66$, $p<0.001$. Thus, participants were easily able to suppress their perceptual processing of pitch in order to identify semantic information. However, they experienced significantly increased difficulty when required to suppress their semantic processing in order to identify pitch information. These results confirm a strong semantic processing bias within typically developing individuals.

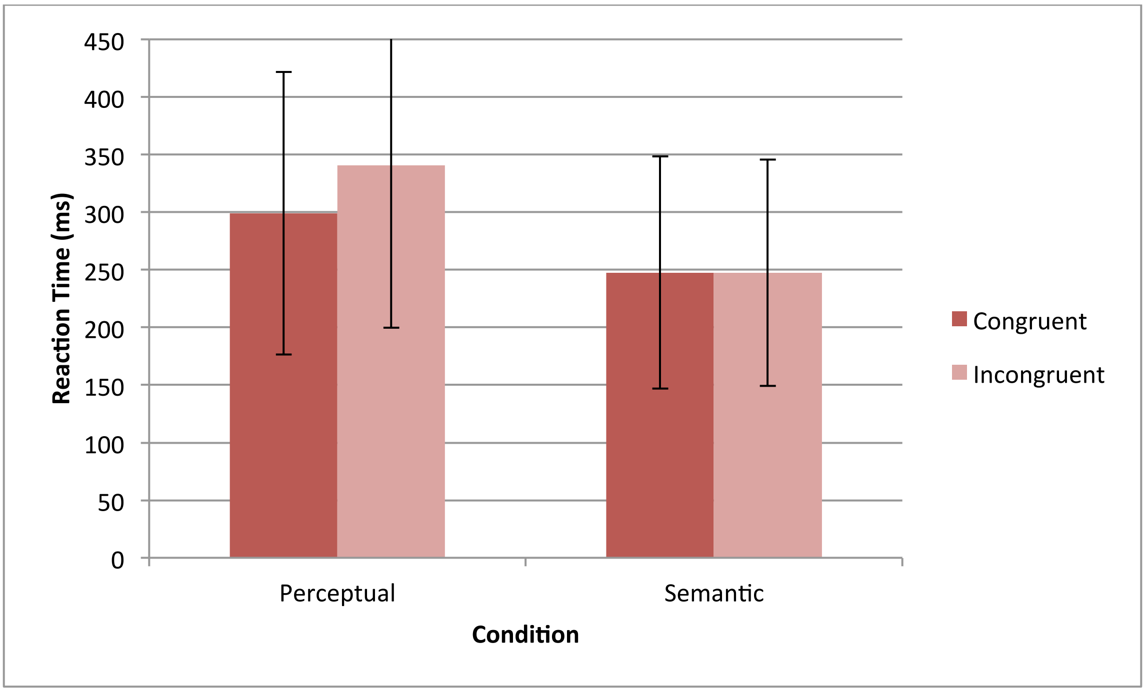

Figure 7-3. *Exp 5a condition x congruency interaction*

Regression Analysis

In order to address the third hypothesis and examine the relationship between autistic traits in a typically developing population and performance on the perceptual and semantic conditions of the pitch Stroop tasks two multiple linear regressions were performed. The dependent variables were the levels of interference that were calculated by subtracting an individual's mean reaction time on the congruent trials from their mean reaction time on the incongruent trials. Thus higher scores indicated a greater level of interference from incongruent information when identifying the perceptual (pitch) component of the stimulus during the perceptual condition or the semantic (word) component of the stimulus during the semantic condition. The predictor variables were individuals' scores on the five subscales of the AQ as well as their total AQ scores. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

Table 7-5 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the AQ predictor variables on the interference effect during the perceptual condition. The results revealed a significant model for the predictor variables with a multiple correlation of 0.53, [F(3,40)= 4.59, p<0.01; adjusted R^2= 0.22]. Thus, roughly 22% of the variability in a participant's interference effect during the perceptual condition was predicted by their level of autistic traits. However, table 7-5 also shows that only the attention to detail, communication and imagination subscales of the AQ were included in the model and of those predictor variables, only imagination and communication were significant predictors of interference effect during the perceptual condition. A closer look at the un-standardised regression coefficients indicates that higher imagination scores on the AQ predicted an increase of 21.21ms in an individual's interference effect whereas higher communication scores on the AQ predicted a decrease of 10.68ms in an individual's interference effect.

Table 7-5. *Exp 5a multiple regression of AQ and interference effects during perceptual condition*

	B	SE *B*	β	*t*	*p*
Attention to Detail	-6.16	3.31	-0.27	-1.86	0.071
Communication	-10.68	5.30	-0.32	-2.01	0.050*
Imagination	21.21	6.31	0.53	3.36	0.002*

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

Table 7-6 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the AQ predictor variables on the interference effect during the semantic condition. The results revealed a trend towards a significant model for the predictor variables with a multiple correlation of 0.38, [F(2,40)= 3.07, p= 0.058; adjusted R^2= 0.10]. Thus, roughly 10% of the variability in a participant's interference effect during the semantic condition was predicted by their level of autistic traits. However, table 7-6 also shows that only the attention switching and imagination subscales of the AQ were included in the model, both of which just failed to meet significance. A closer look at the un-standardised regression coefficients indicates that higher imagination scores on the AQ predicted a decrease of 11.58ms in an individual's interference effect whereas higher attention switching scores on the AQ predicted an increase of 7.29ms in an individual's interference effect.

Table 7-6. *Exp 5a multiple regression of AQ and interference effect during semantic condition*

	B	SE *B*	β	*t*	*p*
Attention Switching	7.29	3.90	0.29	1.87	0.070
Imagination	-11.58	5.84	-0.31	-1.98	0.055

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

SUMMARY OF EXPERIMENT 5A

The results from experiment 5a revealed a strong semantic processing bias in typically developing individuals. Participants were easily able to suppress their perceptual processing of pitch in order to identify semantic information but they experienced significantly more difficulty when they were required to suppress their semantic processing in order to identify pitch information. Furthermore, regression analyses suggested that different aspects of autistic traits were implicated in the amount of interference typically developing individuals experienced from semantic and perceptual information during auditory processing. Higher levels of autistic traits in the realm of attention to detail and communication predicted a decrease in interference from semantic information, whereas higher levels in the realm of imagination predicted an increase in interference from semantic information when participants were asked to identify the pitch component. However, when participants were asked to identify the semantic component higher levels of autistic traits in the realm of attention switching predicted an increase in interference from perceptual information, whereas higher levels in the realm of imagination predicted a decrease in interference from perceptual information.

EXPERIMENT 5B: TESTING SEMANTIC AND PERCEPTUAL PROCESSING BIASES IN TYPICAL POPULATIONS USING AN AUDITORY TIMBRE STROOP PARADIGM

Aims

Although research has established the strong effect pitch has on auditory processing, the role that timbre plays is less clear. Therefore, following on experiment 5a, experiment 5b will require participants to identify perceptual components of the stimuli (timbre) amid congruent or competing semantic information. Furthermore, to examine whether participants also demonstrate a perceptual processing bias they will be asked to identify semantic components of the stimuli amid complementary or competing perceptual (timbre) information. The Autism Spectrum Quotient will again be used to assess the levels of autistic traits experienced by the typically developing participants and regression analyses will be employed during an exploratory analysis of the potential relationship between atypical auditory processing and autistic traits.

Hypotheses

1. Typically developing individuals will demonstrate a semantic processing bias, identifying perceptual components more slowly than semantic components amid competing auditory information.

2. Typically developing individuals with higher levels of autistic traits, as measured by the AQ, will experience less of an interference effect from competing semantic information.

METHODS

Participants and Background Measures

All 40 of the participants described in experiment 5a participated in the present study.

Experimental Methods

Experimental Stimuli

Experiment 5b aimed to examine the extent that typically developing adults can suppress their semantic or perceptual processing amid competing information during auditory processing. The perceptual component in experiment 5b introduced competing information in the form of timbre manipulations that were either congruent or incongruent with the semantic meaning of the spoken word.

The perceptual component was designed to assess the effect of timbre manipulations on semantic and perceptual processing of speech. The stimuli consisted of the words 'him' and 'her' recorded by both an adult British English speaking female and an adult male. The resulting stimuli were then processed and analysed as described above and the fundamental frequencies for the resulting single word stimuli are reported in table 7-7. The average fundamental frequency of female speakers is 207Hz and 119Hz for males (Traunmüller & Eriksson, 1995) thus the stimuli is representative of the pitch range found in a typical population. In each of two conditions, thirty of each of the two types of stimuli were presented to each participant in a computer generated random order using C++, resulting in a total 120 trials, 60 that were congruent (e.g. word ‘him’ spoken by a male) and 60 that were incongruent (e.g. word ‘her’ spoken by a male). In one condition containing 120 trials participants were instructed to respond to the semantic content (i.e. what was the word?) of the stimuli and in the other condition participants were required to respond to the perceptual content (i.e. what was the gender of the speaker?).

Table 7-7. *Exp 5b fundamental frequency of experimental stimuli*

Semantic	‘Him’		‘Her’	
Perceptual	Male	Female	Male	Female
F_0 (Hz)	114.71	238.68	114.71	238.68

Note: F_0= Fundamental Frequency (pitch)

As in the previous experiment, each of the conditions included 120 trials and participants were instructed to respond to the semantic content (i.e. what was the word?) of the stimuli in one condition and to the perceptual content (i.e. what was the gender?) in the other. In order to indicate which word they had heard participants needed to suppress their perceptual processing and to assess the perceptual component they needed to suppress their semantic processing. For each of the two conditions a block of 40 practice trials preceded the experimental trials to ensure accuracy of response. In order to avoid fatigue effects the experimental phase consisted of 120 trials, divided into three blocks of 40 trials each. Within each condition participants were responding to combinations of either congruent perceptual and semantic information or incongruent perceptual and semantic information. Trials within each condition were randomised using C++ software.

Procedure

For each of the two conditions participants were administered 40 practice trials in which they were either instructed to respond to the semantic content (i.e. what was the word?) of the stimuli and in the other condition participants were required to respond to the perceptual content (i.e. what was the gender?). In the semantic condition participants were told that in each trial they would hear one of two words, ‘him’ or ‘her’ and they were instructed to indicate which word they had heard by either pressing the letter ‘Q’ for ‘him’ or ‘P’ for ‘her’ on the keyboard. Each of the keys was covered with a standardised sticker with the words ‘him’ and ‘her’ on them. For the perceptual condition participants were told that in each trial they would hear a word spoken in either an adult male or a female voice and they were instructed to indicate what the gender of the speaker was be either pressing the letter ‘Q’ for male or ‘P’ for female on the keyboard. Each of the keys was covered with a standardised sticker with the symbol ♂ for male or ♀ for female on them. Participants were always instructed to respond as quickly and accurately as possible. Following the relevant instructions, the same procedure employed in experiment 5a was carried out.

Analysis

A factorial analysis of variance (ANOVA) was used to analyse the data from experiment 5b with within-subjects factors of condition (2 levels; semantic and perceptual) and congruency (2 levels; congruent and incongruent). The dependent variable was the mean reaction time for each participant across the 60 trials at each congruency in each of the two conditions. In order to examine the relationship between AQ scores and performance on the timbre Stroop task, a regression analysis was performed.

RESULTS

Data Cleaning

Experiment 5b was designed to generate predominately correct responses due to the training and feedback participants received during the practice trials for each condition. Thus, all incorrect responses were removed from the analysis. In order to remove the noise often reported in reaction time tasks, a bi-participant trim was conducted for each condition. Z-scores were generated for the individual responses for each participant. All responses that were three standard deviations above or below an individual's mean reaction time for each condition were removed as anomalies in the data (e.g. fatigue or a repeated response due to an unrecorded initial response). The resulting case summaries from the data cleaning are described in table 7-8.

Table 7-8. *Exp 5b data cleaning case summary*

	Semantic Condition	Perceptual Condition
Before Data Cleaning	4800	4800
After Incorrect Responses Removed	4774	4713
After 3 SD Bi-Participant Trim	4676	4625

Reaction Time Analysis

In order to assess the hypothesis that participants would show a semantic but not perceptual processing bias, a factorial analysis of variance (ANOVA) was performed. Means and standard deviations for the reaction times for each of the conditions are shown in table 7-9.

Table 7-9. *Exp 5b means and standard deviations for reaction time data*

	Semantic Condition		Perceptual Condition	
	Congruent	Incongruent	Congruent	Incongruent
Mean	253.95	242.45	275.91	274.69
SD	83.46	109.90	110.59	146.85

There was a non-significant trend of the main effect of condition, $F(1, 40)= 3.02$, $p= 0.090$ (Fig. 7-4), with participants responding slower when asked to identify the perceptual (timbre) component in comparison to the semantic component of the stimuli (M= 275.31, SD= 125.80 for perceptual and M= 248.20, SD= 93.01 for semantic). Thus, participants were more able to suppress their perceptual processing to focus on the semantic component of the stimuli than suppress their semantic processing to focus on the perceptual aspects of speech, although this did not reach statistical significance.

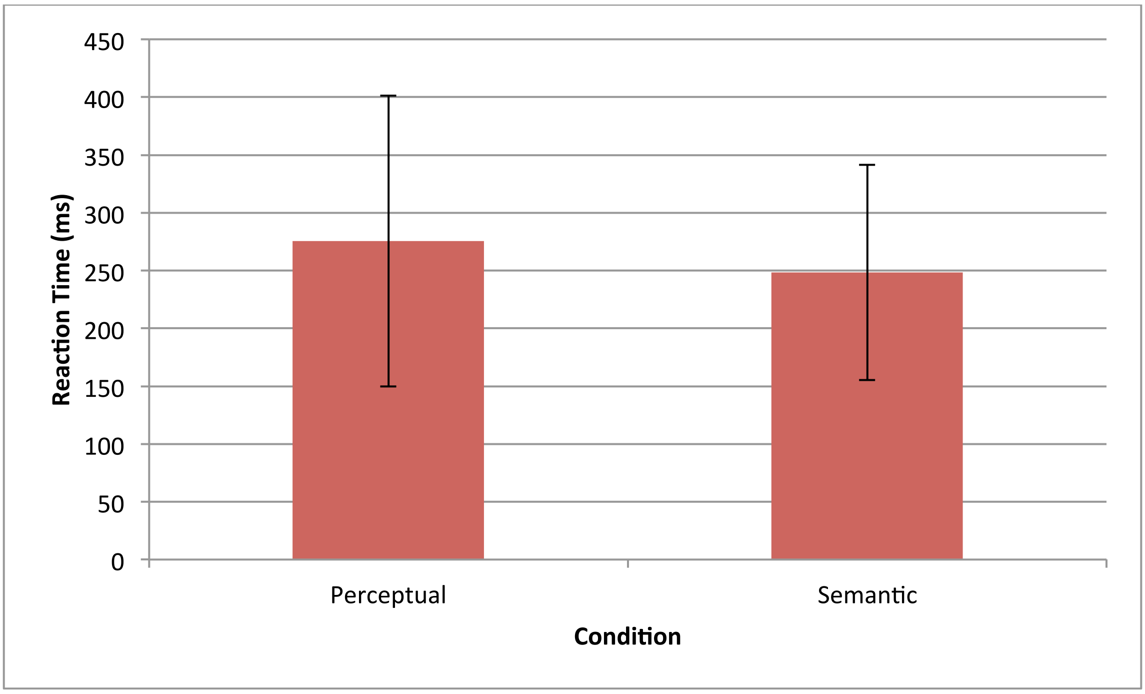

Figure 7-4. *Exp 5b main effect of condition*

The main effect of congruency on participants' reaction times also failed to reach statistical significance, $F(1, 40)= 0.69$, $p= 0.411$ although inspection of the means revealed that participants were responding slightly more slowly during congruent than incongruent conditions (M= 264.93, SD= 87.50 for congruent and M= 258.57, SD= 114.56 for incongruent). Furthermore, the condition by congruency interaction failed to reach statistical significance, $F(1, 40)= 0.69$, $p= 0.412$ (Fig. 7-5). These results suggest that participants were not experiencing a significantly increased amount of difficulty when identifying semantic or perceptual (timbre) information amid competing auditory information.

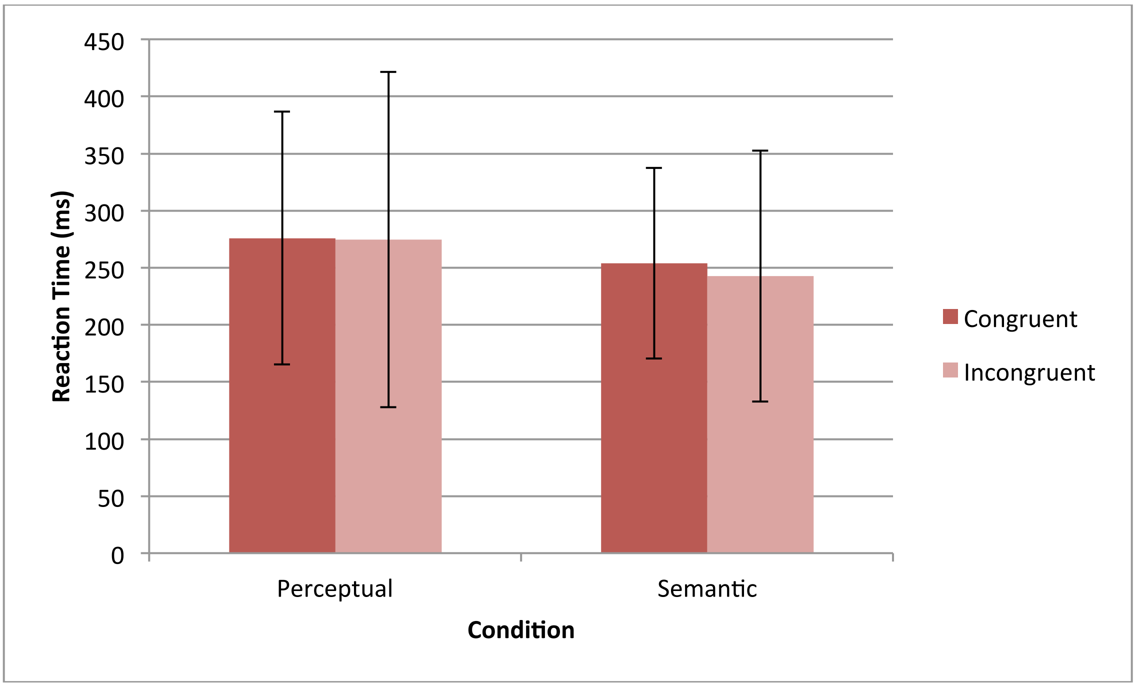

Figure 7-5. *Exp 5b condition x congruency interaction*

Regression Analysis

In order to address the third hypothesis and examine the relationship between autistic traits in a typically developing population and performance on the perceptual and semantic conditions of the timbre Stroop tasks two multiple linear regressions were performed. The dependent variables were the levels of interference that were calculated by subtracting an individual's mean reaction time on the congruent trials from their mean reaction time on the incongruent trials. Thus higher scores indicated a greater level of interference from incongruent information when identifying the perceptual (timbre) component of the stimulus during the perceptual condition or the semantic (word) component of the stimulus during the semantic condition. The predictor variables were individuals' scores on the five subscales of the AQ as well as their total AQ scores. Due to the exploratory nature of this analysis a backwards stepwise entry method was employed.

The results revealed that there was no significant linear relationship between participants' interference effects during the perceptual condition and the AQ subscale predictor variables with a multiple correlation of 0.15, [$F(1,40) = 0.82$, $p = 0.370$; adjusted $R^2 = 0.00$]. Furthermore, the results revealed that there was no significant linear relationship between participants' interference effects during the semantic condition and the AQ subscale predictor variables with a multiple correlation of 0.16, [$F(1,40) = 1.00$, $p = 0.323$; adjusted $R^2 = 0.00$]. Thus, there did not appear to be a relationship between levels of autistic traits in the typical population and their performance on either the perceptual or semantic conditions of the timbre Stroop.

SUMMARY OF EXPERIMENT 5B

The results from experiment 5b did not uncover a semantic or perceptual processing bias in response to congruent or incongruent perceptual (timbre) information. Participants were easily able to suppress their perceptual processing of timbre in order to identify semantic information and their semantic processing in order to identify timbre information. Furthermore, regression analyses did not uncover any significant relationships between autistic traits and the amount of interference typically developing individuals experienced from semantic and perceptual information during auditory processing.

COMPARISION OF DATA FROM EXPERIMENTS 5A & 5B

In order to examine whether typically developing individuals were experiencing different levels of interference from competing semantic and perceptual information during pitch and timbre manipulations t-tests were employed. Means and standard deviations for the interference effects for each of the conditions are shown in table 7-10.

Table 7-10. *Exp 5a&b comparison means and standard deviations for interference effects*

	Perceptual Condition Interference		Semantic Condition Interference	
	Pitch	Timbre	Pitch	Timbre
Mean	41.31	-1.21	0.03	-11.50
SD	56.04	65.47	52.91	59.01

T-tests revealed that participants experienced significantly more interference from incongruent trials when asked to identify the perceptual content of the stimulus in the pitch Stroop compared with the timbre Stroop, t(39)= 2.96, $p<0.01$. Thus, typically developing individuals appear to have more difficulty suppressing their semantic processing when identifying pitch information than timbre information. However, participants did not experience significantly different levels of interference from incongruent trials when asked to identify the semantic content of the stimulus in the pitch and timbre Stroops, t(39)= 1.04, $p= 0.303$. Thus, participants were able to suppress their perceptual processing of pitch and timbre in order to identify semantic information to the same extent.

DISCUSSION OF EXPERIMENTS 5A & 5B

One of the primary aims of experiments 5a and 5b was to examine the extent that typically developing adults would be able to suppress their semantic or perceptual processing amid competing information during auditory processing. Results revealed that participants were able to identify the semantic components significantly more quickly than the perceptual components of the auditory stimuli, confirming the first hypothesis that typically developing individuals would identify semantic components of auditory stimuli faster than perceptual components. In addition to a general semantic processing bias, research has shown that this processing bias may also have implications for the processing of perceptual information when competing semantic stimuli is also present (Järvinen-Pasley & Heaton, 2007; Järvinen-Pasley, Pasley, et al., 2008). The present studies also revealed that participants responded more quickly to congruent than incongruent trials, however this effect was present during the pitch Stroop but not the timbre Stroop. Thus, the present findings replicated previous pitch Stroop effects noted by Cohen and Martin (1975) and Hamers and Lambert (1972), but not the gender Stroop effect reported by Green and Barber (1981). It is possible that experiment 5b did not replicate Green and Barber's finding due to the slight methodological adjustment in the semantic stimuli used. In their study they used the words 'man' and 'girl' spoken by either a man or a woman in order to match for syllable length. This meant that the stimuli were not matched on age of the speaker and so the decision was made to use the words 'him' and 'her' in experiment 5b. This also allowed for the fundamental frequencies of the stimuli to be matched to the average fundamental frequencies of typical male and female speakers and simultaneously reduce the impact of extraneous variables.

The results from the present experiments also revealed that the Stroop effect was only present during the perceptual condition of the pitch Stroop in which participants were required to suppress their semantic processing while identifying the perceptual (pitch) component of the stimuli. Thus the findings demonstrate that the processing of pitch is slowed when competing semantic information is present and provide support for a semantic processing bias in typically developing individuals. This is further reinforced by the fact that no significant difference was found between the reaction time in the congruent and incongruent trials during the semantic condition. That is, when asked to respond to the word, it made no difference if the pitch was congruent or incongruent, presumably because participants' strong semantic processing bias meant that they were not distracted by incongruent pitch information. Confirmation of this effect was obtained when the interference effects across pitch and timbre manipulations were analysed. The results suggest that typically developing individuals experience a stronger semantic processing bias during competing pitch information, but not timbre information. Furthermore, typically developing individuals were equally able to suppress their processing of timbre and pitch information in order to identify the semantic components of auditory stimuli.

Previous research has suggested a weakened semantic processing bias in individuals with ASD and autistic traits are recognised as existing on a continuum that extends into the typical population. Therefore, another aim of experiments 5a and 5b was to investigate the extent that levels of autistic traits impacted on the levels of interference participants experienced when processing competing semantic and perceptual auditory information. Results revealed that there was a significant relationship between autistic traits in typically developing individuals and the level of interference that they experienced when identifying the pitch component amid competing semantic information. Higher imagination scores on the AQ were found to predict an increase of 21.21ms in an individual's interference effect indicating that higher levels of autistic traits in the realm of imagination were related to an increased semantic processing bias during the pitch Stroop task. However, the opposite effect was found within the realm of communication in which higher scores on the AQ predicted a decrease of 10.68ms in an individual's interference effect. Thus, as predicted by the second hypothesis, typically developing adults with higher levels of autistic traits in the realm of communication experienced a reduced semantic processing bias during the auditory pitch Stroop.

EXPERIMENT 6A: TESTING SEMANTIC AND PERCEPTUAL PROCESSING BIASES IN ASD POPULATIONS USING AN AUDIOTRY PITCH STROOP PARADIGM: AN EXPLORATORY STUDY

Aims

The present study aims to examine the extent that high-functioning adults with ASD can suppress their semantic or perceptual processing amid competing information during auditory processing. Previous findings by Järvinen-Pasley, Pasley, et al.s (2008) revealed a semantic processing bias in typically developing individuals that impaired their ability to process perceptual auditory information. However, participants with ASD exhibited a weakened bias to process semantic over perceptual information. Thus, the auditory Stroop tasks used in experiments 5a and 5b were used to further examine perceptual and semantic processing in a group of individuals with ASD. In order to replicate Järvinen-Pasley, Pasley, et al.'s (2008) finding of a weakened semantic processing bias participants were asked to identify perceptual components of the stimuli (pitch) amid complementary or competing semantic information. Furthermore, to examine whether ASD participants would demonstrate a perceptual processing bias not seen in typically developing individuals, they were asked to identify semantic components of the stimuli amid congruent or competing perceptual (pitch or timbre) information.

The final aim of the study was to investigate the extent that cognitive abilities influenced performance on auditory pitch Stroop tasks in adults with ASD. This exploration of relationships between cognitive abilities, clinical background measures and performance on the experimental tasks may provide insights into enhanced perceptual processing and weakened semantic processing biases found in previous studies.

Hypotheses

1. ASD individuals will demonstrate a weakened semantic processing bias, identifying perceptual components at a similar rate to semantic components amid competing auditory information.

2. Individuals with ASD who experience higher levels of sensory abnormalities, communication deficits and autistic symptomatology will exhibit a weakened semantic processing bias.

METHODS

Participants and Background Measures

14 adults with high-functioning ASD (3 females and 11 males) that were a subset of the participants described in chapter two participated in the present study (table 7-11).

Table 7-11. *Exp 6 ASD participant background data*

	Mean	Standard Deviation	Range
CA (months)	501.71	135.32	307-716
WASI Full Scale[a]	112.79	14.85	78-128
WASI Verbal[a1]	109.36	14.88	71-128
WASI Performance[a2]	113.57	13.22	92-129
PPVT[b]	105.36	9.90	83-123
CC-SR-Total[c]	68.43	37.63	32-159
CC-Lang. Struct.[c1]	15.07	13.80	1-49
CC-Pragmatics[c2]	16.78	12.14	0-39
CC-Social Eng.[c3]	36.57	13.81	19-71
Sensory Profile-Total[d]	177.56	27.58	130-218
SP-Low Reg.[d1]	43.64	10.69	31-62
SP-Sensation Seek.[d2]	42.93	8.18	33-63
SP-Sensory Sens.[d3]	46.57	11.01	23-62
SP-Sensation. Avoid.[d4]	44.71	9.15	31-59
AQ-Total[e]	34.64	7.55	21-45
AQ-Social Skills[e1]	6.50	2.50	3-10
AQ-Atten. Switch[e2]	8.64	1.28	6-10
AQ-Atten.to Detail[e3]	6.93	2.27	1-10
AQ-Communication.[e4]	6.21	2.61	2-10
AQ-Imagination[e5]	6.36	2.17	3-10
ADOS-Diagnostic[f]	9.57	3.69	5-17
ADOS-Commun.[f1]	2.93	1.73	1-6
ADOS-Soc. Int.[f2]	6.64	2.50	4-12
ADOS-Imag.[f3]	1.14	0.66	0-2
ADOS-Rep. Behav.[f4]	1.50	1.09	0-3
WM-Total[g]	20.78	4.59	14-30
WM-Forward[g1]	11.78	2.55	7-16
WM-Backward[g2]	9.00	2.35	6-14

Note: CA= chronological age, ASD= autism spectrum disorders, TD= typically developing
[a]Weschler Abbreviated Scales of Intelligence (WASI), standard score (Wechsler, 1999)
[a1]WASI Verbal IQ; [a2]WASI Performance IQ
[b]Peabody Picture Vocabulary Test (PPVT), standard score (Dunn & Dunn, 1997)
[c]Communication Checklist – Self Report (CC-SR), raw score (Bishop et al., 2009)
[c1]CC-SR Language Structure; [c2]CC-SR Pragmatics; [c3]CC-SR Social Engagement
[d]Adult/Adolescent Sensory Profile (SP), (Brown & Dunn, 2002)
[d1]SP Low Registration; [d2]SP Sensation Seeking; [d3]SP Sensory Sensitivity; [d4]SP Sensation Avoiding
[e]Adult Autism Spectrum Quotient (AQ), (Baron-Cohen et al., 2001)
[e1]AQ Social Skills; [e2]AQ Attention Switching; [e3]AQ Attention to Detail; [e4]AQ Communication; [e5]AQ Imagination
[f]Autism Diagnostic Observation Schedule (ADOS), diagnostic score (Lord et al., 2001)
[f1]ADOS Communication; [f2]ADOS Reciprocal Social Interaction; [f3]ADOS Imagination & Creativity; [f4]ADOS Repetitive Behaviours
[g]Working Memory Digit Span (WM), Weschler Adult Intelligence Scales, (Wechsler, 2008)
[g1]WM Forward Digit Span; [g2]WM Backward Digit Span

Experimental Methods

Experimental Stimuli

The experimental stimuli for experiment 6a were the same as that described in experiment 5a.

Procedure

The procedure for experiment 6a was carried out in the same manner as in experiment 5a previously described.

Analysis

A factorial analysis of variance (ANOVA) was used to analyse the data from experiment 5a with within-subjects factors of condition (2 levels; semantic and perceptual) and congruency (2 levels; congruent and incongruent). The dependent variable was the mean reaction time for each participant across the 60 trials at each congruency in each of the two conditions. In order to examine the relationship between cognitive, behavioural and clinical correlates and performance on the pitch Stroop task, a regression analysis will be performed.

RESULTS

Data Cleaning

Experiment 6a was designed to generate predominately correct responses due to the training and feedback participants received during the practice trials for each condition. Thus, all incorrect responses were removed from the analysis. In order to remove the noise often reported in reaction time tasks, a bi-participant trim was conducted for each of the two conditions. Z-scores were generated for the individual responses for each participant. All responses that were three standard deviations above or below an individual's mean reaction time for each condition were removed as anomalies in the data (e.g. fatigue or a repeated response due to an unrecorded initial response). The resulting case summaries from the data cleaning are described in table 7-12.

Table 7-12. *Exp 6a data cleaning case summary*

	Semantic Condition	Perceptual Condition
Before Data Cleaning	1680	1680
After Incorrect Responses Removed	1673	1555
After 3 SD Bi-Participant Trim	1638	1518

Reaction Time Analysis

In order to assess the hypothesis that participants would show a semantic but not perceptual processing bias, a factorial analysis of variance (ANOVA) was performed. Means and standard deviations for the reaction times for each of the conditions are shown in table 7-13.

Table 7-13. *Exp 6a means and standard deviations for reaction time data*

	Semantic Condition		Perceptual Condition	
	Congruent	Incongruent	Congruent	Incongruent
Mean	339.16	326.31	468.60	527.93
SD	174.27	144.26	287.62	337.04

The results revealed a significant main effect of condition on participants' reaction times, $F(1, 14) = 7.43$, $p<0.05$ (Fig. 7-6), with participants responding slower when asked to identify the perceptual (pitch) component in comparison to the semantic component of the stimuli (M= 498.27, SD= 306.18 for perceptual and M= 332.74, SD= 157.55 for semantic). Thus, participants were more able to suppress their perceptual processing to focus on the semantic component of the stimuli than suppress their semantic processing to focus on the perceptual aspects of speech.

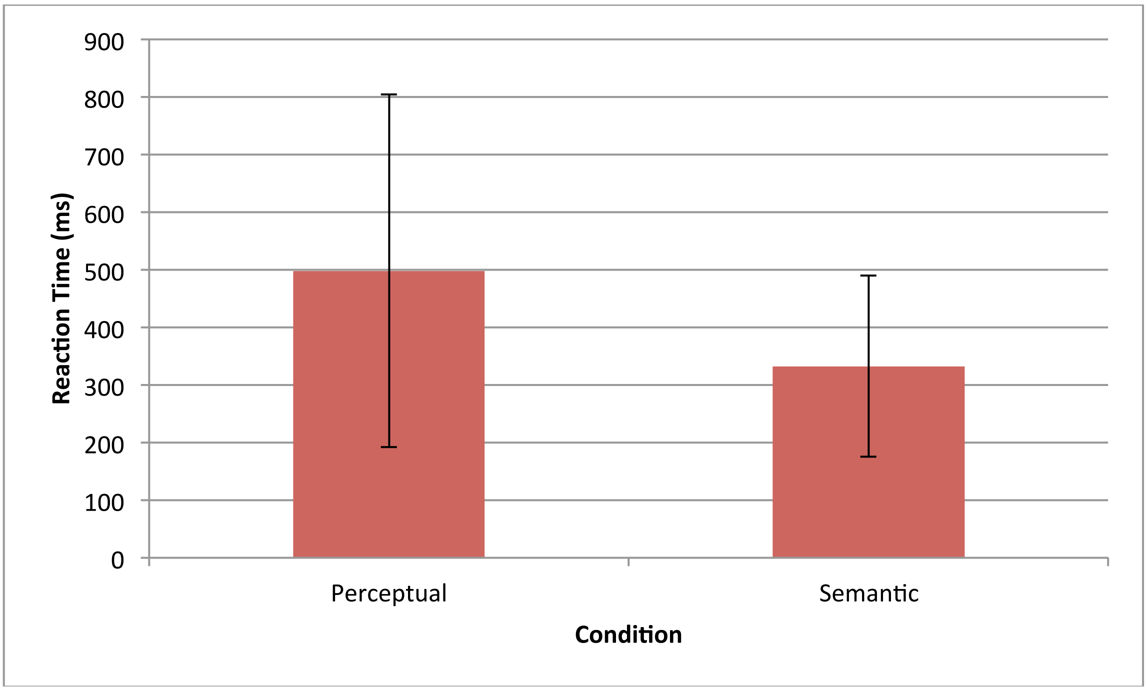

Figure 7-6. *Exp 6a main effect of condition*

There was no significant main effect of congruency on participants' reaction times, $F(1, 14)= 1.36$, $p= 0.264$ (Fig. 7-7), although participants responded more slowly during incongruent than congruent trials (M= 427.12, SD= 224.05 for incongruent and M= 403.88, SD= 212.90 for congruent). As hypothesised, participants were experiencing slightly more difficulty identifying either the perceptual or semantic component of the stimuli when there was competing information.

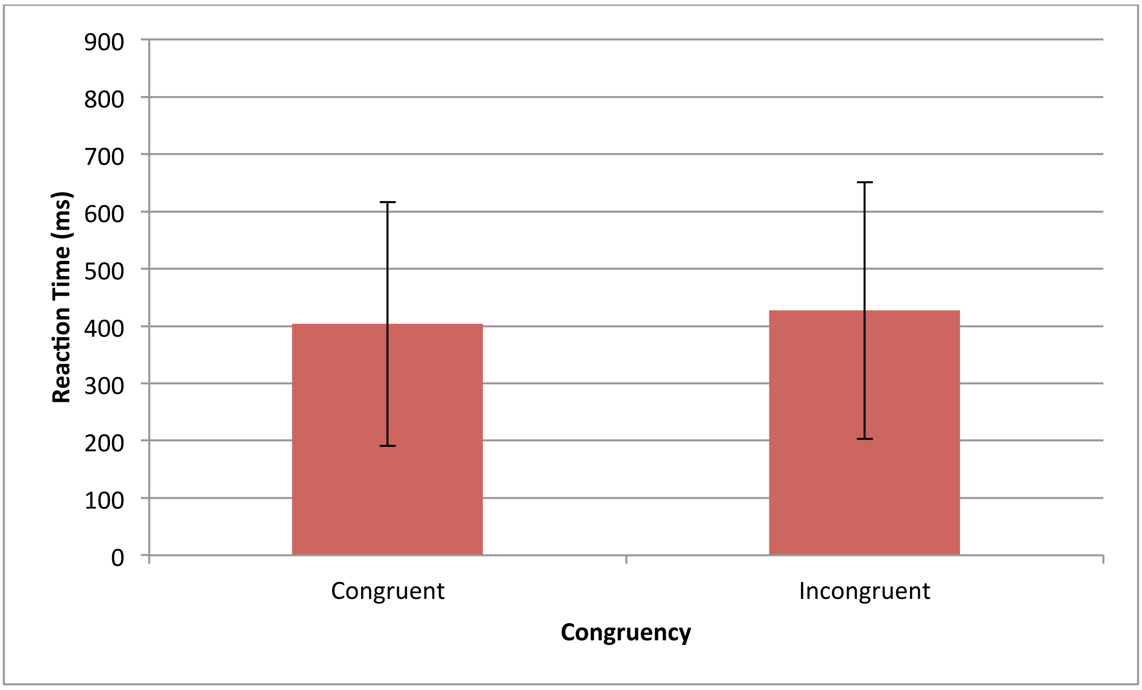

Figure 7-7. *Exp 6a main effect of congruency*

Finally, there was a non-significant trend towards an interaction between condition and congruency, $F(1, 14)= 3.79$, $p= 0.074$ (Fig. 7-8). This non-significant interaction trend suggests that participants were experiencing different levels of interference when asked to isolate semantic content amid competing perceptual information and when asked to isolate perceptual content amid competing semantic information. A significant effect had been observed in the typically developing group on this paradigm, therefore post hoc tests were carried out to determine the direction of this nearly significant effect. Post hoc pairwise comparisons (N.B. with a Bonferroni corrected p threshold of 0.025) revealed that participants responses were not significantly slowed by incongruent trials when asked to identify the semantic content of the stimulus, $t(13)= -0.87$, $p= 0.402$, or when asked to identify the perceptual content of the stimulus, $t(13)= 1.67$, $p= 0.119$. Thus, ASD participants appeared to be able to suppress their perceptual processing of pitch in order to identify semantic information, as well as suppress their semantic processing in order to identify pitch information. These results differ from those obtained from the TD group and whilst differences in group sizes must be considered, they tentatively suggest a weakened semantic processing bias within ASD individuals.

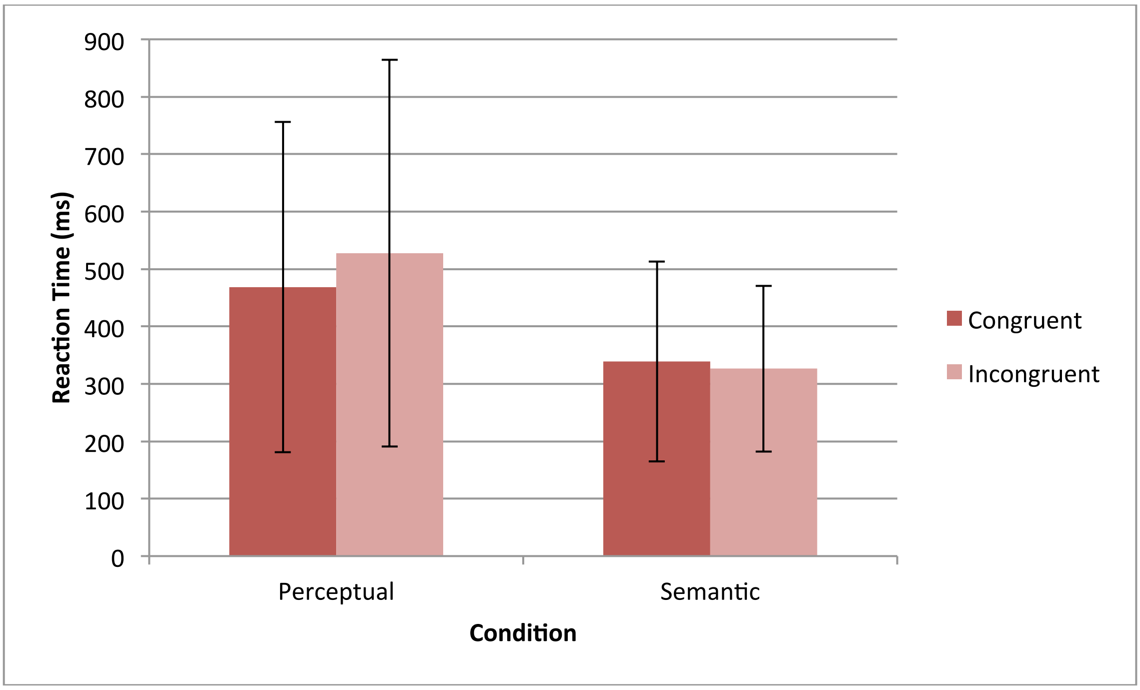

Figure 7-8. *Exp 6a condition x congruency interaction*

Correlation Analysis

Another aim of experiment 6a was to identify the cognitive, behavioural and clinical correlates of perceptual and semantic interference effects during auditory processing. The results tentatively suggested a weakened semantic processing bias amid competing pitch information in individuals with ASD and the extent that variations in performance are associated with cognitive, behavioural and clinical factors is an important question.

In order to assess the cognitive correlates of pitch and semantic interference effects, a correlation analysis was performed. Participants' interference effects during the experimental conditions along with participants' WASI Verbal, WASI Performance, WASI Full Scale, PPVT, WM forward, WM backward and WM total scores were used in the correlation. No significant correlations between any of the cognitive background measures and interference effect sizes in either of the conditions.

In order to assess the behavioural correlates of pitch and semantic interference effects, a correlation analysis was performed. Participants' interference effects during the experimental conditions along with participants' Communication Checklist – Language Structure, Communication Checklist – Pragmatic Skills, Communication Checklist – Social Engagement and Communication Checklist – Total standard scores and their Sensory Profile – Low Registration, Sensory Profile – Sensation Seeking, Sensory Profile – Sensory Sensitivity, Sensory Profile – Sensation Avoiding and Sensory Profile – Total scores were used in the correlation.

There was a significant negative correlation between participants' interference effect during the semantic condition of the pitch Stroop and their scores on the language structure, $r= -0.73$, $p<0.01$ and pragmatic skills subscales, $r= -0.61$, $p<0.05$ as well as their total communication checklist scores, $r= -0.64$, $p<0.01$. These results indicate that the more communication abnormalities ASD participants reported, the less of an interference effect they experienced when they were required to identify the semantic component of the stimuli amid competing perceptual (pitch) information. There were no significant correlations between any of the quadrants of the sensory profile and interference effect sizes in either of the conditions.

In order to assess the clinical correlates of pitch and semantic interference effects, a correlation analysis was performed. Participants' interference effects during the experimental conditions along with participants' Autism Spectrum Quotient – Social Skills, Autism Spectrum Quotient – Attention Switching, Autism Spectrum Quotient – Attention to Detail, Autism Spectrum Quotient – Communication, Autism Spectrum Quotient – Imagination and Autism Spectrum Quotient – Total and ASD participants'

ADOS – Communication, ADOS – Reciprocal Social Interaction, ADOS – Diagnostic, ADOS – Imagination and Creativity and ADOS – Stereotyped and Repetitive Behaviours scores were used in the correlation.

There was a significant positive correlation between ASD participants' interference effect during the perceptual condition and their scores on the reciprocal social interaction subscale of the ADOS, $r = 0.63$, $p<0.01$. Thus higher levels of autistic symptom severity in the realm of reciprocal social interaction were associated with an increased interference effect when required to identify the perceptual (pitch) component of the stimuli amid competing semantic information. There were no significant correlations between any of the subscales of the AQ and interference effect sizes in either of the conditions.

All significant correlations between participants' scores on all levels of the background measures and their interference effects during both conditions are summarised below (table 7-14).

Table 7-14. *Exp 6a summary of sig. correlations between interference effect and background measures*

	Pitch Perceptual	Pitch Semantic
Communication Checklist		
Language Structure	NS	-0.73**
Pragmatic Skills	NS	-0.61*
Total Score	NS	-0.64**
ADOS		
Reciprocal Social Interaction	0.63**	NS

Note: Red= significant in ASD group; NS= non-significant; *$p<0.05$, **$p<0.01$, ***$p<0.001$ (two-tailed)

Regression Analysis

In order to examine the extent that the significant cognitive, behavioural and clinical correlates in the table above accounted for the variance in interference from pitch or semantic information during auditory processing in individuals with ASD two multiple linear regressions were performed. The dependent variables were the interference effects from either pitch or semantic information. The predictor variables were individuals' scores on the language structure and pragmatic skills subscales as well as the total scores for the Communication Checklist and the reciprocal social interaction subscale of the ADOS. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

The results revealed a significant model for the predictor variables on the interference effect from pitch information with a multiple correlation of 0.78, [$F(2,14)= 8.50$, $p<0.01$; adjusted $R^2= 0.54$]. Thus, roughly 54% of the variability in a participant's interference effect during the semantic condition was predicted by their language structure difficulties and autistic symptomatology in the realm of reciprocal social interaction. Table 7-15 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value *(t)* and significance *(p)* for the predictor variables on the interference effect during the semantic condition. A closer look at the un-standardised regression coefficients indicates that higher scores on the language structure subscale of the Communication Checklist predicted a decrease of 5ms in an individual's interference effect, whereas higher reciprocal social interaction scores on the ADOS predicted an increase of 46.15ms in an individual's interference effect from pitch during the semantic condition.

Table 7-15. *Exp 6a multiple regression of interference effect in semantic condition*

	B	SE *B*	B	*t*	*p*
CC-Language Structure	-4.96	2.05	-0.51	-2.42	0.034*
ADOS-Recip. Soc. Inter.	46.15	11.31	0.87	4.08	0.002**

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

The results also revealed a significant model for the predictor variables on the interference effect from semantic information with a multiple correlation of 0.73, [F(1,14)= 13.79, p<0.01; adjusted R^2= 0.50]. Thus, roughly 50% of the variability in a participant's interference effect during the perceptual condition was predicted by their language structure difficulties. Table 7-16 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t)* and significance (*p)* for the predictor variables on the interference effect during the perceptual condition. A closer look at the un-standardised regression coefficients indicated that higher scores on the language structure subscale of the Communication Checklist predicted a decrease of 3ms in an individual's interference effect from semantic information during the perceptual condition.

Table 7-16. *Exp 6a multiple regression of interference effect in perceptual condition*

	B	SE *B*	B	*t*	*p*
CC-Language Structure	-2.94	0.79	-0.73	-3.71	0.003**

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

SUMMARY OF EXPERIMENT 6A

The results from experiment 6a tentatively suggested a weakened semantic processing bias within ASD individuals. Participants were able to suppress their perceptual processing of pitch in order to identify semantic information to a similar extent as when they were required to suppress their semantic processing in order to identify pitch information. Furthermore, regression analyses suggested that similar aspects of cognitive, behavioural and clinical correlates were implicated in the amount of interference ASD individuals experienced from semantic and perceptual information during auditory processing. For example, higher levels of communication difficulties in the realm of language structure predicted a decrease in interference from semantic information when participants were asked to identify the pitch component and from pitch information when participants were asked to identify the semantic component. Additionally, higher levels of autistic symptomatology in the realm of reciprocal social interaction predicted an increase in interference from pitch information when asked to identify the semantic component of the auditory stimuli.

EXPERIMENT 6B: TESTING SEMANTIC AND PERCEPTUAL PROCESSING BIASES IN ASD POPULATIONS USING AN AUDITORY TIMBRE STROOP PARADIGM: AN EXPLORATORY STUDY

Aims

Following on experiments 5b and 6a, experiment 6b required participants to identify perceptual components of the stimuli (timbre) amid congruent or competing semantic information and semantic components of the stimuli amid congruent or competing perceptual (timbre) information.

Another aim of the present study was to examine how cognitive, behavioural and clinical correlates influenced performance on an auditory timbre Stroop tasks in adults with ASD.

Hypotheses

1. ASD individuals will demonstrate a weakened semantic processing bias, identifying perceptual components at a similar rate to semantic components amid competing auditory information.

2. Individuals with ASD who experience higher levels of sensory abnormalities, communication deficits and autistic symptomatology will exhibit a weakened semantic processing bias.

METHODS

Participants and Background Measures

All 14 of the participants described in experiment 6a participated in the present study.

Experimental Methods

Experimental Stimuli

The experimental stimuli for experiment 6b were the same as that previously described in experiment 5b.

Procedure

The procedure for experiment 6b was carried out in the same manner as in experiment 5b previously described.

Analysis

A factorial analysis of variance (ANOVA) was used to analyse the data from experiment 5b with within-subjects factors of condition (2 levels; semantic and perceptual) and congruency (2 levels; congruent and incongruent). The dependent variable was the mean reaction time for each participant across the 60 trials at each congruency in each of the two conditions. In order to examine the relationship between AQ scores and performance on the timbre Stroop task, a regression analysis will be performed.

RESULTS

Data Cleaning

Experiment 6b was designed to generate predominately correct responses due to the training and feedback participants received during the practice trials for each condition. Thus, all incorrect responses were removed from the analysis. In order to remove the noise often reported in reaction time tasks, a bi-participant trim was conducted for each condition. Z-scores were generated for the individual responses for each participant. All responses that were three standard deviations above or below an individual's mean reaction time for each condition were removed as anomalies in the data (e.g. fatigue or a repeated response due to an unrecorded initial response). The resulting case summaries from the data cleaning are described in table 7-17.

Table 7-17. *Exp 6b data cleaning case summary*

	Semantic Condition	Perceptual Condition
Before Data Cleaning	1680	1680
After Incorrect Responses Removed	1657	1658
After 3 SD Bi-Participant Trim	1620	1621

Reaction Time Analysis

In order to assess the hypothesis that participants would show a semantic but not perceptual processing bias, a factorial analysis of variance (ANOVA) was performed. Means and standard deviations for the reaction times for each of the conditions are shown in table 7-18.

Table 7-18. *Exp 6b means and standard deviations for reaction time data*

	Semantic Condition		Perceptual Condition	
	Congruent	Incongruent	Congruent	Incongruent
Mean	330.54	332.25	356.15	331.05
SD	140.85	194.13	143.60	132.20

There was no significant main effect of condition on participants' reaction times, $F(1, 14)= 0.07$, $p= 0.794$, although participants did respond slightly slower when asked to identify the perceptual (timbre) component in comparison to the semantic component of the stimuli (M= 343.58, SD= 133.80 for perceptual and M= 331.39, SD= 166.06 for semantic). Thus, participants were slightly more able to suppress their perceptual processing to focus on the semantic component of the stimuli than suppress their semantic processing to focus on the perceptual aspects of speech, although this did not reach statistical significance.

The was also no significant main effect of congruency on participants' reaction times, $F(1, 14)= 0.80$, $p= 0.388$. Means revealed that participants were responding slightly slower during congruent than incongruent trials (M= 343.34, SD= 118.44 for congruent and M= 331.65, SD= 134.12 for incongruent). Furthermore, the condition by congruency interaction failed to reach statistical significance, $F(1, 14)= 1.11$, $p= 0.311$. These results suggest that participants were not experiencing significantly increased difficulty when identifying semantic or perceptual (timbre) information amid competing auditory information in this task.

Correlation Analysis

Another aim of experiment 6b was to identify the cognitive, behavioural and clinical correlates of perceptual and semantic interference effects during auditory processing. The results showed a great amount of variability in performance in individuals with ASD and the extent that variations in performance are associated with cognitive, behavioural and clinical factors is an important question.

In order to assess the cognitive correlates of timbre and semantic interference effects, a correlation analysis was performed. Participants' interference effects during the experimental conditions along with participants' WASI Verbal, WASI Performance, WASI Full Scale, PPVT, WM forward, WM backward and WM total scores were used in the correlation. No significant correlations between any of the cognitive background measures and interference effect sizes in either of the conditions.

In order to assess the behavioural correlates of timbre and semantic interference effects, a correlation analysis was performed. Participants' interference effects during the experimental conditions along with participants' Communication Checklist – Language Structure, Communication Checklist – Pragmatic Skills, Communication Checklist – Social Engagement and Communication Checklist – Total standard scores and their Sensory Profile – Low Registration, Sensory Profile – Sensation Seeking, Sensory Profile – Sensory Sensitivity, Sensory Profile – Sensation Avoiding and Sensory Profile – Total scores were used in the correlation.

There was a significant positive correlation between ASD participants' interference effect during the semantic condition of the timbre Stroop and their scores on the language structure subscale of the Communication Checklist, $r= 0.560$, $p<0.05$. Thus the more communication abnormalities in the realm of language structure reported, the more of an interference effect they experienced when they were required to identify the semantic component of the stimuli amid competing perceptual (timbre) information. There were no significant correlations between any of the quadrants of the Sensory Profile and interference effect sizes in either of the conditions in the ASD population.

In order to assess the clinical correlates of timbre and semantic interference effects, a correlation analysis was performed. Participants' interference effects during the experimental conditions along with participants' Autism Spectrum Quotient – Social Skills, Autism Spectrum Quotient – Attention Switching, Autism Spectrum Quotient – Attention to Detail, Autism Spectrum Quotient – Communication, Autism Spectrum Quotient – Imagination and Autism Spectrum Quotient – Total and ASD participants' ADOS – Communication, ADOS – Reciprocal Social Interaction, ADOS – Diagnostic, ADOS – Imagination and Creativity and ADOS – Stereotyped and Repetitive Behaviours scores were used in the correlation.

There was a significant positive correlation between ASD participants' interference effect during the perceptual condition of the timbre Stroop and their scores on attention to detail subscale of the AQ, $r = 0.63$, $p<0.05$. Thus the higher levels of autistic traits in the area of attention to detail reported, the more of an interference effect they experienced when they were required to identify the perceptual (timbre) component of the stimuli amid competing semantic information. There were also significant positive correlations between participants' interference effect during the semantic condition of the timbre Stroop and their scores on the communication, $r = 0.60$, $p<0.05$ and reciprocal social interaction, $r = 0.71$, $p<0.01$ subscales as well as their total diagnostic scores, $r = 0.760$, $p<0.01$ on the ADOS. These results indicate that the more autistic symptom severity that was noted during the ADOS, the more of an interference effect they experienced when they were required to identify the semantic component of the stimuli amid competing perceptual (timbre) information.

All significant correlations between participants' scores on all levels of the background measures and their interference effects during both conditions are summarised below (table 7-19).

Table 7-19. *Exp 6b summary of sig. correlations between interference effect and background measures*

	Timbre Perceptual	Timbre Semantic
Communication Checklist		
Language Structure	NS	0.56*
AQ		
Attention to Detail	0.63*	NS
ADOS		
Communication	NS	0.60*
Reciprocal Social Interaction	NS	0.71**
Diagnostic	NS	0.76**

Note: Red= significant in ASD group; NS= non-significant; **p<0.05, **p<0.01, ***p<0.001 (two-tailed)*

Regression Analysis

In order to examine the extent that the significant cognitive, behavioural and clinical correlates detailed in the table above accounted for the variance in interference from timbre or semantic information during auditory processing in individuals with ASD two multiple linear regressions were performed. The dependent variables were the interference effects from either timbre or semantic information. The predictor variables were individuals' scores on the language structure subscale of the Communication Checklist, attention to detail subscale of the AQ and the communication, reciprocal social interaction and diagnostic subscales of the ADOS. Due to the exploratory nature of this analysis, a backwards stepwise entry method was employed.

The results revealed a significant model for the predictor variables on the interference effect from timbre information with a multiple correlation of 0.79, [F(2,14)= 9.36, p<0.01; adjusted R^2= 0.56]. Thus, roughly 56% of the variability in a participant's interference effect during the semantic condition was predicted by their autistic symptomatology in the realm of attention to detail and total diagnostic score. Table 7-20 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t*) and significance (*p*) for the predictor variables on the interference effect during the semantic condition. A closer look at the un-standardised regression coefficients indicated that higher scores on the attention to detail subscale of the AQ predicted an increase of 21ms in an individual's interference effect and higher overall diagnostic scores on the ADOS predicted an increase of 9ms in an individual's interference effect from timbre during the semantic condition.

Table 7-20. *Exp 6b multiple regression of interference effect in semantic condition*

	B	SE *B*	B	*t*	*p*
AQ- Attention to Detail	21.63	5.58	0.72	3.88	0.003**
ADOS-Diagnostic	9.07	3.43	0.49	2.65	0.023*

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

The results also revealed a significant model for the predictor variables on the interference effect from semantic information with a multiple correlation of 0.76, [$F(1,14)= 16.34$, $p<0.01$; adjusted $R^2= 0.54$]. Thus, roughly 54% of the variability in a participant's interference effect during the perceptual condition was predicted by their total ADOS diagnostic score. Table 7-21 shows the un-standardised regression coefficients (*B*), standard error (SE *B*), regression coefficients (β), t-test value (*t*) and significance (*p*) for the predictor variables on the interference effect during the perceptual condition. A closer look at the un-standardised regression coefficients indicates that higher scores on the diagnostic subscale of the ADOS predicted an increase of 14ms in an individual's interference effect from semantic information during the perceptual condition.

Table 7-21. *Exp 6b multiple regression of interference effect in perceptual condition*

	B	SE *B*	Β	*t*	*p*
ADOS-Diagnostic	14.17	3.50	0.76	4.04	0.002**

Note: B= un-standardised beta coefficient, SE B= standard error, β= standardised beta coefficient, t= t-test statistic, *p*= significance value

SUMMARY OF EXPERIMENT 6B

The results from experiment 6b did not uncover a semantic or perceptual processing bias from timbre information. ASD participants were easily able to suppress their perceptual processing of timbre in order to identify semantic information and their semantic processing in order to identify timbre information. Furthermore, regression analyses suggested that similar aspects of cognitive, behavioural and clinical correlates were implicated in the amount of interference ASD individuals experienced from semantic and perceptual information during auditory processing. For example, higher levels of autistic symptomatology in the overall diagnostic scores predicted an increase in interference from semantic information when participants were asked to identify the timbre component and from timbre information when participants were asked to identify the semantic component. Additionally, higher levels of autistic traits in the realm of attention to detail predicted an increase in interference from timbre information when asked to identify the semantic component of the auditory stimuli.

COMPARISION OF DATA FROM EXPERIMENTS 6A AND 6B

In order to examine whether ASD individuals were experiencing different levels of interference from competing semantic and perceptual information during pitch and timbre manipulations t-tests were employed. Means and standard deviations for the interference effects for each of the conditions are shown in table 7-22.

Table 7-22. *Exp 6a&6b comparison means and standard deviations for interference effects*

	Perceptual Condition Interference		Semantic Condition Interference	
	Pitch	Timbre	Pitch	Timbre
Mean	59.33	-25.10	-12.85	1.71
SD	132.87	67.67	55.48	68.92

Similar to the results from the comparison between experiments 5a and 5b, carried out with TD participants, t-tests revealed that participants experienced significantly more interference from incongruent trials when asked to identify the perceptual content of the stimulus in the pitch Stroop compared with the timbre Stroop, t(13)= 2.67, $p<0.01$. Thus, ASD individuals also appear to have more difficulty suppressing their semantic processing when identifying pitch information than timbre information. However, participants did not experience significantly different levels of interference from incongruent trials when asked to identify the semantic content of the stimulus in the pitch and timbre Stroops, t(13)= -0.47, $p= 0.647$. Thus, ASD participants were able to suppress their perceptual processing of pitch and timbre in order to identify semantic information to the same extent.

DISCUSSION OF EXPERIMENTS 6A AND 6B

One of the primary aims of experiments 6a and 6b was to examine the extent that adults with ASD would be able to suppress their semantic or perceptual processing amid competing information during auditory processing. Results revealed that participants were able to identify the semantic components significantly more quickly than the perceptual components of the auditory stimuli, similar to the effect demonstrated by typically developing individuals in experiments 5a and 5b. However, unlike the results from those studies, the results from experiment 6a, testing a pitch Stroop effect did not reveal a difference between participants' response times to congruent and incongruent trials. However, the results suggested that participants were experiencing different levels of interference when asked to isolate semantic content amid competing perceptual information and when asked to isolate perceptual content amid competing semantic information. Whilst results from the present study failed to reveal clear Stroop effects, further examination revealed that ASD participants appeared to be able to suppress their perceptual processing of pitch in order to identify semantic information, as well as suppress their semantic processing in order to identify pitch information. These results suggest a weakened semantic processing bias within ASD individuals compared with that found in typically developing adults in experiments 5a and 5b. However, similar to the previous studies, this effect was present during the pitch Stroop but not the timbre Stroop. Thus, it appears that competing pitch information is more salient than timbre information during auditory processing of speech stimuli. Confirmation of this effect was uncovered when comparing the interference effects participants experienced during pitch and timbre manipulations. The results suggest that ASD individuals experience a stronger perceptual processing bias during competing semantic information during the pitch Stroop, but not the timbre Stroop. Furthermore, ASD individuals were equally able to suppress their processing of timbre and pitch information in order to identify the semantic components of auditory stimuli. These results mirror those found in with typically developing individuals in experiments 5a and 5b.

It is important to note that a limitation of experiments 6a and 6b is the small number of participants (14) compared with the much larger typically developing sample (40) that participated in experiments 5a and 5b. Although the present results suggest a weakened semantic processing bias in adults with ASD than that found in their typically developing peers, it is possible that this effect is due to a lack of power in experiments 6a and 6b. Reaction time studies, especially those that are looking for very fine-grained differences in performance, often require a larger sample for these effects to appear.

Future research should seek to recruit a larger ASD sample as well as compare their performance to a well-matched typically developing control group.

The final aim of experiments 6a and 6b was to examine how cognitive, behavioural and clinical correlates impacted performance on auditory Stroop tasks in adults with ASD. Interestingly regression analyses revealed that higher levels of communication abnormalities in the realm of language structure predicted a reduced interference effects from competing pitch information when participants were required to identify the semantic content and from competing semantic information when participants were identifying the pitch component of the auditory stimuli. Research has suggested that overly selective attention towards the perceptual components of speech may hinder the development of higher-level language processing and even in some cases language acquisition and development in individuals with ASD (Schreibman et al., 1986). However the results from the present study suggest that higher levels of self-reported communication abnormalities are actually related to reduced interference from the perceptual components of speech. Future research should seek to examine whether this effect is isolated within higher-functioning autistic individuals or whether it also extends to the lower-functioning end of the spectrum that is characterised by more marked communication deficits.

In partial support of the final hypothesis, regression analyses revealed that higher levels of ASD symptomatology, as measured by the total diagnostic score on the ADOS and the attention to detail subscale of the AQ, were related to increased levels of perceptual disturbance from competing timbre information when participants were required to identify the semantic component and from competing semantic information when participants were asked to identify the timbre component of the auditory stimuli. Given the wealth of research that has indicated pitch is a particularly salient perceptual aspect of the auditory signal in individuals with ASD it is interesting that this finding is restricted to timbre and does not extend to pitch. Furthermore, it is intriguing that in typically developing individuals the relationship with autistic traits was related to pitch information, whereas in ASD individuals they are related to timbre information. However, these results should be interpreted with caution given the exploratory nature of the present study and the lack of a matched typically developing control group with which to compare the cognitive and clinical mechanisms underlying performance.

CHAPTER 8: DISCUSSION

The studies presented in this thesis, summarised in table 8-1, investigated speech processing in high-functioning adults with ASD.

Table 8-1 *Summary of experimental study results*

Experiment 1	Pitch Discrimination in Linguistic and Non-Linguistic Stimuli	• No significant group differences. • Both groups had more difficulty with word rather than analogue contour stimuli. • Participants' ability to discriminate 'different' pitches improved as the pitch interval difference increased. • Moderate correlations between better pitch discrimination of tones and higher working memory scores in ASD participants.
Experiment 2	Encoding and Memory of Prosodically Manipulated Speech	• No significant group differences. • Participants showed reduced recall of sentences with abnormal prosody. • Small correlations between ASD participants' reduced recall of exaggerated speech and higher scores on communication measures and chronological age.
Experiment 3	Encoding and Memory of Temporally Manipulated Speech	• No significant group differences. • Participants showed reduced recall in the fast speed condition. • Significant correlations between ASD participants' reduced recall of fast speed and higher scores on communication, sensory, and autistic trait measures and chronological age.
Experiment 4	The Effect of Combined Prosodic and Temporal Manipulations on Encoding and Memory of Speech	• No significant group difference in accuracy. • Participants experienced more difficulty as the speed of speech increased regardless of the prosody. • ASD but not TD individuals tended to experience more perceptual disturbance during grammatically complex but not simple sentences. • Significant correlations between ASD participants reduced perceptual disturbance from perceptually and grammatically complex sentences and higher scores on cognitive measures.
Experiment 5a	Semantic and Perceptual Biases in Typical Populations – Pitch Stroop	• Participants were more able to suppress their pitch processing to identify on the semantic component than the other way around. • Participants' level of autistic traits predicted 22% of the variability in their interference effect when identifying the pitch.
Experiment 5b	Semantic and Perceptual Biases in Typical Populations – Timbre Stroop	• There was a non-significant trend for participants to be more able to suppress their timbre processing in order to identify the semantic component than the other way around. • Participants' levels of autistic traits did not significantly predict the variability in their interference effects.
Experiment 6a	Semantic and Perceptual Biases in ASD Populations – Pitch Stroop	• Participants were more able to suppress their pitch processing to identify on the semantic component than the other way around. • Higher diagnostic scores predicted a significant increase in an individual's interference effect from competing pitch information.
Experiment 6b	Semantic and Perceptual Biases in ASD Populations – Timbre Stroop	• Participants did not experience a Stroop effect in either condition. • Higher diagnostic scores and levels of autistic traits predicted a significant increase in an individual's interference effect from competing timbre and semantic information.

Five main aims, outlined in chapter two, were tested in a series of experiments examining pitch discrimination, encoding and memory for grammatically simple and complex, perceptually manipulated sentences and the effects of pitch and timbre in auditory Stroop tasks. In the following discussion results from the individual studies within this thesis will be discussed and the implications of these results will be explored, all within the context of the overall aims of the thesis.

The first aim was to test hypotheses about perceptual and cognitive processing, in respect to speech processing, drawn from current theories of ASD. A wealth of empirical evidence, including a large number of studies that have looked at enhanced pitch discrimination, have supported the enhanced perceptual functioning (EPF) theory of ASD. The function of pitch in speech is very well understood and has been shown to enrich the informational content of the spoken word. Given the large body of neuropsychological studies showing abnormal processing of speech and hypersensitivity to pitch information in ASD it was plausible to address questions about how these different characteristic might be related. There are a number of studies showing a weakened semantic processing bias in ASD, thus it was also plausible to suggest that increased attention to pitch information could partially explain this. However, the results from the present studies failed to demonstrate clearly enhanced pitch encoding in ASD.

Experiment one assessed pitch discrimination abilities across speech and non-speech stimuli through an explicit same/different pitch discrimination task. The paradigm used for this experiment had previously revealed superior discrimination in children and adolescents with ASD compared with age and intelligence matched controls (Heaton, Hudry, et al., 2008). In experiment one a group difference failed to emerge and the results from the child and adolescent study were not replicated. However, when the data from samples of children and adolescents who had previously been tested with the same paradigm were compared with the data from experiment one an interesting finding emerged. It appeared that pitch discrimination was extremely stable over the child, adolescent and adults groups of individuals with ASD, whereas non-autistic individuals showed a significant improvement in pitch discrimination over the three age groups. Whilst diagnostic data were not available for the two younger cohorts of participants with ASD and there may have been differences in symptom severity or other factors impacting on perceptual processing, it was suggested that pitch information may be more salient at earlier stages of development in ASD. Furthermore, it was suggested that non-autistic individuals may show poor speech pitch discrimination in childhood because of a strong semantic information processing bias during language acquisition. Increasing expertise may increase the typically developing person's ability to effectively process the two streams of information, semantic and perceptual, simultaneously. Conversely, the local processing bias, outlined in the Weak Central Coherence theory may cause individuals with ASD to process both streams of information simultaneously from an early age. However, it was noted that these findings should be interpreted with caution due to the different matching criteria employed with the cohorts and the inclusion of individuals in the child and adolescent control groups that had mild to moderate learning difficulties.

Prosodic abnormalities are reported across the spectrum in ASD (Shriberg et al., 2001) and anecdotal evidence from speech therapists suggests that some children with ASD understand speech better when it is either very flat or singsong, If prosodic contours of speech are very flat the perceptual components may be less distracting, however if it is more singsong the perceptual components may attract and sustain an individual's interest. Whilst the participants tested in the experiments described in this thesis possessed generally good verbal IQ scores, superior discrimination of fundamental frequencies in speech have been described in at least one verbally high-functioning adult with ASD (Heaton, Davis, et al., 2008) and it was hypothesised that deficits, resulting from atypical pitch processing, might emerge in implicit tasks, for example during memory recall. Thus, experiment two aimed to test the effect of prosody on encoding and memory of speech in ASD. The participants were presented with a series of prosodically manipulated sentences that were either spoken in a monotone or exaggerated pitch and asked to perform a verbatim sentence recall. Although the data analysis failed to reveal a significant group difference there was a significant degree of variability within the groups and the correlation and regression analyses revealed links between symptom severity and the effects of pitch change on memory in the ASD group. As this result is of most relevance to aim two, which was to investigate heterogeneity within the ASD group, this will be further considered. In chapter four, the relationship between fine-grained pitch discrimination, tested in experiment one and speech encoding and recall in experiment two was investigated. The rationale for this was that individuals who exhibited fine-grained pitch discrimination would show a decrease in memory encoding and recall of sentences with prosodic manipulations. However no significant correlations were found between these measures for either group. Whilst these results may suggest that different mechanisms underpin performance on the two tasks, the absence of any association could also be due to the fact that one task was explicit and lower-order (discriminating simple pitch change) and the other was implicit and higher-order (encoding and memory under pitch change conditions).

Previous research into speech perception in ASD has demonstrated that deficits are often associated with difficulties in discriminating temporal auditory features (Kujala et al., 2000) and impairments in temporal processing have often been noted in such individuals. Furthermore, theoretical accounts of ASD have predicted that temporal processing deficits in speech processing occur because it involves the rapid decoding of a constantly changing signal that must occur in real time. Thus, experiment three aimed to investigate the impact of temporal changes on encoding and recall of speech. Whilst the data confirmed earlier findings showing that increases in temporal presentation do decrease sentence recall, this was equally true for individuals with ASD and their typically developing peers. The results from experiments two and three did not reveal clear group differences and it was suggested that perceptual processing abnormalities were either absent or difficult to isolate in these very high functioning individuals. The correlations and regression analyses were important in exploring these different interpretations of these results and will be discussed in the context of aim two. Unlike the stimuli used in experiments two and three, real speech involves changes across both pitch and speed and it was hypothesised that ASD related deficits, hinted at in the results from the regression analyses of experiments two and three, would emerge on a more complex task that more closely resembled real speech, in terms of its perceptual and cognitive demands.

Experiment four aimed to directly test Samson's et al.'s (2006) neural complexity hypothesis by investigating the effects of temporal and prosodic manipulations across two levels of grammatical complexity. This study aimed to test the complexity theory at the behavioural level. Complexity of speech was operationalized on two different levels. The perceptual level was investigated through combined temporal and prosodic manipulations with monotone pitch/moderate speed representing the lowest level of perceptual complexity and exaggerated pitch/fast speed representing the highest level of perceptual complexity. The higher-order level of structure was investigated through grammatical manipulations with non-subordinate clause sentences representing the lowest level of grammatical complexity and subordinate clause sentences representing the highest level of grammatical complexity. Whilst no group differences emerged during the main analysis of the data focusing on the effects of the perceptual manipulations, further analyses revealed different interactions within the two groups between levels of grammatical complexity and perceptual manipulations. Furthermore, as the interactions between perceptual and higher-order manipulations in the ASD group were observed for both temporal and prosodic manipulations, the results suggested that prosody was influencing encoding and recall of speech in experiment four. Such an effect was not observed for the typical control group and these data provided some support for the complexity hypothesis.

This first experiment described in the thesis used an explicit task to examine enhanced pitch perception in ASD and controls and it was suggested that high levels of performance in the control group, might have been observed because they were directly instructed to make pitch comparisons. Experiments two, three and four, whist implicit in nature, were testing high levels of processing using memory recall tasks. Thus experiments 5a, 5b, 6a, 6b attempted to take the investigation full circle by investigating the effects of pitch and timbre, during speech processing, within low-level tasks. This final group of experiments aimed to investigate semantic and perceptual processing biases by presenting perceptual (either pitch or timbre) or semantic information amid congruent or competing information. The results from experiment 5a indicated a strong semantic processing bias amid competing pitch information in typically developing individuals. However, the results from experiment 6a indicated a weakened semantic processing bias amid competing pitch information in adults with ASD.

Whilst experiment 6a tested a much smaller sample of individuals (with ASD) than experiment 5a, the analyses carried out to investigate aim two of this thesis revealed that there were significant predictors underlying perceptual and semantic processing of pitch in ASD and these will be further discussed. Although the effects of timbre have previously been demonstrated in a Stroop task (Green & Barber, 1981) neither the TD or ASD individuals showed a Stroop effect on this experiment. Furthermore, a comparison of the two perpetual conditions revealed that both typically developing and ASD individuals appeared to have more difficulty suppressing their semantic processing when identifying pitch information than timbre information. In summary the studies did not provide unequivocal support for the enhanced perceptual functioning theory or the neural complexity hypothesis at the group level. However, some of the predictions from these theories appear to have been manifested at the individual level within the ASD group.

The second main aim of the thesis was to increase understanding of the heterogeneity in speech perception deficits in high-functioning adults with ASD by identifying their cognitive and behavioural correlates. This aim gained prominence in the thesis because of the absence of group differences in the studies. This was an extremely surprising finding as a large body of research has revealed brain abnormalities when processing speech in ASD and the results from the background data both confirmed diagnosis and showed significant levels of communication impairments, sensory abnormalities and ASD traits on the other measures used. However, great lengths were taken to ensure that the groups were very well matched on chronological age, IQ and working memory and it is likely that this reduced the likelihood of observing differences on the experimental paradigms at the group level. Aim two was to investigate heterogeneity and the importance of this aim was highlighted by the degree of variability in performance in the experimental paradigms. Investigation into the cognitive, behavioural and clinical correlates of performance on the experiments therefore attempted to shed light on this heterogeneity.

Correlation and regression analyses carried out on the data showed a strong effect of intelligence in the ASD group over the majority of studies. Indeed the only studies on which no intelligence and task performance correlations were observed were the Stroop and enhanced pitch tasks that were measuring explicit perceptual processing. However, on experiments two, three and four that were looking at the negative effects of perceptual manipulations on memory encoding and recall, intelligence was strongly correlated with recall scores for the ASD but not the control group. The participants in the pilot studies for experiments two and three were less intellectually able than the participants in the main studies and they provided some evidence for decreased memory encoding and recall in response to perceptual manipulation. The significant discrepancy score and IQ correlation observed in the ASD group in experiment two suggests that the less able individuals in the group were showing decreases similar to those observed in the pilot studies. Furthermore, in experiment four that included a higher order component of grammatical complexity, a similar relationship between intelligence and reduced disturbance was observed. Again, no such correlations were observed in the typically developing group. The results from the Sensory Profile revealed significant abnormalities in the ASD group and the results from the memory experiment presented in this thesis strongly suggest that intelligence enabled individuals with ASD to overcome these perceptual processing abnormalities. Given the importance of intelligence and the evidence from the pilot studies, it is plausible to suggest that group differences would emerge on these studies if the paradigms were administered with individuals on the lower functioning end of the spectrum.

Unlike the cognitive correlates in which the groups were extremely well matched, the groups differed significantly on all of the behavioural background measures. Thus, ASD individuals had significantly more sensory processing abnormalities and communication difficulties. What is interesting is that within the ASD group it did not appear that high levels of sensory abnormalities, as measured by the Sensory Profile, were associated with performance on the experimental tasks. However, this pattern was not replicated in the analyses of the Communication Checklist and experimental data. Indeed, increased deficits, for example in language structure, predicted more difficulties in memory encoding and recall in experiments. Because these experiments used discrepancy scores that calculated the extent that an individual's recall was diminished by the perceptual manipulation, this meant that the calculated score was a direct measure of an individual's improvement or loss against their own baseline. Thus poorer performance was not related to an individual's overall poorer recall or language abilities. Therefore, this meant that individuals with more severe language impairments, in the realm of language structure, were those same individuals that showed the greatest decrease in encoding and recall performance in response to both prosodic manipulations carried out in experiment two and the moderate speed manipulation in experiment three. Whilst it was not possible to carry out the Stroop test with a large sample of ASD individuals and directly compare the data with that of the typically developing individuals, an extremely interesting result came out of the regression analyses. This showed that individuals with higher levels of difficulties on the language structure component of the Communication Checklist also showed reduced interference from both pitch and semantic content in the pitch task. Given that the typically developing data showed a powerful effect of semantic interference, suggesting a semantic processing bias that was observed to a much weaker extent in the ASD study, this finding may be consistent with Järvinen-Pasley and Heaton's (2007) reduced domain specificity hypothesis. However, this suggestion should be treated with caution and an important next step will be to significantly increase the ASD group size as well as to directly compare their performance to age and intelligence matched typically developing peers. Some very surprising findings emerged in the analysis of the data from the typically developing participants, particularly with respect from the sensory profile and these will be discussed further when the third aim exploring broader phenotypes is addressed.

Similar to the behavioural correlates, the groups also different significantly across the clinical background measures. Thus unsurprisingly, individuals with ASD were exhibiting more autistic traits and symptomatology than their typically developing peers. It is interesting that individuals with ASD and relatively mild ASD symptomatology on the ADOS, especially in the realms of reciprocal social interaction and imagination, were better at discriminating small pitch changes in complex tone stimuli and were also most affected by exaggerated prosody during encoding and recall of sentences. Furthermore, this result was highly consistent with the results from the analysis of the Communication Checklist data, again showing that milder deficits in the realm of reciprocal social interaction and overall diagnostic criteria, showed less interference from perceptual and semantic information on the Stroop tasks. Again, this tentatively supports the hypothesis of reduced auditory domain specificity. Thus when considered across experiments, it appears that those individuals with ASD who exhibited enhanced discrimination of complex tones, are influenced by exaggerated prosody and also seem to have reduced auditory domain specificity, are those individuals with milder reciprocal social interaction deficits.

Another interesting and unexpected finding to emerge from the studies was a negative relationship between chronological age and encoding and recall of perceptually manipulated speech in the ASD but not the control group. The comparison of the child, adolescent and adult data in experiment two was interesting in that it suggested that perceptual discrimination trajectories may differ across ASD and TD groups and additional correlation analyses with chronological age data were carried for the subsequent experimental tasks. Correlations revealed a significant negative relationship between age and encoding and memory scores in response to the perceptual manipulations carried out in experiments two, three and four in the ASD group. Whilst the two groups were matched on mean age and range, no correlations between these measures were observed for the control group. Furthermore, as previously discussed discrepancies scores, used across all memory studies, provided a direct measure of an individual's improvement or loss against their own baseline. Therefore, poorer performance was not directly related to an individual's age, but rather reflected their specific disturbance in relation to the perceptual information. This then suggested that individuals with ASD might be more susceptible to age related cognitive processing deficits than typically developing individuals.

The third aim of this thesis was to contribute to the growing literature on the continuum conceptualisation of ASD by examining the effects of ASD traits on perceptual processing of speech within a typically developing population. Although no clear group difference emerged on the experimental paradigms between typically developing and ASD individuals, correlation and regression analyses suggested that there may be different underlying mechanisms influencing the performance of individuals in TD and ASD groups. It is important to note that the correlation and regression analyses that were conducted to address this aim were exploratory in nature and should be interpreted with caution. Interestingly, higher levels of communication difficulties and sensory abnormalities, characteristic of ASD, were related to abnormal perceptual processing within the typically developing group on some of the experimental paradigms. For example, higher levels of sensory abnormalities, especially in the realm of sensation avoiding, were related to enhanced pitch discrimination on word stimuli in experiment one. Additionally, higher levels of communication difficulties, particularly in terms of language structure and total Communication Checklist scores, were related to more increased disturbance in response to fast speech in experiment three. These findings are intriguing given that the language structure subscale of the Communication Checklist was also found to be highly related to increased disturbance from perceptual manipulations in individuals with ASD. Thus, it is plausible that other aspects of ASD symptomatology, in particular higher levels of autistic traits, as measured by the AQ, may also be associated with higher levels of perceptual processing abnormalities in typically developing individuals.

The attention to detail subscale of the AQ includes questions such as “I am fascinated by dates”, “I notice patterns in things all the time” and “I usually concentrate more on the whole picture, rather than the small details”, thus it appears to isolate interests in numbers and patterns and probes local versus global processing mechanisms. Analyses with the TD group showed that higher levels attention to detail were associated with increased disturbance in response to moderately fast speech and less interference from semantic information during the pitch Stroop. These associations are to some extent consistent with findings from the ASD group. Furthermore, the imagination subscale of the AQ, which includes questions probing one’s abilities to make up stories, read characters intentions and the extent that restricted interests may be present, also appeared to be important in typically developing individuals. This factor was associated with more disturbance from the least perceptually and least grammatically complex speech stimuli during experiment four and more semantic interference and less perceptual interference from the pitch Stroop. However, of the five factors tested by the AQ, the one that was the most interesting was the attention switching factor, which probed characteristics such as repetitive behaviours and insistence on sameness. This factor was correlated with increased levels of communication deficits and increased levels of sensory abnormalities in the typically developing group. Interestingly attention switching was also associated with increased perceptual interference during the pitch Stroop task. Although there were different patterns of significant cognitive, behavioural and clinical correlates with the ASD and typically developing groups, the results from the studies reported in this thesis do lend support to the continuum conceptualisation of ASD as higher levels of autistic traits, as measured by the AQ and higher levels of communication deficits and sensory abnormalities, were often associated with increased levels of perceptual disturbance and interference, suggesting perceptual processing abnormalities frequently observed in individuals with an Autism Spectrum Disorders diagnosis.

The fourth aim of this thesis was to provide behavioural data on speech processing in high-functioning adults with ASD that will inform the development of future electrophysiological and neuroimaging investigations. Whilst there was an absence of significant group differences on many of the experimental tasks the interesting relationships found between the cognitive, behavioural and clinical correlates and the experimental measures in the TD and ASD groups, provide support for the suggestion that high-functioning individuals with ASD may achieve the same explicit behavioural goals as TD individuals, utilising different processing routes. Thus an interesting question that arises from the results described in this thesis is whether high-functioning adults with ASD process auditory perceptual information in speech in qualitatively different ways, perhaps enlisting different brain regions, than their typically developing peers. This question is especially intriguing within the context of the results from the two Stroop tasks examining perceptual and semantic processing biases. Furthermore, the significant relationship between higher IQ scores, relatively mild communication difficulties in the realm of language structure and reduced perceptual disturbance on the experimental tasks suggests that higher functioning adults with ASD may be able to develop compensatory strategies that increase their speech processing efficiency, whereas intellectually lower-functioning individuals, like those tested in the pilot studies for experiments two and three, may not develop such effective strategies and may be more susceptible to interference from perceptual information in speech. The questions raised by the relationship between intelligence and perceptual disturbance are especially intriguing given that it was only characteristic of individuals with ASD, but not their typically developing peers.

The fifth and final aim of this thesis was to provide data that will be informative for professionals who deliver services to adults with Autism Spectrum Disorders. As previously discussed, outcomes for adults with ASD have been reported to be generally poor (Kanner, 1973) and it has been suggested that early diagnosis and intervention may lead to improvements in outcome for individuals with ASD (Howlin & Moss, 2012). It should be noted that the majority of the ASD participants in this thesis received a diagnosis in adulthood therefore it is unlikely that they underwent any type of speech and language therapy, or other forms of intervention aimed at remediating any speech processing abnormalities. However, these individuals were able to perform at very similar levels to typically developing individuals and the analyses showed that this could largely be explained by higher levels of intelligence. Whilst the hypotheses for the experiments presented were not supported by the data analyses at the group level, it appeared from the correlation and regression analyses that some individuals experienced the kind of difficulties that were consistent with the experimental hypotheses proposed in the studies. Intelligence scores ranged between 78 and 133 in the ASD group and given the high correlations between intelligence and efficient speech processing, it is likely that speech processing interventions would be most effective with adults with IQ scores at the low average end of that range. Whilst all of the participants studied showed some degree of independence within the community, the results from the studies showed that those with lower IQ had been less able to remediate speech perception difficulties, on their own, than those individuals with higher levels of intelligence. This is consistent with findings from outcome studies that have noted that intellectual ability is a significant factor predicting better outcomes in adulthood (Howlin & Moss, 2012). The very able adults with ASD assessed in this thesis appeared to process, encode and recall speech similarly to their typically developing peers and it may be the case that speech processing difficulties does not contribute to their communication difficulties Research shows that only around 49% of individuals with ASD are in education or some form of work, only 14% are married and only 25% report having at least one friend (Howlin & Moss, 2012). The results from the studies presented in this thesis suggest that some individuals with ASD, who do not have significant intellectual impairment, experience difficulties in processing speech. This may serve to increase communication difficulties and limit the individual's psychosocial and vocational opportunities. Such findings underscore the need for intervention services specifically targeting adults on the spectrum. Furthermore, although these services are particularly important for lower-functioning adults who may need extra support developing compensatory strategies focused on speech processing, this thesis has also highlighted the importance of developing services for individuals without marked cognitive impairment. Research by Farley et al. (2009) suggests that community based interventions have been extremely effective for adults with ASD as they reported much higher levels of employment, close relationships and positive outcomes overall in their cohort who were living in a cohesive society with strong values encouraging the inclusion of people with disabilities. Professional services and interventions for individuals with ASD at all stages of development are incredibly important and future research should aim to further inform the development of effective support.

Study Limitations

Within any empirical investigation a number of limitation will arise that should be taken into consideration when interpreting and generalising the results. Limitations specific to the individual experiments were discussed in their respective chapters, however there are several potential limitations that due to methodological and theoretical similarities span the experiments in this thesis. In particular, issues regarding the correlation analyses, sample sizes and statistical power, and the ratio of male to female participants will be explored.

One of the primary aims of this thesis was to increase understanding of the heterogeneity in speech perception deficits in high-functioning adults with ASD by identifying the cognitive, clinical and behavioural correlates. Additionally, the experiments in this thesis sought to set up the basis of what will be the author's future research. The measures and subscales utilised to assess possible correlates had the potential to distinguish between the underlying mechanisms driving auditory perception in individuals with and without ASD. Due to the large number of potential variables that may impact on an individual's auditory processing, another purpose of the present thesis was to reduce these variables in order to enhance future research. In order to achieve these two goals correlation analyses with the 28 background variables and the experimental measures were carried out at the end of each study, followed by multiple linear regressions which incorporated all of the variables that were significantly correlated in the preceding analyses.

Generally when conducting multiple comparisons statistical corrections should be implemented to decrease the possibility of making a Type I error. However, in this thesis the decision was made to not include statistical corrections on the correlation analyses in order to best address the two goals previously outlined. Statistical corrections based on the use of 28 variables would have resulted in the mild and moderately significant correlations being excluded. In order to ensure that possible underlying mechanisms weren't dismissed without further exploration and thus excluded from future research on the basis of the findings of the studies in this thesis, it was decided that a wider statistical filter should be applied. Although this decision was made for specific methodological reasons, it limited the degree to which clear conclusions could be drawn regarding the significant cognitive, clinical, and behavioural correlates identified in each experiment. The impact of the underlying mechanisms on the experimental results implicated in the mild and moderate correlations should be interpreted with caution. Additionally, several of the background measures and their subscales were correlated with each other, which further limits the conclusions that can be drawn until the nature of the relationships between these mechanisms is better understood. Future research should aim to confirm the identified underlying mechanisms that may be driving auditory perception in individuals with and without ASD through replication, excluding those variables that were not implicated in the present findings, and achieving larger sample sizes that will provide more robust statistical results.

Statistical power was also a potential limitation within the experiments included in this thesis. This is because of the moderate sample sizes and the high degree of variability in performance within each group on the individual experiments. Low statistical power can result in an increased possibility of a Type II error and lead to difficulties interpreting the results. Preliminary sample size estimates were conducted for three of the experiments in this thesis based on previous published studies as well as pilot studies conducted and reported in chapters four and five and suggested that 15-16 participants per group would provide sufficient statistical power. However, it is important to not that a priori power analyses could not be conducted for experiment four and experiments 5a, 5b, 6a and 6b.

A literature review was also conducted and revealed that auditory processing studies with ASD individuals have typically included groups of between 14-20 individuals (Adams & Jarrold, 2009; Bonnel et al., 2003, 2010; Foxton et al., 2003; Heaton, Hudry, et al., 2008; Järvinen-Pasley & Heaton, 2007; Järvinen-Pasley, Wallace, et al., 2008; Mottron et al., 2000), and previous studies with clinical populations have suggested that reliable results can be obtained from reaction time studies with participant groups ranging between 8-17 individuals (Jolliffe & Baron-Cohen, 1997). The preliminary sample size analyses combined with the sample sizes of previous studies of individuals with ASD that utilised similar methodologies suggested that the 19 individuals per group in the present thesis would provide reliable results with sufficient statistical power. Post hoc power analyses were not conducted within this thesis because conducting power analyses in this manner can often be misleading. In post hoc analyses, null results are generally associated with insufficient power, whereas significant results are associated with high power. However, further experiments within this area will be able to base a priori power analyses and sample size calculations on the results presented in this thesis.

The final limitation that spanned across the studies within this thesis was the ratio of male to female participants within each group. Experiments one, two, three and four used the same participant groups that each contained 15 males and four females and experiments 6a and 6b had three females and 11 males. These samples are representative of the 4:1 ratio of males to females that exist within the ASD population according to the Autism and Developmental Disabilities Monitoring Network in the United States (Rice, 2009). Although it is possible that gender differences may influence performance on the experiments within this thesis, it was not possible to recruit enough participants overall, and in particular female participants with ASD, to make up groups that would produce the statistical power to reliably interpret any gender difference that may have emerged.

Therefore, it was decided that a more appropriate approach would be to recruit one ASD sample a ratio of male and female participants to represent the population.

Whilst the ASD studies utilised a representative sample in terms of gender, experiments 5a and 5b, which were examining task performance and autistic traits within the typical population, had a sample of 31 females and 9 males. These studies utilised an opportunity sample of psychology undergraduate students, and due to the nature of such a sample the strong female skew was to be expected. Whilst the uneven gender distribution is not ideal, several AQ studies have taken a similar opportunity sample approach and thus produced uneven samples of 79 males and 122 females (Austin, 2005), 21 males and 34 females (Grinter, Maybery, Van Beek, et al., 2009) and 37 females and 18 males (Steward & Ota, 2008). However, the 3.4:1 female to male ratio in the studies presented in this thesis compared to the 4:1 male to female ratio seen in the ASD population limits the comparisons that can be made between the results of experiments 5a and 6a and 5b and 6b. Additionally, according to Baron-Cohen, et al. (2001) females score slightly, but significantly, lower than males on the AQ measuring autistic traits. Therefore conclusions drawn between semantic and perceptual interference effects and levels of autistic traits within the typical population should be interpreted with caution as an equal sample of males and females would be expected to produce a slightly different distribution of AQ scores. Experiments 6a and 6b were exploratory and will be further developed to include a matched control group that will allow for direct comparisons to be made between the semantic processing bias observed in typically developing individuals and the performance of individuals with ASD.

Conclusion

The present thesis examined speech processing in high-functioning adults with ASD and performed exploratory analyses into the possible cognitive, behavioural and clinical underlying mechanisms. Six experiments were conducted and revealed that adults with ASD were affected by prosodic and temporal manipulations to speech during higher-order tasks in a similar manner to that observed in typically developing adults. Furthermore, adults with ASD did not demonstrate superior speech pitch discrimination previously observed in children with ASD. Taken together these findings suggest that high-functioning adults with ASD responded to perceptual manipulations carried out on speech stimuli in similar ways to typically developing adults. However, correlation and regression analyses carried out on the cognitive, behavioural and clinical data suggested that different underlying mechanisms may have influenced perceptual and recall performance in the two groups and age, intelligence and symptom severity appeared to be associated with the extent that atypical perception, encoding and recall of speech stimuli were manifested.

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APPENDICES

APPENDIX I. SENTENCE STIMULI FOR EXPERIMENT 2

1. Among the birds of prey, eagles have the unique state of having no natural enemies.
2. The day is gone when one buys a savings bond as an investment for grandchildren.
3. Puerto Rico is exporting light rum which has been distilled by natives from sugar cane.
4. The British flag remained the flag of the colonists for more than a hundred years.
5. Bears are the most popular animals in a number of United States western national parks.
6. Research in leukaemia therapy has kept pace with studies of the causes of the disease.
7. When rain falls or when water runs downhill on bare soil, it creates soil erosion.
8. A cataract is a cloudiness of the lens of the eye that interferes with vision.
9. Among the major categories of equipment that are displayed at many camping show are tents.
10. Temperatures around the South Pole are thirty degrees colder than those around the North Pole.
11. When fishermen take more than the permitted surplus of fish, the numbers available will decline.
12. Some good sources of vitamin A include dark green leafy vegetables and deep yellow vegetables.
13. It is difficult to resist the flood of new low-cost camping equipment and campsites.
14. A complete Braille library and a growing collection of tapes services thousands of blind readers.
15. The number of calories needed to maintain present weight is called the daily caloric need.
16. Instead of expensive cleaning products, good materials for washing windows are vinegar and leftover newspapers
17. It is often very hard to sort out the facts regarding types of car insurance.
18. Trees grow fast in the South because of the long summers and the abundant rainfall.
19. The snowshoe rabbit has white fur during the winter which turns brown during the summer.
20. The ancient Chinese used to use kites in order to carry ropes over wide rivers.
21. Many countries have developed one or more varieties of cheese particular to their own taste.
22. About 150 different kinds of waterweeds are endangering the use of our outdoor water resources.
23. Many wildlife sanctuaries lie near urban stretches of the western seaboard and the eastern coast.
24. Statistics have shown that a large proportion of accidents such as poisonings occur at home.
25. For more than a century, the U.K. Ministry of Agriculture has carried out many services.

26. Today's air pollution is an unfortunate by-product of the growth of civilization and industrialization.
27. The city of London is accustomed to being largest or best known in many things.
28. Most manufacturing plants use processed water at some point in the course of their operations.
29. Fireplaces are not an economical means of heating, being one-third as efficient as a radiator.
30. Some of the excellent materials available for compost include shredded leaves, grass, weeds and seaweed.

APPENDIX II: SENTENCE STIMULI FOR EXPERIMENT 3

1. The ancient people who lived near the sea probably wondered what lay beneath its surface.
2. Water is really quite unevenly distributed over the earth's surface in oceans, rivers and lakes.
3. Some of the pygmies in Africa hunt for their prey using a bow and arrow.
4. The setting of Greece and its ancient monuments make it a fascinating place to visit.
5. Houses are now being built with foundations made of pressure-treated wood instead of concrete.
6. Men and women eighteen years and over are eligible to vote for a political party.
7. The bald eagle sometimes nests in the eleven national forests of the American lake states.
8. An economy's main purpose is to produce goods and services for the members of society.
9. The Virgin Islands are situated directly in the path of the tradewinds from Western Europe.
10. The economy in the region of the Caribbean Islands is based on farming of plantations.
11. Birds that are insect-eaters have thin bills that allow them to remove insects from leaves.
12. The bald eagle is one of the largest and the rarest birds in North America.
13. A major factor in a woman's satisfaction with marriage is the sharing of household chores.
14. Scientists have not yet obtained a full report of the effects of pollution on trees.
15. Today's consumer wants unique and beautiful handcrafted objects to wear and have for his home.
16. The Forest Service operates eight major forest experiment stations, with research projects at various locations.
17. For some people, a combination of public transit and private transportation may answer their needs.
18. Gold was probably the first metal to be mined because it is beautiful and long-lasting.
19. Many elderly people find their homes too large for their needs and expensive to maintain.
20. The Statue of Liberty was constructed from a steel framework and a coating of copper.
21. We have all learned that the resources of this planet cannot be treated as infinite.
22. A lack of equipment and overcrowded facilities are often cited as excuses for not exercising.
23. In the early years of strip mining, 100 years ago, acreages disturbed were very small.
24. Water systems should be disinfected with a chlorine solution after completion or after major repairs.
25. In future years Boy Scouts hope to include plantings of all important species of trees.
26. Some more adventurous gardeners might like to try growing mushrooms indoors in cool, dark basements.

27. In recent years volunteer groups have realized that England has a wealth of elderly people.
28. People from dry countries have always been aware that water is a very precious commodity.
29. Landslides are a common and very serious natural hazard in many areas of the world.
30. An adult in today's society should be knowledgeable about finances and the use of credit.

APPENDIX III:SENTENCE STIMULI FOR EXPERIMENT 4

Subordinate Clause Sentences

1. The mother wishes her son would vacuum the carpet.
2. The general that ordered the attack had no authority.
3. It was the pilot that she saw start the helicopter.
4. The chef that cooks at that restaurant uses exquisite knives.
5. It was the carousel that he found the toddlers riding.
6. Should the butcher grind the meat because he chopped it?
7. Should the family thank the fireman that saved their cat?
8. The engineer bought the shirt while it was in front.
9. The clerk straightened the shelf after the customer broke it.
10. The analyst opened the Web site because it contained the information.
11. The accountant did the tax forms because I paid him.
12. The artist composed the letter after he mailed a package.
13. Did the bassist listen to the track before it was recorded?
14. Please juice the lemon before he lays it in the bowl.
15. The actress that I saw win the award was the best.
16. The jeweller designed the ring that is in the display box.
17. Was it the biker that she witnessed pass the stop sign?
18. The player caught the ball that her teammate threw to her.
19. The dog that he watched run down the street bit his leg.
20. Should the assistant print the documents after they are in the computer?
21. The librarian shelved the item because I set it in the bin.
22. Will the critic attend the premiere because the actor is in the movie?
23. Will the carpenter chisel the design after he transfers it onto the dresser?
24. Did the patient that the pharmacist advised about the pills buy the ice pack?
25. Please fertilize the plant that he put by the window.

Non-Subordinate Clause Sentences

26. Can the paediatrician inspect the instruments in the kit?
27. Did the ad talk about the new prices and the discount?
28. Did the broke merchant need to sell the silver rings?
29. Did the comedian present the monologue and smooth his hair?
30. Did the quick swimmer need to wear the cap in the pool?
31. Did the roommate need to whine about the large apartment?
32. Have the handsome groom and the dazzling bride chosen the perfect chapel?
33. Please arrange the fresh yellow flowers and water the growing plants.
34. The attendant and the conductor punched the little white stubs.
35. The dentist and hygienist need to examine many hospital records.
36. The determined runner did not miss the awaited marathon.
37. The elegant princess in the ballet twirled beside her strong partner.

38. The energetic sailor needs to anchor the boat to the dock.
39. The famous painter chose the bright colours from the samples.
40. The infant in the crib grasped the fringe on the blanket.
41. The lawyer and the aide at the firm fired the employee.
42. The nervous pianist played the piece and finished the tiring concert.
43. The obsessive fan ran through the crowd in front of the band.
44. The sleepy passenger shoved his luggage under the seat.
45. The stubborn worker needed to scan the glossy colour prints.
46. The stunning model needs to talk with the photographer.
47. The weary commuter on the train closed his eyes.
48. Why did the snobby estate agent need to see the house?
49. Will the guest hang his wool coat and his blue umbrella?
50. The noisy resident slammed the metal door in the screen gate.