Auditory processing and autistic symptomatology

by

Nikolaos Kargas

The thesis is submitted in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy of the University of Portsmouth.

September 2014
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_In memory of my dad Aris._
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<th>Description</th>
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<tbody>
<tr>
<td>2IFC</td>
<td>Two-interval forced-choice</td>
</tr>
<tr>
<td>AASP</td>
<td>Adolescent/Adult Sensory Profile</td>
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<tr>
<td>ADT</td>
<td>Auditory Discrimination Task</td>
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<tr>
<td>ADOS</td>
<td>Autism Diagnostic Observation Schedule</td>
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<tr>
<td>ASD</td>
<td>Autism Spectrum Disorders</td>
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<td>CC-SR</td>
<td>Communication Checklist-Self Report</td>
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<tr>
<td>FIQ</td>
<td>Full Scale Intelligence Quotient</td>
</tr>
<tr>
<td>LC</td>
<td>Language &amp; Communication</td>
</tr>
<tr>
<td>MMF</td>
<td>Magnetic Mismatch Field</td>
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<tr>
<td>MMN</td>
<td>Mismatch Negativity</td>
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<tr>
<td>PIQ</td>
<td>Performance Intelligence Quotient</td>
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<tr>
<td>RRBs</td>
<td>Restricted and repetitive behaviours</td>
</tr>
<tr>
<td>SBRI</td>
<td>Stereotyped Behaviours and Restricted Interests</td>
</tr>
<tr>
<td>TYP</td>
<td>Typical group</td>
</tr>
<tr>
<td>TD</td>
<td>Typically Developed</td>
</tr>
<tr>
<td>VIQ</td>
<td>Verbal Intelligence Quotient</td>
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Dissemination of research from this thesis

Publications


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Conference presentations


Abstract

Autism spectrum disorders (ASD) are defined in terms of qualitative atypicalities in social communication and interaction in the presence of restricted, repetitive patterns of behaviour, interests and activities (RRBs). Part of the main criteria for RRBs is hyper/hypo reactivity to sensory input, which appear to be particularly prevalent in the auditory domain and could result in atypical behaviours (APA, 2013). Despite the crucial role that sensory processing plays in learning, attention, cognitive and brain maturation, emotional regulation, and social communication development in humans (e.g., Ahn et al., 2004; Bundy et al., 2007), it remains unclear what precisely causes the sensory atypicalities observed in ASD or how they are associated with the development of key autistic symptomatology such as impairments in social communication (e.g., Jones et al., 2009; Leekam Prior & Uljarević, 2011). Thus, the main aim of the present thesis is to explore the nature of the auditory sensory issues and their relationship with core symptoms (i.e., RRBs and communicative ability) in ASD and the broader autism phenotype (BAP). In addition, the associations among speech perception and production, and communication were investigated. Four studies were conducted using adult samples with and without ASD. Chapter 2 reports findings indicating that the perception of intensity and frequency auditory parameters influence the severity of RRBs and that primary auditory discrimination abilities are characterised by high variability in ASD. Chapters 3 & 4 present evidence showing that the relationship between auditory intensity perception and sensation avoiding behaviours contribute to the communicative difficulties observed in adults with ASD or high levels of autistic traits. Chapter 5 provides a direct demonstration of deficits on primary syllable stress perception in ASD and its role on the speech production abnormalities and socio-communicative atypicalities in ASD. Taken together, the outcome of these investigations highlights the
importance of considering the development of core autistic symptoms as an interactional multi-developmental process, which extends into the general population.
Declaration

Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award.

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Nikolaos Kargas. Signature: Nikolaos Kargas Date: 30th September 2014
1 GENERAL INTRODUCTION

For many people, the ability to relate to and communicate with others is an integral part of life and an intuitive process that requires limited effort. However, people with autism spectrum disorders (ASD) find it harder to communicate with, understand and relate to other people. In our days, ASDs are considered to be one of the most important causes of social disability (Fombonne, 1999). ASDs are etiologically complex neurodevelopmental disorders, typically characterised by difficulties with social communication and interaction as well as restricted, repetitive patterns of behaviour, interest and activities (RRBs) (American Psychiatric Association (APA), 2013; World Health Organization (WHO), 1993). Therefore, since ASD is conceptualized as a neurodevelopmental disorder, a rational assumption would be that the phenomenon of ASD has existed since the origins of human society (see also Gernsbacher et al., 2005). In fact, it has been suggested that numerous accounts of important historical figures with autistic like behaviours can be found worldwide and throughout history (see Feinstein, 2010; Frith, 1989; Wing, 1997 for examples).

1.1 The new diagnostic criteria of ASD

Since Kanner’s (1943) and Asperger’s (1944) descriptions of the disorder the journey of the diagnostic and classification criteria for ASD has witnessed many changes, which illustrates the widespread conflicts in research on the spectrum. One of the most important changes in the latest version of Diagnostic and Statistical Manual of Mental Disorders (DSM-5; APA, 2013) is the inclusion of hyper or hypo reactivity to sensory input and/or unusual interest in sensory aspects of the environment as part of the RRBs criteria. Moreover, in contrast to DSM-4 (APA, 2000), in the new version an individual
necessarily has to exhibit some symptoms within this area (e.g., hyper/hypo sensory
sensitivities) for a diagnosis of ASD. It is worth mentioning that the label ‘high-
functioning’ is commonly used to refer to individuals with ASD and average or above
average intelligence and cognitive functioning (Diehl & Paul, 2013). Similarly, within
this thesis the term ‘low-functioning’ and ‘high-functioning’ will be used to
differentiate between individuals with ASD that display below average and average or
above average range of cognitive functioning and IQ accordingly.

1.2 Issues and controversies in ASD research

Since the earliest accounts of ASD (Asperger, 1944, Kanner, 1943) the process of
understanding the disorder has been fascinating, puzzling, controversial and massively
researched (Colson, 2010; Donnellan, 1985; Wolff, 2004). For example, Asperger
described autism as a life-long and static personality disorder (implying a singular
cause) whereas Kanner conceptualized autism as a psychopathy, characterized by a
course (Attwood, 2006; Feinstein, 2010). For the next nearly 60 years many researchers
on ASD presumed that there was a unifying pathological or neurobiological etiology for
the symptoms observed in individuals across the spectrum with little change over time.
However, during the last decades there is a growing consensus that there is no singular
cause for ASD but rather there are many complex etiologies and that the expression of
symptoms may change across the course of development (e.g., Annaz, Karmiloff-Smith
& Thomas 2008; Geschwind & Levitt, 2007; Happé, Ronald, & Plomin, 2006; López,
2013; Karmiloff-Smith, 2009; Mayer, Hannent, & Heaton, 2014; Thomas et al., 2009;

The heterogeneity in clinical symptoms observed in individuals in the spectrum
is also depicted in findings across all areas of research in ASD. For instance, despite
evidence indicating strong genetic, cognitive, neural and social contributing factors to the emergence of autistic symptoms, research in each of these areas is characterised by contradictory findings (e.g., Valla & Belmonte, 2013). Specifically, genetic research on ASD has provided evidence suggestive of a strong genetic hereditary component. For instance, the concordance rates are estimated around 90% in monozygotic twins and 10% in dizygotic twins (e.g., Bailey et al., 2009; Buxbaum, 2009; Ritvo et al., 1989) and is also more common in males (1 in 54) than in females (1 in 252) with a ratio of 4 to 1 (e.g., Ehlers & Gillberg, 1993; Kanner, 1943). However, the lack of 100% penetrance in monozygotic twins and the discordance in heritability between identical twins and dizygotic twins (Piven & Palmer, 1997; Ronald et al., 2006) indicate that a genetic etiology cannot fully account for this neurodevelopmental disorder. Furthermore, multiple genes have been associated with increased risk for ASD (e.g., Buxbaum, 2009; Ziat & Rennert, 2011) and little is known about how these genes relate to disruptions in brain development and about the role that epigenetic interactions influence gene expression (e.g., Eagleson, Campbell, Thompson, Bergman & Levitt, 2010; Geschwind & Levitt, 2007; Ziat & Rennert, 2011).

Similarly, structural and functional neuroimaging findings in ASD have been characterized by inconsistencies and there is yet no a reliable identified neural marker for the disorder (for reviews see Gepner & Féron, 2009; Minshew & Keller, 2010; O’Connor, 2012; Penn, 2006; Stanfield et al., 2008). For example, although structural abnormalities have been reported in the cerebellum and amygdala (e.g., Frith, 2003) and in the frontal lobes and the limbic system (e.g., Sokol & Edwards-Brown, 2004) these findings are contradictory and non-specific (e.g., Gargaro, Rinehart, Bradshaw, Tonge & Sheppard, 2011). Furthermore, a similar pattern of inconsistencies is evident in cognitive behavioural and electrophysiological findings in several domains such as in
gaze perception (e.g., Webster & Potter, 2011; 2008), auditory perception (e.g., Bonnel et al., 2010) and language skills (Kjellmer, Hedvall, Fernell, Gillberg & Norrelgen, 2012; for recent reviews see Haesen, Boets & Wagemans, 2011; O’Connor, 2012; Valla & Belmonte, 2013).

A possible explanation for the inconsistencies in the findings observed across all areas of research in ASD may relate to the considerable variability in the expression of autistic symptomatology, which is evident not just across the autistic spectrum but also within the same level of severity (e.g., high-functioning ASD). In other words, social communication and interaction impairments may be expressed behaviourally in different ways among individuals with high-functioning ASD. For example, clinical reports indicate that some people in the spectrum demonstrate an aloof style of social participation whereas others may appear to actively seek social interactions, although in an atypical social manner (Geschwind & Levitt, 2007; Volkmar, Cohen, Bregman, Hooks & Stevenson, 1989; Wing & Gould, 1979)

1.3 The thesis view for ASD

The current thesis stems from the view that a developmental dynamic interactional process influences the progression of autistic behaviours. Specifically, it is suggested that dynamic interactions among idiosyncratic innate perceptual and sensory sensitivities, cognitive abilities and atypical socio-communicative experiences across the course of development result in different specific autistic phenotypes. In addition, it is argued that although initial independently heritable social and non-social autistic characteristics are not two sides of the same coin, during the course of development they develop into fixed patterns of repeated behaviours.
Despite the growing recognition by researchers and clinicians of the crucial role that sensory processing plays in learning, attention, emotional regulation and social communication development in humans (e.g., Ahn, Miller, Milberger & McIntosh, 2004; Bundy, Shia, Qi & Miller, 2007) and reports indicating that over 90% of people with ASD exhibit atypical sensory behaviours (e.g., Chang et al., 2014), little is known about the associations between sensory perception and other diagnostic symptoms such as communication skills in ASD (Chang et al., 2014; Jones et al., 2009; Leekam, Prior & Uljarević, 2011).

Attempts to understand the aetiology and the multifarious factors that contribute to the ASD symptomatology has led to interest in how differences in auditory information. For instance, researchers believe that due to the significant role auditory processing plays in language acquisition, communication and social functioning (e.g., Blake & Sekuler, 2006; Lehiste, 1970; McCleert, Elliott, Sampanis & Stefanidou, 2013; Watson et al., 2011) the study of auditory perception is essential to considering the roots of the socio-communicative and language difficulties observed in individuals with ASD. Another reason why it is important to study auditory processing in ASD is that part of the main diagnostic criteria in DSM-5 is hyper- or hypo-reactivity to sensory input, which appears to be particularly prevalent in the auditory domain and could result in atypical sensory behaviours such as adverse response to sounds and avoiding noisy social settings (APA, 2013). For example, clinical observations indicate that people with ASD and hyper-sensitive hearing appear to have difficulties in coping with loud sounds and in some cases this may also cause them to feel pain. On the other hand individuals with ASD and hypo-sensitive hearing may actively seek auditory stimulation by making sounds such as humming and flapping (e.g., Bogdashina, 2004;
Chapter 1


The broad aim of this thesis is to explore the relationships among speech perception and associated aspects of auditory processing and key autistic symptomatology (i.e., RRBs and social communication). To do this, four studies were conducted in adults with and without ASD. The aim of the study reported in Chapter 2 was twofold; 1) to investigate whether auditory discrimination abilities across a range of parameters (intensity, frequency, duration) differ between adults with and without ASD and 2) to explore their associations with the degree of RRBs in ASD. In the study presented in Chapter 3, the role of auditory discrimination ability and auditory sensory behaviours in social communication skills in ASD was investigated with the aim to identify potential factors that contribute to these socio-communicative difficulties. In light of these findings I further explored whether the relationships among auditory perception, auditory sensory behaviours and communication skills found in ASD samples also extend to the typical population, using a large sample of typically developed adults (Chapter 4). Finally, the study reported in Chapter 5 investigated the associations among syllable stress detection, speech abnormalities and socio-communicative ability. Chapter 6 provides a summary of these studies and the findings of the thesis are discussed as a whole. The final section of that chapter addresses the limitations of the thesis and proposes practical, theoretical and methodological applications and future directions.
1.4 References


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Feinstein, A. (2010). *A history of autism: Conversations with the pioneers.* London:
Chapter 1


2 THE RELATIONSHIP BETWEEN AUDITORY PROCESSING AND RESTRICTED, REPETITIVE BEHAVIORS IN ADULTS WITH AUTISM SPECTRUM DISORDERS

2.1 Abstract

Current views suggest that autism spectrum disorders (ASD) are characterised by enhanced low-level auditory discrimination abilities. Little is known, however, about whether enhanced abilities are universal in ASD and how they relate to symptomatology. We tested auditory discrimination for intensity, frequency and duration in 21 adults with ASD and 21 IQ and age-matched controls. Contrary to predictions, there were significant deficits in ASD on all acoustic parameters. The findings suggest that low-level auditory discrimination ability varies widely within ASD and this variability relates to IQ level, and influences the severity of restricted and repetitive behaviours (RRBs). We suggest that it is essential to further our understanding of the potential contributing role of sensory perception ability on the emergence of RRBs.

2.2 Introduction

From the earliest descriptions, unusual sensory experiences have been reported as characterising autism spectrum disorders (ASD) (Asperger, 1944; Kanner, 1943). Sensory symptoms in ASD include atypical sensory sensitivities (i.e., hyper / hypo), which seem to be particularly prevalent in the auditory domain (Dahlgren & Gillberg, 1989; Hermelin & O'Connor, 1970; Ornitz, 1974; Rosenhall, Nordin, Sanstrom, Ahlsen & Gillberg, 1999). Sensory atypicalities, and in particular anomalous auditory
functioning, are beginning to be recognised as a significant contributing factor in ASD (e.g., Jones et al., 2009).

To date, there are mixed findings regarding low-level auditory processing abilities in ASD (for a review see Haesen, Boets & Wagemans, 2011; O’Connor, 2012; Samson, Mottron, Jemel, Belin & Ciocca, 2006). The contradictory reports may be due to the variability in the populations studied. For example, age and IQ level have been shown to affect frequency discrimination (Heaton, Williams, Cummins & Happé, 2008; Jones et al., 2009) in ASD. Another explanation for the discrepancy in findings may be due to the considerable variation in paradigms used (Marco, Hinkley, Hill & Nagarajan, 2011). Auditory perceptual abilities in ASD may depend on the nature and complexity of the stimulus and the task (Bertone Mottron, Jelenic & Faubert 2005; Samson et al., 2006; Mongillo et al., 2008). Specifically, Samson et al., (2006) have suggested that auditory tasks comprising simple material (pure tones) and low-level operations (e.g., detection, labelling) that are processed in primary auditory cortical regions are characterised by enhanced performance. In contrast, tasks involving spectro-temporal complex material (e.g., speech) and operations (evaluation, attention) that require higher order auditory processing are characteristically diminished in ASD (Samson et al., 2006; see also Bertone et al., 2005). More importantly, the relationship between auditory processing and autistic symptomatology is far from complete. It has been suggested that future research employing correlational analyses between auditory perceptual abilities and behavioural phenotypes could help to clarify the inconsistencies in the findings (e.g., Marco et al., 2011).

The most consistently investigated auditory parameter has been the perception of frequency. Evidence for enhanced frequency discrimination ability of isolated pure tone stimuli has been found in children with ASD (Bonnel et al., 2003; Heaton, et al.,
2008; O’Riordan & Passetti, 2006) and in adults with autism (although not in adults with Asperger’s syndrome) in combined four-interval with two-forced choice (2IFC) frequency discrimination tasks (Bonnel et al., 2010). Furthermore, a similar pattern of ability has been observed also at neural levels in electrophysiological studies investigating neural response to changes of frequency in individuals with ASD, at the pre-attentive level (Ferri et al., 2003; Gomot et al., 2011; Gomot, Giard, Adrien, Barthelemy & Bruneau, 2002; Kujala et al., 2010; Lepistö et al., 2008; 2006; 2005).

Relatively few research studies have investigated intensity and duration discrimination abilities in ASD. Despite the fact that previous research shows that people with ASD have increased sensitivity (Frith and Baron-Cohen, 1987) and reduced tolerance (hyperacusis) (Khalfa et al., 2004; Rosenhall et al., 1999) to loudness, intensity discrimination ability appears to be intact in adults and adolescents with ASD (Bonnel et al., 2010; Jones et al., 2009). Of note, one study used pure tones of varying intensities (the ‘oddball’ paradigm) to investigate auditory stream segregation (mismatch negativity (MMN) responses) in children with ASD (Lepistö et al., 2009). Intensity discrimination was intact in ASD when stream segregation (to separate sounds that come from different sources) was not required. Interestingly, both previous studies exploring intensity discrimination ability in ASD (Bonnel et al., 2010; Jones et al., 2009) utilized paradigms where stream segregation was not needed. Studies on duration discrimination are scarce. It appears that duration discrimination ability is intact in adolescents (Jones et al., 2009) and adults with ASD (Kasai et al., 2005).

To our knowledge only one study has thus far gone beyond single indicators to investigate perceptual discrimination in ASD across a range of primary auditory parameters. Jones and colleagues (2009) explored low-level auditory discrimination
ability of intensity, frequency and duration using a 2IFC procedure in a large sample of adolescents with ASD and representing a wide range of IQs and ASD diagnoses. They found that, at the group level, auditory discrimination abilities were not different between individuals with and without ASD and between types of diagnosis (autism vs. other ASD). However, enhanced frequency discrimination was found in a subgroup (20%) of adolescents with ASD that shared particular characteristics (higher IQs and delayed onset of first words). Moreover, enhanced pure tone pitch discrimination has been suggested to represent a cognitive correlate of speech delay in individuals with ASD (Bonnel et al., 2010). Interestingly, Heaton and colleagues (2008) using a pure tone pitch identification task also found exceptional frequency discrimination skills in a subgroup (9%) of high functioning adolescents with ASD, who exhibit more language related impairments compared to other participants with ASD. It appears, therefore, that although atypical auditory discrimination ability is not a characteristic of most people with ASD, enhanced frequency discrimination might be suggestive of a specific phenotype in ASD. The aforementioned findings have led to the broad conclusion that enhanced frequency perception may be related to language ability in ASD.

In sum, research on auditory discrimination abilities in ASD presents a confusing picture. On the one hand some studies report enhanced abilities and support the most prominent view of ASD, the Enhanced Perceptual Functioning (EPF) theory (Mottron, Dawson, Soulières, Hubert & Burack, 2006), which suggests that low-level perceptual processing is enhanced in ASD. On the other hand, several studies fail to find enhanced performance and instead report either intact abilities on specific parameters or intact abilities in adults but not in children with high-functioning ASD. In general, we know very little about the links between different parameters of auditory discrimination in ASD, and even less about the relation between these parameters and intelligence or key
symptomatology such as restricted and repetitive patterns of behaviour, interests or activities (RRB’s).

RRBs are part of the core criteria for ASD and represent a heterogeneous class of behaviours. These include atypical sensory behaviours such as hyper/hypo-reactivity to sensory input or unusual interests in sensory aspects of the environment, and an insistence on sameness in the environment (APA, 2013). RRBs vary in their severity and occurrence among people with ASD (e.g., Bodfish, Symons, Parker, and Lewis, 2000). Distinctive subclasses of RRBs have been identified in ASD (Leekam, Prior & Uljarevic, 2011) and are suggested to represent different neural pathways (Langen, Durston, Kas, Van Engeland & Staal, 2011). RRBs are thought to interfere with social adaptation (e.g., Loftin, Odon & Lantz, 2008) as well as the acquisition of skills (e.g., Dunlap, Dyer & Koegel, 1983) and are also associated with anxiety in people with ASD (e.g., Lidstone et al., 2014; Rodgers, Clod, Connolly & McConachie, 2012).

Previous reports indicate that RRBs are linked to sensory features in ASD (e.g., Boyd, McBee, Holtzclaw, Baranek & Bodfish, 2009; Chen, Rodgers & McConachie, 2009), even after partialling out IQ and age (Boyd et al., 2010; Gabriels et al., 2008). For example, atypical sensory responses to environmental stimulation are highly related with the occurrence and expression of RRBs in ASD (e.g., Baranek, Foster & Berkson, 1997; Gal, Dyck & Passmore, 2002; Willemsen-Swinkels, Buitelaar, Dekker & van Engeland, 1998), and in turn, auditory discrimination ability is found to correlate with auditory sensory behaviours (Jones et al., 2009). Furthermore, it has been proposed that different subclasses of RRBs are associated with different types of sensory features, helping to either increase or reduce sensory stimulation (Leekam et al., 2011). For example, individuals with ASD and hypo-sensitive hearing might actively seek out stimulation by tapping things or making vocalizations and noises such as humming (e.g.,
Bogdashina, 2003). On the other hand, people with hyper-sensitive hearing often cover their ears to block out loud sounds because they are painful for them (e.g., Williams, 1998). The paucity of information on the association between distinctive auditory perceptual features and RRBs is surprising given their elements could potentially help us to discern the aetiology or function for some types of RRBs. To our knowledge the association between auditory discrimination sensitivity and RRBs remains unexplored. Identifying which, if any, auditory parameters relate to RRBs in ASD would enhance our understanding of how auditory perceptual factors may contribute to the onset and maintenance of RRBs (see also Leekam et al., 2011). This specialised knowledge could facilitate the development of new effective interventions and diagnostic tools.

In the present study we investigated auditory discrimination sensitivity in pairs of pure tones across three auditory parameters (intensity, frequency, duration) in an adult sample with high-functioning ASD. To allow direct comparisons to previous studies that also compared performance across different parameters (Bonnel et al., 2010; Jones et al., 2009), we employed auditory tasks that were similar in terms of the nature of the stimuli, type of discrimination and support (e.g., stepwise procedure, feedback). We also investigated how performance on the three auditory discrimination tasks (ADTs) related to the commonly reported ASD symptomatology of RRBs and to IQ. Based on the only two previous studies that investigated auditory discrimination ability across a range of parameters (Bonnel et al., 2010; Jones et al., 2009), we predicted that intensity and duration discrimination skills would be intact in high-functioning adults with ASD whereas frequency discrimination skills would be enhanced. Also we predicted that enhanced performance on the auditory tasks, that is, lower thresholds, would be related to higher IQ (Heaton et al., 2008; Jones et al., 2009) and increased RRBs in ASD.
2.3 Method

2.3.1 Participants

In total 42 native English adult speakers participated in this study. The participants included 21 people with ASD ($M = 30$ years 4 months, $SD = 10.4$ months, 3 females in each group) and 21 people without ASD ($M = 29$ years 4 months, $SD = 11.4$ months). Participants with ASD were selected from the database of the Autism Research Network (ARN, Portsmouth) and through a local adult support group for people with ASD. All participants in the ASD group had a formal diagnosis of high-functioning ASD according to standard clinical criteria (APA, 1994). To support their diagnoses, the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) was administered.

The comparison group was recruited through the University of Portsmouth participant pool and local social groups. The exclusion criteria included psychiatric or developmental diagnoses and pharmacological treatments. Ethical approval was obtained from the University of Portsmouth, Psychology Department Ethics Committee. All participants were administered the Wechsler Adult Intelligence Scale-Third Edition (WASI; Wechsler, 1999). Verbal IQ (VIQ), performance IQ (PIQ), full-scale IQ (FIQ) and chronological age characteristics of the participants in the ASD and TYP group did not differ significantly ($t$-test, all $p > .1$). See Table 2-1 for participant characteristics. Participants received a short hearing test for the standard range of frequencies (250-8000 Hz) using an audiometer. All participants had hearing thresholds equal or better than 25 dB HL range (normal auditory acuity) and no formal musical training, which was a condition of being included in the study.
Table 2-1. Participants’ mean scores and standard deviations (SD) for chronological age and IQ scores across groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Chronological age</th>
<th>Verbal IQ</th>
<th>Performance IQ</th>
<th>Full IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASD</td>
<td>Mean</td>
<td>30.3</td>
<td>109.8</td>
<td>107.2</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(10.4)</td>
<td>(18.2)</td>
<td>(15.7)</td>
</tr>
<tr>
<td>TYP</td>
<td>Mean</td>
<td>29.5</td>
<td>113.9</td>
<td>114.2</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(11.4)</td>
<td>(9.2)</td>
<td>(10.7)</td>
</tr>
</tbody>
</table>

2.3.2 Design and general procedure

2.3.2.1 Auditory Discrimination Tasks

The psychoacoustic stimuli were presented binaurally through headphones at a hearing level comfortable for the participants (74 dB). All participants completed three ADTs: intensity (loudness), frequency (pitch) and duration (temporal processing) over one session. The order of the presentation of the discrimination tasks was counterbalanced across participants. The ADTs were presented using HD-3030 headphones on a sound-calibrated laptop. All three tasks followed the same format, a 2IFC, to evaluate differential discrimination threshold for static pure tones with 500 ms inter-stimulus interval between tones and 2000 ms inter-trial interval. In each pair of tones, the participants were presented with one standard tone and a probe tone that varied according to an adaptive procedure. The thresholds were measured using a combined 2-up 1-down and 3-up 1-down adaptive staircase procedure to alter the gap separating two sounds, targeting the 79.4% level on psychometric function (Levitt, 1971). Specifically,
following 2 reversals, the 2-up 1-down staircase procedure shifts into a 3-up 1-down. Finally, the step size halves after the 4th and 6th reversal. Initially, the participants have to make very easy discriminations and larger step sizes were used to increase the level of difficulty. The discrimination becomes easier when an error is made. The task is terminated after 8 response reversals have occurred or alternatively a maximum of 40 trials has been completed. The threshold score was calculated using the mean of the last four reversals in the task (Leong, Hämäläinen, Soltész & Goswami, 2011). The standard tone was randomized across positions (first/second tone). Participants were requested to be as accurate and fast as possible, at the end of the second tone, by pressing the appropriate one of two buttons in a standard keyboard with their preferred hand. Five practice trials with feedback (verbal and text on the computer screen) including a range of difficulty levels were given prior to each testing to ensure familiarity. All participants understood the procedure at the end of practice. Note that a low threshold (score is close to 0) is indicative of optimal performance.

2.3.2.2 General stimulus characteristics

The standard stimulus in all three tasks was a pure tone with a frequency of 500 Hz presented at 74 dB. In the intensity discrimination and the frequency discrimination task the duration of the standard tone was 200 ms. In the intensity discrimination task, the intensity of the second tone ranged from 55 to 73.5 dB. The participants were asked to discriminate pairs of tones varying in loudness. Their task was to decide which tone was louder. In the frequency discrimination task the comparison tone ranged from 560 Hz to 500.8 Hz. The participants were asked to discriminate pairs of tones varying in pitch. Their task was to decide which tone sound was ‘higher’. In the duration discrimination task the standard stimulus had 400 ms duration. The duration of the other tones ranged from 410 ms to 600 ms. Participants’ task was to decide which tone sound was longer.
Full description of the stimuli parameters of the three auditory tasks can be found in Leong and colleagues (2011). The parameters of the three auditory tasks are presented in Table 2-2.

Table 2-2. Parameters of the three auditory discriminations tasks (ADTs).

<table>
<thead>
<tr>
<th></th>
<th>Intensity</th>
<th>Frequency</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard stimuli</td>
<td>74 dB</td>
<td>500 Hz</td>
<td>400 ms</td>
</tr>
<tr>
<td>Starting probe</td>
<td>55 dB</td>
<td>560 Hz</td>
<td>600 ms</td>
</tr>
<tr>
<td>Lowest difference between probes</td>
<td>.5 dB</td>
<td>.8 Hz</td>
<td>5 ms</td>
</tr>
<tr>
<td>Intensity</td>
<td>Variable</td>
<td>74 dB</td>
<td>74 dB</td>
</tr>
<tr>
<td>Frequency</td>
<td>500 Hz</td>
<td>Variable</td>
<td>500 Hz</td>
</tr>
<tr>
<td>Duration</td>
<td>200 ms</td>
<td>200 ms</td>
<td>Variable</td>
</tr>
<tr>
<td>ISI</td>
<td>500 ms</td>
<td>500 ms</td>
<td>500 ms</td>
</tr>
</tbody>
</table>

2.3.2.3 Repetitive and Restricted Behaviours

The ADOS (Lord et al., 2000) Module 4 provides accurate assessment and diagnosis of autism for verbally fluent adolescents and adults suspected of having ASD and is commonly used by clinicians and in research. An ADOS assessment takes approximately 40 minutes to complete. The ADOS consists of semi-structured situations and standardized activities, which allow the examiner to observe behaviours important to the diagnosis of ASD such as communication, social interaction, RRBs and play or imaginative use of materials. Stereotyped behaviours and restricted interests (SBRIs) is one of the four ADOS components (i.e. Communication, Reciprocal social interaction, Imagination/Creativity, SBRIs) used for an ASD diagnosis. The SBRI component consists of the following items, unusual sensory interest in play
material/person (e.g., preoccupations with parts of objects), stereotyped and restricted patterns of sensory interests (e.g., excessive interest in unusual or highly specific topics or objects), inflexible adherence to routines (e.g., compulsions or rituals) and stereotyped – repetitive motor mannerisms (e.g., hand and finger and/or other complex mannerisms). Thus, we used the ADOS SBRI total scores in order to investigate the relationship between auditory perceptual ability and RRBs in the ASD group.

2.4 Results

2.4.1 Low-level auditory discrimination performance

On all three ADTs the ASD group performed significantly worse than the TYP group (using independent samples t-tests with Bonferroni correction applied). The Cohen’s d values reported in Table 2-3 show that in all three measures these group differences are substantial. There was, however, unequal variance in performance between the two groups on two of the measures. Levene’s test for equality of variance revealed greater variability in the ASD group for intensity discrimination ($F = 7.26, p = .010$) and for frequency discrimination ($F = 13.1, p = .001$), but not for duration discrimination (see Table 2-3 for SDs). Because of the unequal variances we conducted Mann-Whitney tests to check for group differences. These analyses also revealed significant diminished performance in the ASD group across the three tasks (all $p < .05$).

Based on previous reports indicating that enhanced frequency discrimination may be a characteristic of a small subgroup with ASD (Heaton et al., 2008; Jones et al., 2009), we further explored the participants’ discrimination scores in each auditory task in order to determine whether we had a subgroup of exceptionally good discrimination skills in ASD. Exceptional discrimination performance in each auditory task was
defined by 100% accuracy. As in Heaton et al. (2008), around 9% (9.05%) of the people within the ASD group ($n = 2$) demonstrated exceptional frequency discrimination performance. Also, exceptional intensity discrimination was found in one individual with ASD. However, the number of performers in the TYP group with exceptional discrimination ability in frequency ($n = 3$) and intensity ($n = 2$) tasks were similar to the group with ASD. Thus, the difference in distribution for both enhanced frequency discrimination ($X^2 (df = 1) = 0.22, p = .634$) and enhanced intensity discrimination ($X^2 (df = 1) = 0.35, p = .549$) was not significant. Also, consistent with Jones et al.’s (2009) findings, none of the participants in the ASD group and the comparison group demonstrated exceptional duration discrimination.

We also investigated whether we had a subgroup of exceptionally poor discrimination skills in ASD. In our study, exceptionally poor performance was defined as a threshold score above $3SDs$ from the control mean. In the intensity and frequency discrimination tasks we found five participants with ASD (23.8%) in each task that had thresholds $3SDs$ above the TYP group mean (intensity: $M = 1.8, SD = 0.84$; frequency: $M = 7.10, SD = 6.60$). In contrast, the TYP group did not include any participants scoring over the $3SDs$ threshold. The difference in distribution for both exceptionally poor intensity discrimination performance ($X^2 (df = 1) = 5.67, p = .017$) and exceptionally poor frequency discrimination performance ($X^2 (df = 1) = 5.67, p = .017$) was significant. Also, none of the participants in the two groups showed exceptionally poor duration discrimination skills. Finally, it is worth pointing out that as in Jones et al., (2009) the participants in the subgroups were distinct, or in other words that good or poor performers were not the same participants across the tasks.
Table 2-3. Mean threshold values (and standard deviations) for the intensity, frequency and duration tasks in the two groups. A low score is indicative for optimal performance.

<table>
<thead>
<tr>
<th></th>
<th>ASD</th>
<th>TYP</th>
<th>t(df)</th>
<th>p</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity (dB)</td>
<td>Mean</td>
<td>3.32</td>
<td>1.76</td>
<td>t(24) = 2.6</td>
<td>.013</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(3.0)</td>
<td>(.90)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>Mean</td>
<td>17.90</td>
<td>7.10</td>
<td>t(32) = 3.8</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(11.10)</td>
<td>(6.60)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (ms)</td>
<td>Mean</td>
<td>79.40</td>
<td>55</td>
<td>t(40) = 3.1</td>
<td>.004</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(24.0)</td>
<td>(27)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Previous studies have excluded outliers. In order to understand the effects of outliers we conducted non-parametric analyses, which demonstrated the same effects as parametric (Intensity, \( p = .009 \); Frequency, \( p = .002 \); Duration, \( p = .005 \)).

2.4.2 Correlations between SBRI and low-level ADT performance in ASD

Using Spearman’s rho, the SBRI scores were significantly negatively correlated with intensity discrimination (\( r = -.730, p < .05 \)) and frequency discrimination (\( r = -.653, p < .05 \)), but not with duration discrimination (see Table 2-4). Specifically, participants with enhanced auditory discrimination had higher SBRI scores. These relationships remained the same when VIQ, PIQ and FIQ were partialled out.
Table 2-4. Spearman’s *Rho* correlations between auditory discrimination tasks and ADOS scores for ASD participants only.

<table>
<thead>
<tr>
<th>SBRI</th>
<th>Intensity</th>
<th>Frequency</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-.730*</td>
<td>-.653*</td>
<td>-.299</td>
</tr>
</tbody>
</table>

* Correlation is significant at .001

2.4.3 IQ and low-level ADT performance in ASD

In the ASD group VIQ was significantly negatively correlated with intensity discrimination (\(r = -.461, p < .05\)) and frequency discrimination (\(r = -.490, p < .05\)) (using Pearson’s correlations see Table 2-5). Higher levels of VIQ related to lower intensity and frequency thresholds. In the TYP group, on the other hand, there were no significant correlations between VIQ and any ADT performance. Both PIQ and FIQ were also significantly negatively correlated with frequency discrimination in the ASD group (\(r = -.535, p < .05; r = -.547, p < .05\), respectively). In contrast, in the TYP group, the only auditory task to correlate with any IQ measure was duration, which correlated with both PIQ (\(r = -.439, p < .05\)) and FIQ (\(r = -.444, p < .05\)).
Table 2-5. Pearson correlations between auditory discrimination tasks and three measures of IQ across groups.

<table>
<thead>
<tr>
<th></th>
<th>ASD</th>
<th>TYP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VIQ</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>-.416*</td>
<td>-.184</td>
</tr>
<tr>
<td>Frequency</td>
<td>-.490*</td>
<td>.018</td>
</tr>
<tr>
<td>Duration</td>
<td>-.244</td>
<td>-.323</td>
</tr>
<tr>
<td><strong>PIQ</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>-.296</td>
<td>-.261</td>
</tr>
<tr>
<td>Frequency</td>
<td>-.535*</td>
<td>-.300</td>
</tr>
<tr>
<td>Duration</td>
<td>-.306</td>
<td>-.439*</td>
</tr>
<tr>
<td><strong>FIQ</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>-.415</td>
<td>-.252</td>
</tr>
<tr>
<td>Frequency</td>
<td>-.547*</td>
<td>-.167</td>
</tr>
<tr>
<td>Duration</td>
<td>-.306</td>
<td>-.444*</td>
</tr>
</tbody>
</table>

* Correlation significant at $p < .05$

### 2.5 Discussion

Four key findings emerged from this study. First, we found diminished performance across all three low-level ADTs in the ASD group relative to the typical group. Second, auditory discrimination ability was characterized by high variability in ASD. Third, the pattern of correlation between IQ and performance on ADTs in the two groups indicates a dissociation between duration discrimination and the other two ADTs (i.e. intensity
and frequency). Fourth, there were significant correlations between two of the ADTs (intensity and frequency discrimination) and RRBs in the ASD group.

These findings combine to suggest that low-level auditory discrimination shows a complex picture in ASD. To date the literature on low-level perceptual processing in ASD has been sparse and often contradictory. The current suggestion that low-level auditory discrimination performance is enhanced in ASD (Bertone et al., 2005; Mottron, et al., 2006) is thus challenged by the only two studies to test this so far across a range of auditory parameters, to the extent that it only appears to be true for a subgroup of persons with ASD (see also Jones et al., 2009).

There are several reasons for being cautious about claiming either enhanced or impaired low-level ADT performance in ASD. First, the greater variability found in the ASD sample is typical of findings reported in several domains (Valla & Belmonte, 2013). Conceiving of ASD as a homogenous group on any performance indicator thus seems unwarranted, and sampling variability may explain some of the apparent contradictions between the findings of different studies in this domain. Hence, conceiving performance in terms of deficits or assets at the group level may itself be inappropriate. Second, the current findings support the notion of the presence of a meaningful sub-group of ASD with enhanced frequency discrimination (Heaton et al., 2008; Jones et al., 2009) despite the fact that, in contrast to previous studies, performance at the group level was diminished. Our findings show that individual differences in frequency discrimination ability significantly correlate with levels of IQ. Also, enhanced intensity discrimination was found in one participant with ASD, indicating that enhanced auditory perceptual processing may not be exclusively within the frequency domain in a subgroup with ASD (Jones et al., 2009). Furthermore, two meaningful subgroups (24% each) of exceptionally poor intensity or frequency
discrimination were found in with ASD, but not in the comparison group. Finally, duration discrimination did not include any participants with either enhanced or reduced performance in both groups. The aforementioned findings taken together suggest that first, auditory perceptual processing in ASD is characterized by high variability and second, that enhanced or reduced auditory discrimination abilities are present only within the intensity and frequency domains.

Conceptualising auditory discrimination ability in autism, which is, after all, a developmental condition, as stable over time may also lead to contradictory findings. Karmiloff-Smith (2009) powerfully shows that understanding the developmental trajectories in any specific domain is crucial for understanding the nature of these impairments; interpretations of specific deficits change when developmental changes are considered (see also López, 2013; Valla & Belmonte, 2013). Visual reception, for instance, develops differently in toddlers with ASD than in neuro-typical toddlers (Landa & Garrett-Mayer, 2006) whereas neurophysiological evidence on the perception of language suggest that the representation of, and attention to, language has an atypical developmental path in ASD (Kujala, Lepistö & Näätänen, 2013). It is important therefore to further understand the developmental role of auditory sensitivities in the progression of the autistic symptomatology.

In recent years the literature has begun to investigate RRBs as both causal of secondary impairments in ASD and possibly consequence of other underlying problems (see Leekam et al., 2011 for a review). The linking of RRBs and other low-level perceptual abilities and their developmental interplay may be crucial in understanding the bases of ASD. The large correlation between the ADOS SBRI total scores and intensity and frequency discrimination, suggests that idiosyncratic perceptual characteristics (such as enhanced auditory discrimination) may have an important
influence on the presence of greater repetitive, restricted behaviours and interests. For example, it is possible that RRBs represent compensatory behaviours for dealing with sensory hyper/hypo sensitivities that develop over time. We considered Jones et al.’s (2009) findings on the associations between performance on similar auditory tasks and a self-report measure of sensory behaviours as supportive evidence for the aforementioned suggestion.

It has been speculated that RRBs may stem from atypicalities in the detection of novel or salient stimuli (Jeste & Nelson, 2008). Under this view, the preference for insistence to sameness and the repetitive behaviours people with ASD display are thought to relate to their hyper/hypo sensitivities to detect change. Studies in pre-attentional auditory novelty detection and pre-attentive neural responses (e.g., MMN) in children with ASD have provided evidence of enhanced (Ferri et al., 2003), intact (Ceponiene et al., 2003; Kamner, Verbaten, Cuperus, Camfferman & van Engeland, 1995) and reduced (Gomot et al., 2006; Seri, Cerquiglini, Pisani & Curatolo, 1999) frequency detection. A similar pattern of results is also evident in the findings across the studies on low-level discrimination ability in ASD. Therefore, it is possible that pre-attentional auditory novelty detection might be related to the auditory discrimination abilities in ASD and in turn to the degree of RRBs. To truly answer this question, one would have to investigate MMN in pre-identified subgroups with specific auditory perception abilities (enhanced, intact, diminished). To our knowledge, this hypothesis has not been explored. The suggestion that initial abilities influence exploratory behaviour, which develops over time into fixed neural and behavioural patterns (see also Valla & Belmonte, 2013), could be meaningfully used to posit perceptual discrimination abilities as the base from which specific subclasses of RRBs develop (see also Leekam et al., 2011).
This study had a few limitations for assessing RRBs that must be mentioned. The ADOS is not the best measure of RRBs as it depends on what the individual spontaneously does in an approximately 40 minute assessment and may not represent the true extent of RRBs in the individuals assessed. Therefore, we suggest that future studies should employ additional clinical tools to assess RRBs. Despite this, the high correlations between auditory perceptual ability and ADOS SBRIIs indicate that this relationship is of a great significance. Also, we used the SBRIIs total scores as a measure for RRBs. Distinctive subclasses of RRBs have been identified in previous research (for review see Leekam et al., 2001). However, the ADOS SBRIIs total score is a composite of different types of behaviours and does not distinguish between subclasses of RRBs. Thus, although our main aim was to identify whether there were any auditory parameters that might be particularly important contributing factors for RRBs (intensity, frequency), we could not show which specific subclasses of RRBs were associated with different auditory parameters. Future research is needed to clarify the latter associations.

Overall, across all these findings, a pattern emerges of the closer integration of two of the ADTs (intensity and frequency discrimination) to the exclusion of the third (duration discrimination). These two abilities correlate with IQ and RRBs in the ASD group. Further, in the TYP group, it was duration discrimination rather than intensity and frequency discrimination that correlated with IQ. Also, the presence of subgroups with ASD with enhanced or reduced discrimination abilities were present only within the intensity and frequency domain. Thus, duration discrimination appears to be a different ability to the other two. This difference between the three low-level ADTs may be due to the way in which different aspects of auditory information are differently processed at the neurological level: the intensity and frequency of auditory input are both represented in the auditory cortex, albeit in a different manner (Lockwood et al.,
1999), while duration is processed outside the auditory cortex, in the basal ganglia (e.g., Coull, Nazarian & Vidal, 2008; Jones & Jahanshahi, 2014) and they play a crucial role for both perceptual and motor timing (for reviews see Coull, Cheng & Meck 2011; Jones & Jahanshahi, 2009; Meck, Penney & Pouthas, 2008; Nayate, Bradshaw & Rinehart, 2005).

Previous studies on time perception in ASD using a variety of auditory paradigms such as duration discrimination of complex tones (e.g., Lepistö et al., 2006), temporal processing of complex low-level auditory information (Alcántara, Weisblatt, Moore & Bolton, 2004; Alcántara, Cope, Cope & Weisblatt, 2012; Groen et al., 2009) and temporal order judgment tasks (Kwakye, Foss-Feig, Cascio, Stone & Wallace, 2011) have provided evidence for diminished abilities in auditory temporal processing. It is also found that children with ASD have difficulties reproducing the lengths of auditory stimuli of standardized durations (Szelag, Kowalska, Galkowski & Pöppel, 2004). Our results on duration discrimination extend these findings by showing that temporal aspects of simple low-level auditory information processing may be impacted in ASD. We considered our results as suggestive evidence that diminished abilities of time perceptual information may also reflect deficits in the basic encoding of auditory stimuli.

It is worth mentioning that our unexpected findings of diminished low-level auditory perceptual processing in ASD at the group level and the presence of meaningful subgroups with ASD (see also Heaton et al., 2008; Jones et al., 2009) may be due to the complexity of the ADTs (Samson et al., 2006). The current study employed three discrimination tasks to assess auditory discrimination ability. However, identification and discrimination tasks may require the intervention of different memory modes and tap different perceptual processes (e.g., Bonnel & Hafter, 1998). For
example, identification (e.g., same/different) relies on simpler neural activation than discrimination (e.g., higher, longer). In fact, it is proposed that an identification task would be relatively easier compared to a discrimination task to individuals with enhanced perception such as persons with ASD (Samson et al., 2006). Further research is needed to clarify whether the presence of subgroups with specific discrimination abilities in ASD results from the complexity of the tasks or they reflect the characteristics of the groups tested. However, the fact that we used the same auditory discrimination paradigm as in Jones et al., (2009) suggests that this argument cannot fully account as an explanation for the varying results of previous research.

Another possible explanation for the inconsistencies in the findings of auditory perceptual processing in ASD may relate to the adaptive methodologies of ADTs employed across the studies. For instance, experimental variables that could influence the results include the initial starting value of the stimulus, the step size and the tracking algorithm (Leek, 2001). These variables have not been consistent in the studies exploring auditory perceptual processing in ASD. For example, although we used the same auditory discrimination paradigm as in Jones et al. (2009) there were differences in the adaptive procedures, which may account, to some extent, for the inconsistencies in the results.

2.5.1 Conclusion

This is the first study to report evidence for diminished low-level auditory discrimination abilities across a range of auditory parameters in ASD. However, this unexpected finding may relate to high variability of low-level auditory processing abilities in ASD. We suggest that future studies in ASD should give further consideration to 1) the characteristics of the ASD samples - especially in terms of IQ
and age, 2) the nature of the auditory stimuli and complexity of the tasks and 3) the investigation of homogeneous subgroups rather than a heterogeneous broader ASD group might be more helpful to identify the multifarious factors that contribute to RRBs (see also Abrahams & Geschwind, 2008).

To our knowledge, the current study provides the first empirical evidence showing a relationship between low-level auditory processing and RRBs as measured with ADOS SBRI. Specifically, intensity and frequency discrimination ability correlate with the degree of RRBs, indicating that the expression of these behaviours may be influenced by the degree to which sounds are detected or missed in the environment. We suggest that these findings may be indicative of a specific phenotype in ASD and that further research on the developmental relationship between individual differences in low-level auditory perception and different subclasses of RRBs is essential to enhance our understanding of how RRBs initially emerge (e.g., coping with loudness) and change over time in ASD. Understanding the role of auditory perception in ASD could contribute to identifying behaviours that may have a negative functional impact, and consequently facilitate the development of the autistic behaviours.
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3 THE ROLE OF AUDITORY PERCEPTION AND AUDITORY SENSORY BEHAVIOURS IN PRAGMATIC COMMUNICATION SKILLS IN AUTISM

3.1 Abstract

The study explored the role that auditory perception and atypical sensory behaviours play in the manifestation of deficits in social communication in autism spectrum disorders (ASD). We compared 20 adults with ASD with 20 typically developing (TD) adults matched for IQ and chronological age on three low-level auditory discrimination tasks (intensity, frequency, duration) and on self-reported communication skills and auditory sensory behaviours. The results showed that both intensity discrimination ability and auditory sensory avoiding behaviours were significantly associated with pragmatic skills in ASD. Partial correlations revealed that auditory sensory avoiding behaviours rather than intensity discrimination per se influenced pragmatic ability. We conclude that communication deficits in ASD are a result of atypical sensory behaviours and atypical socio-communicative experience.

3.2 Introduction

This study focuses on the relation between basic auditory perceptual abilities, atypical auditory sensory behaviours and deficits in skills associated with social communication in autism spectrum disorders (ASD). ASD are an etiologically complex neurodevelopmental spectrum of conditions characterized by mild to severe qualitative difficulties on two core behavioural symptoms: socialisation and communication impairments, and restricted, repetitive and stereotyped patterns of behaviours and interests. In the updated Diagnostic and Statistical Manual (APA, 2013), atypical
sensory sensitivities are now part of the clinical diagnostic criteria for ASD. These include hyper/hypo reactivity to sensory input such as idiosyncratic behavioural responses to the auditory environment and atypical interests in sensory features of the environment. Language and communication impairments have been widely documented in ASD (e.g., Baron-Cohen, Baldwin & Crowson, 1997; Boucher, 2012a; Eigsti, de Marchena, Schuh & Kelley, 2011; Tager-Flusberg, Paul & Lord, 2005) and are believed to be linked to social interaction impairments (e.g., Baron-Cohen, 1995; Happé & Frith, 2006). However, the role that atypical sensory behaviours play in the manifestation of deficits in social communication in ASD remains unclear.

The social interaction difficulties that people with ASD experience have been attributed to impairments in comprehension and production of communicative messages (e.g., Diehl & Paul, 2011; Paul, Bianchi, Augustyn, Klin & Volkmar, 2008; Peppé, McCann, Gibbon, O'Hare & Rutherford, 2007; Shriberg et al., 2001). Previous research in ASD has provided strong evidence for atypical processing of affective and pragmatic prosodic cues as well as for grammatical cues, although less consistently for the latter (for a review see Eigsti et al., 2011; O’Connor, 2012). Prosody in particular, plays an important role in a range of communicative functions that have been categorized as affective, pragmatic and grammatical (Cruttenden, 1997; Roach, 2000; Samuelsson, Nettelbladt & Lofqvist, 2005), and relies not only upon linguistic information (phonological and grammatical, for example) but also on lower level acoustic information (rhythm, amplitude, pitch, stress). These lower level factors are important from sub-parts of the syllable up to the structure of words within a phrase (Lehiste, 1970; Pierrehumbert, 2003).

At the level of the auditory signal these specific aspects are associated with variations in intensity, frequency, duration and pauses (Cutler, 2005; Goetry &
Kolinsky, 2000). Combinations of these aspects are thought to play a crucial role in comprehension of receptive prosodic information and therefore in communication. In fact, impaired perceptual processing of the ‘low-level’ auditory speech signal is seen as a possible early marker for phonological deficits in developmental dyslexia (e.g., Goswami et al., 2002). In ASD the perception of low-level auditory information has been found to be atypical (i.e., enhanced, diminished) (e.g., Kargas, López, Reddy & Morris, 2014; for a review see Haesen, Boets & Wagemans, 2011; O’Connor, 2012; Samson, Mottron, Jemel, Belin & Ciocca, 2006) characterised by atypical developmental trajectories (Mayer, Hannent & Heaton, 2014). Specifically, it is suggested that although pitch discrimination improves with age and correlates with receptive vocabulary in typical development, auditory perceptual ability is enhanced in early development and remains stable across the course of development in ASD (Mayer et al., 2014). Furthermore, enhanced auditory perceptual processing has been associated with language delay (Jones et al., 2009) whereas pitch discrimination skills are not associated with receptive vocabulary in ASD (Mayer et al., 2014). Therefore, due to the significant role that prosodic-acoustic features play in children’s linguistic, cognitive, emotional and social development (e.g., Kempe, 2009; Matychuk, 2005; Murray, 1992), it is crucial to investigate low-level auditory perception in relation to communicative ability in people with ASD. To our knowledge the relationship between auditory processing and communication skills in ASD has not yet been investigated. Thus, in this study we aimed to investigate this relationship between auditory discrimination ability and communication skills.

Another factor that may contribute to communication difficulties in ASD is their atypical sensory behaviours. In recent years, there is compelling evidence suggesting that individuals with ASD demonstrate different patterns of sensory behaviours.
compared to individuals with other clinical disorders, as for example Down’s Syndrome (Carter, Capone, Gray, Cox & Kaufmann, 2006) intellectual disability (Baranek, David, Poe, Stone & Watson, 2006; Dahlgren & Gillberg, 1989), developmental delay (e.g., Baranek et al., 2006; Rogers, Hepburn and Wehner, 2003; Wiggins, Robins, Bakeman & Adamson, 2009) and specific sensory impairments (Wing & Gould, 1979). Furthermore, studies on sensory experiences have reported consistent differences between individuals with ASD and neurotypical individuals (e.g., Crane, Goddard & Pring, 2009; Horder, Wilson, Mendez & Murphy, 2013; Leekam, Nieto, Libby, Wing & Gould, 2007) and these are linked to the development of language and socio-communicative ability in infants, children and adults with ASD (e.g., Mayer & Heaton, 2014; McCleert, Elliott, Sampanis & Stefanidou, 2013; Watson et al., 2011). Moreover, researchers have consistently reported how atypical sensory sensitivities in people with ASD interfere with functions of daily life such as parent-child interaction, learning, work and the ability to explore and interact with the social environment as for instance avoiding noisy social settings (e.g., Baranek et al., 2006; Bogdashina, 2003; Kern et al., 2007; Tomchek & Dunn, 2007; Trembath, Germano, Johanson & Dissanayake, 2012), which could in turn hinder the development of communicative skills.

The paucity of information on the association among low-level auditory perceptual processing, auditory sensory behaviours and communication skills in ASD is surprising given their elements serve various paralinguistic and linguistic functions and influence exploratory behaviour and social functionality, which could contribute to the pathogenesis of autistic symptoms. For example, during infancy, sensory experience is essential for the development of auditory processing abilities, such as discriminating one sound from another, discriminating native language phonemes and in learning how to connect sounds with meaning (Bogdashina, 2005; Kuhl et al., 2006). Clarification of
these relationships could potentially enhance our understanding of autistic symptomatology and its development, which could in turn be important for the development of new diagnostic tools and interventions.

Our current understanding about the nature and causes of atypical auditory sensory behaviours and their role in the development of communicative abilities in ASD is limited. Support for reduced tolerance to loudness (hyperacusis) has been provided by Khalfa et al., (2004) and Rosenhall, Nordin, Sanstrom, Ahlsen and Gillberg (1999), who reported that children with ASD exhibit lower loudness tolerance levels to pure tones compared to typically developing children. Interestingly, as in the development of language and communication, it appears that low-level auditory discrimination ability is related to the expression of auditory sensory behaviours in ASD. To our knowledge, there is only one study in this area (Jones et al., 2009) on auditory discrimination of intensity, frequency and duration, and auditory sensory behaviours as measured by the Adolescent/Adult Sensory Profile (AASP) in adolescents with ASD. They concluded that auditory discrimination ability was associated with the degree of self-reported auditory sensory behaviours in ASD. Specifically, poor performance in their intensity discrimination task was related to difficulties coping with loud sounds, good performance in duration discrimination was related to more auditory sensory atypicalities across all auditory measures of the AASP while frequency discrimination was unrelated to auditory sensory behaviours.

Hence, the present study aimed: first, to investigate the associations between low-level auditory discrimination ability and auditory sensory behaviours in an adult sample; and second, to investigate the associations between auditory sensory behaviours and communication skills in ASD. In summary, the main aim of the present study was
to investigate whether communicative abilities in ASD may be explained by low-level auditory perceptual ability and related sensory behaviours.

### 3.3 Methods

#### 3.3.1 Participants

In total, 40 native English adults participated in this study. Participants’ details are shown in Table 3-1. The participants were 20 individuals with ASD and 20 typically developing (TD) adults (3 females in each group). Participants with ASD were recruited through a local adult support group for people with ASD and from the database of the Autism Research Network (ARN, Portsmouth). All participants in the ASD group had a formal diagnosis of ASD according to standard clinical criteria (APA, 1994, 2000) and the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) was administered to confirm their diagnoses. The comparison group was selected through the University of Portsmouth participant pool and local social groups. Ethical approval was given by the relevant University Ethics Committee. Based on self-reports, it was confirmed that all 20 typically developed participants did not have a psychiatric or developmental diagnosis.

All participants completed the Wechsler Adult Intelligence Scale-Third Edition (WASI; Wechsler, 1999). IQ measures (Verbal, VIQ; Performance, PIQ; Full-Scale, FIQ) and chronological age characteristics of the participants in the ASD and TD group did not differ significantly (all p > .1). Participants received a short hearing test for the standard range of frequencies (250-8000 Hz) using an audiometer. All of the participants had normal auditory acuity (inferior to 25dB) with no formal musical training, which was a condition of being included in the study.
Table 3-1. Participants’ mean scores and standard deviations (SD) for chronological age, IQ scores and auditory discrimination thresholds across groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Age</th>
<th>VIQ</th>
<th>PIQ</th>
<th>FIQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASD</td>
<td>Mean</td>
<td>29.60</td>
<td>109.80</td>
<td>105.74</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(10.40)</td>
<td>(18.04)</td>
<td>(14.77)</td>
</tr>
<tr>
<td>TD</td>
<td>Mean</td>
<td>29.35</td>
<td>113.50</td>
<td>113.50</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>(11.65)</td>
<td>(9.26)</td>
<td>(10.40)</td>
</tr>
</tbody>
</table>

3.3.2 Design and general procedure

3.3.2.1 Auditory discrimination tasks

Auditory discrimination thresholds for intensity, frequency and duration were measured using an adaptive staircase procedure (Levitt, 1971) in a two-forced choice format with 500 ms inter-stimulus interval between tones and 2000 ms inter-trial interval. Please note that a low threshold (score close to 0) is indicative of optimal performance. Full details of the auditory discrimination tasks (ADTs) can be found in Kargas, et al., (2014).

3.3.2.2 Auditory sensory behaviours

Each participant completed the AASP (Brown & Dunn, 2002). Twenty individuals with ASD and twenty without ASD returned completed questionnaires. The AASP is a self-report questionnaire measuring level of sensory processing in daily life across sensory modalities (e.g. auditory, visual). However, due to the nature of our investigation only the auditory items were included. The AASP is based on Dunn’s (1997) model of
sensory processing, which suggests that four sensory processing patterns characterize the perceptual process. These patterns are characterized by individual differences in two dimensions of neurological thresholds (high – low) and self-regulation strategies (active – passive). It is worth pointing out that neurological thresholds refer to the amount of stimulation required for a neuron or neuron system to respond to sensory input whereas self-regulation strategies refer to the individual’s style of behavioural response (active, passive).

The resultant AASP’s orthogonal quadrants are: the Low registration and Sensation seeking quadrants both reflect a high neurological threshold for detecting and responding to auditory sensory input. On the other hand, the Sensory sensitivity and Sensation avoiding quadrants both reflect a low neurological threshold for detecting and responding to auditory sensory input. Low registration and Sensory sensitivity denote a passive behavioural response (i.e., item 55: not noticing when your name is called; item 60: difficulties with background noise) whereas Sensation seeking and Sensation avoiding represent an active self-regulation strategy (i.e., item 50: making noises such as humming, singing or whistling; item 57: avoiding noisy environments). The AASP auditory sensory processing questionnaire is scored on a five-point scale. The maximum scores are 10 for sensation seeking and 15 on the other three quadrants. A high score indicates a high level of auditory sensory behaviours.

3.3.2.3 Communication Skills

All participants were required to complete the Communication Checklist-Self Report (CC-SR; Bishop, Whitehouse & Sharp, 2009). One of the participants with ASD did not return the questionnaire. The CC-SR is a 70-item questionnaire that assesses three domains of communicative skills that people use to interact on a regular basis and in a
wide variety of contexts. These are: Language structure, which focuses on the linguistic aspects of language (speech, syntax and semantics); Pragmatic skills, which measures the individual’s expressive pragmatic behaviours and Social engagement which assesses nonverbal aspects of communication and interests. Twenty behavioural statements focus on communicative strengths and 50 on communicative weaknesses. The CC-SR is scored on a four-point scale. A scaled score of 6 in any of the three composites indicates the presence of communicative disorder whereas a score of 7 and above indicates the absence of a communicative disorder.

3.4 Results

Auditory discrimination, auditory sensory behaviours and communication skills scores were explored to test that assumptions of normality were met. Due to violations of normality of some of the relevant variables, non-parametric methods were employed to explore group differences and associations between variables.

3.4.1 Group differences

A series of Mann-Whitney U tests was conducted to explore group differences in the three ADTs, the auditory sensory behaviour quadrants and the three communication skills composites (see Table 3-2). As predicted the results demonstrated that the ASD group exhibited atypical auditory discrimination ability (Bonferroni corrected p threshold of 0.016) for intensity ($U = 105, z = -2.58, p < .01, r = -.40$), frequency ($U = 86.5, z = -3.07, p < .01, r = -.48$) and duration ($U = 97.5, z = -2.77, p < .01, r = -.43$). The effect size of the difference was substantial in all three of the comparisons.

Further, consistent with our hypothesis the results demonstrated that the ASD group reported more auditory sensory behaviours (Bonferroni corrected $p$ threshold of
0.012) in Low registration ($U = 75, z = -3.40, p < .001, r = -.53$), Sensory sensitivity ($U = 68, z = -3.59, p < .001, r = -.56$) and Sensation avoiding ($U = 23.50, z = -4.80, p < .001, r = -.76$) compared to the TD group (again with substantial effect sizes). No significant differences were observed between groups on the Sensation seeking quadrant ($p > .05$).

As predicted, the results showed (with a Bonferroni corrected $p$ threshold of 0.016) that the ASD group reported significantly more difficulties in Pragmatic skills ($U = 27, z = -4.60, p < .001, r = -.72$), Social engagement ($U = 25, z = -4.69, p < .001, r = -.74$) and Language structure ($U = 95, z = -2.69, p < .01, r = -.42$), again all with substantial effect sizes.
Table 3-2. Group Median and Range scores for the ADTs, the auditory quadrant scores on the AASP and the three measures of ability on the CC-SR in the two groups.

<table>
<thead>
<tr>
<th></th>
<th>ASD</th>
<th>TD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity discrimination</td>
<td>2.70</td>
<td>1.50</td>
<td>20</td>
</tr>
<tr>
<td>Range</td>
<td>10.80</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Frequency discrimination</td>
<td>22.50</td>
<td>5.25</td>
<td>20</td>
</tr>
<tr>
<td>Range</td>
<td>33.00</td>
<td>24.2</td>
<td></td>
</tr>
<tr>
<td>Duration discrimination</td>
<td>85.00</td>
<td>60.00</td>
<td>20</td>
</tr>
<tr>
<td>Range</td>
<td>82.00</td>
<td>97.00</td>
<td></td>
</tr>
<tr>
<td>AASP Low registration</td>
<td>10.00</td>
<td>7.00</td>
<td>20</td>
</tr>
<tr>
<td>Range</td>
<td>10.00</td>
<td>13.00</td>
<td></td>
</tr>
<tr>
<td>AASP Sensation seeking</td>
<td>7.00</td>
<td>6.50</td>
<td>20</td>
</tr>
<tr>
<td>Range</td>
<td>6.00</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>AASP Sensory sensitivity</td>
<td>12.00</td>
<td>7.50</td>
<td>20</td>
</tr>
<tr>
<td>Range</td>
<td>9.00</td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>AASP Sensation avoiding</td>
<td>11.00</td>
<td>5.50</td>
<td>20</td>
</tr>
<tr>
<td>Range</td>
<td>8.00</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>CC-SR Language structure</td>
<td>6.00</td>
<td>8.50</td>
<td>19</td>
</tr>
<tr>
<td>Range</td>
<td>10.00</td>
<td>14.00</td>
<td></td>
</tr>
<tr>
<td>CC-SR Pragmatic skills</td>
<td>1.00</td>
<td>9.00</td>
<td>19</td>
</tr>
<tr>
<td>Range</td>
<td>8.00</td>
<td>9.00</td>
<td></td>
</tr>
<tr>
<td>CC-SR Social engagement</td>
<td>.50</td>
<td>8.50</td>
<td>19</td>
</tr>
<tr>
<td>Range</td>
<td>6.00</td>
<td>14.00</td>
<td></td>
</tr>
</tbody>
</table>

Note: In the ADTs a lower threshold is indicative of optimal performance. In AASP a higher score is indicative for more self-reported auditory sensory behaviours. The
maximum scores are 10 for sensation seeking and 15 on the other three items. In CC-SR a score 7 or above indicates absence of a communicative disorder.

3.4.2 Associations between auditory discrimination, auditory sensory behaviours and communication skills.

Spearman’s correlations were performed between low-level auditory thresholds, auditory sensory profiles and communicative abilities. As can be seen in Table 3-3, in the ASD group these correlations revealed significant relationships between intensity and three of the four sensory quadrants in the AASP, Low registration ($r = .51, p < .05$), Sensation seeking ($r = .50, p < .05$) and Sensation avoiding ($r = -.39, p < .05$) as well as with one of the three composites of the CC-SR, Pragmatics ($r = .43, p < .05$).

Specifically, higher threshold scores (indicative of poor performance) on intensity discrimination were associated with higher scores on Low registration, Sensation seeking and Pragmatic skills whereas lower discrimination thresholds (indicative of good performance) were related to higher scores on Sensation avoiding. Also, a significant correlation was observed between frequency and Low registration ($r = .41, p < .05$), suggesting that higher frequency thresholds scores were associated with higher scores on Low registration. However, in the comparison group a different pattern of correlations was found. Specifically, the only significant relationship found was a negative correlation between duration discrimination and Sensory sensitivity ($r = -.57, p < .05$).

Furthermore, in the ASD group, Spearman’s correlations between auditory sensory behaviours and communication skills revealed significant negative correlations between Sensory sensitivity and Language structure ($r = -.41, p < .05$) and Social
engagement \((r = -.44, p < .05)\) as well as between Sensation avoiding and Language structure \((r = -.42, p < .05)\) and Pragmatics \((r = -.74, p < .001)\). These results indicate that high scores on the two AASP quadrants (Sensory sensitivity, Sensation avoiding), that is, more sensory behaviours, were related to lower scores on the three CC-SR composites or in other words with more difficulties in communication skills.

Table 3-3. Spearman’s correlations between intensity discrimination, the AASP and CC-SR questionnaires for the ASD group.

<table>
<thead>
<tr>
<th>Intensity discrimination</th>
<th>CC-SR Language structure</th>
<th>CC-SR Pragmatics</th>
<th>CC-SR Social Engagement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>-</td>
<td>.294</td>
<td>.426*</td>
</tr>
<tr>
<td>AASP Low registration</td>
<td>.512*</td>
<td>-.321</td>
<td>-140</td>
</tr>
<tr>
<td>AASP Sensation seeking</td>
<td>.505*</td>
<td>.056</td>
<td>0</td>
</tr>
<tr>
<td>AASP Sensory sensitivity</td>
<td>.073</td>
<td>-.410*</td>
<td>-.212</td>
</tr>
<tr>
<td>AASP Sensation avoiding</td>
<td>-.392*</td>
<td>-.424*</td>
<td>-.745**</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05
** Correlation is significant at the 0.01
3.4.3 Partial correlations

In the ASD group, with the exception of the relationship between frequency discrimination and Low registration, frequency and duration discrimination abilities did not correlate with any measure of auditory sensory behaviours or communication skills (all \( p > .05 \)). Moreover, the relationship between Sensation avoiding and intensity discrimination remained significant when VIQ, PIQ and FIQ were partialled out. To explore the contribution that intensity discrimination and sensory avoiding behaviours had on pragmatic skills in ASD, two partial correlations were calculated. One, between intensity discrimination and Pragmatic skills controlling for Sensation avoiding and the other, between Sensation avoiding and Pragmatic skills controlling for intensity discrimination (see Figure 3-1). These correlations revealed that while the correlation between Sensation avoiding and Pragmatic skills remained highly significant even when controlling for intensity discrimination \((r = -.69, p = .002)\), the correlation between intensity discrimination and Pragmatic skills when controlling for Sensation avoiding was no longer significant \((r = .20, p > .05)\). This pattern of results suggests that it is sensory avoiding behaviours rather than auditory perceptual ability *per se* that influence pragmatic ability.
Figure 3-1. Illustration of patterns of bivariate and partial Spearman’s correlations for sensation avoiding behaviours and intensity discrimination ability associations with pragmatic skills in ASD.

3.5 Discussion

The prediction that auditory perceptual processing would be related to the degree of self-reported auditory sensory behaviours (Jones et al., 2009) and communication skills in ASD was confirmed by our findings. Overall, a pattern of relations emerges with one of the ADTs (intensity discrimination) to the exclusion of the other two (frequency and duration discrimination). Intensity discrimination correlates both with three of the auditory sensory behaviour quadrants (Low registration, Sensation seeking, Sensation avoiding) and one composite of the communication skills (Pragmatic skills).
Specifically, we found that good performers on the intensity discrimination task reported worse pragmatic skills as well as more auditory sensory behaviours associated with under-responsiveness to auditory input and actively avoiding auditory stimulation (see also Bogdashina, 2003). Moreover, the correlation values indicate that the effect sizes for these associations were large.

Interestingly, Jones and colleagues (2009) also reported an association between intensity discrimination and sensory avoiding behaviours although in the opposite direction. A possible explanation for this reversed pattern might lie in differences between the two studies on the auditory intensity parameters of the ADTs. Specifically, although both studies utilized similar ADTs, (e.g. nature of the stimuli, type of discrimination, stepwise procedure, feedback), in the present study the probe stimulus was 55dB and the standard 74db compared to a 81.1 dB probe stimulus and a 73dB standard stimulus in Jones et al., (2009). This means that intensity discrimination trials in Jones and colleagues were presented at louder levels compared to our intensity discrimination task. Thus, it is likely that individuals hypersensitive to loudness would demonstrate superior performance in our ADT in comparison to their performance in Jones et al’s ADT (2009). This would explain the opposite findings of the two studies and support the suggestion that hypersensitivity to loudness (hyperacusis) is related to more auditory sensory avoiding behaviours.

In contrast to their findings, about a positive association between good performance in duration discrimination and auditory sensory behaviours across all AASP quadrants, we did not find any significant correlations between duration discrimination and auditory sensory behaviours. Further, in contrast to Jones et al we did find an association between frequency discrimination and auditory sensory behaviours associated with under-responsiveness to auditory information. A potential
explanation for the differences between the results produced by the only two studies to explore the associations between auditory perceptual processing and auditory sensory behaviours in ASD might lie in the considerable variability in ASD that is frequently reported in several domains, for example in language and communication skills (e.g., Kjellmer, Hedvall, Fernell, Gillberg & Norrelgen, 2012), auditory discrimination ability (Kargas et al., 2014) and sensory behaviours (e.g., Bogdashina, 2003). Conceptualizing perceptual abilities and sensory behaviours in autism as stable over time rather than as developmentally changing as part of a developmental condition (which after all is what autism is), may also lead to contradictory findings (see also, López, 2013; Valla & Belmonte, 2013). Another potential explanation, therefore, might be based on the different age characteristics of the two studies. For example, our participants were adults with ASD whereas in Jones et al., (2009) the participants were adolescents.

Our findings about auditory sensory behaviours were consistent with our hypothesis and largely, with the pattern of results found by Jones et al. (2009). However, although both groups in the present study reported more auditory sensory behaviours than in the Jones study (ibid), the ASD group reported twice as many as the control participants, an increased group difference that may be due to the greater chronological age in the present study. Atypical sensory sensitivities in ASD have been found to be present at infancy (e.g., Annaz et al., 2010; Baranek, 1999; Landa & Garrett-Mayer, 2006) and persist into adulthood (Crane et al., 2009), but there are no studies directly comparing age effects in this domain and we still do not know whether sensory atypicalities get worse, remain the same or get better with chronological age.

Our hypothesis that auditory sensory behaviours are related to communication skills in ASD was confirmed. Specifically, significant negative correlations indicated that individuals who detect more auditory sensory input (Sensory sensitivity) and/or
have more difficulties to cope with auditory sensory input than others (Sensation avoiding) also reported poorer skills on linguistic aspects of language (Language structure). Moreover, individuals with ASD with more Sensory sensitivity behaviours reported poorer skills on nonverbal aspects of communication and interests (Social engagement), whereas those who experience more Sensation avoiding behaviours reported fewer expressive pragmatic behaviours (Pragmatic skills). The large effect sizes of the correlations between communication skills and Sensory sensitivity and Sensation avoiding suggest that idiosyncratic auditory sensory processing sensitivities may have an important influence in the manifestation of language and communication impairments in ASD.

The finding, through partial correlations, that the key association with Pragmatic skills lay in Sensation avoiding behaviours rather than in intensity discrimination supports clinical observations of the central importance of sensory behaviours as internal subjective sensory experiences (e.g., Bogdashina, 2003; Robledo, 2012). These may play a causal role in the development of aversive practices, such as the avoidance of noisy social settings and consequently may have a negative impact on the development of pragmatic communication skills. We propose a two-step model for the strong associations between intensity discrimination, Sensation avoiding behaviours and poor Pragmatic skills. Initial hyperacusis (common in ASD, Iarocci & McDonald, 2006; Khalfa et al., 2004) may be responsible for the enhanced perception of intensity (loudness) that contributes to the development of auditory sensory behaviours associated with avoiding loud contexts, which result in the expressive pragmatic difficulties observed in ASD. Future research is needed in order to test this explanation and develop adequate theories of socio-communicative abilities in ASD.
Our findings of greater difficulties in the ASD group (compared to the TD group) on aspects of Pragmatic skills and Social engagement supported our predictions. However, our findings challenge beliefs about intact language structure ability in ASD. Some linguistic aspects of language, such as syntax, in the ASD group were reported as significantly poorer compared to the TD group. Interestingly, in recent years, findings on the structural aspects of language in children with ASD have been somewhat contradictory (e.g., Boucher, 2012b) as for instance in syntactic ability and semantic skills (for a review see Eigsti et al., 2011).

The fact that the majority of research on communicative ability in ASD has focused on children and adolescents is surprising, given its elements develop across the life span. For example, although cognitive functions such as memory decline with age, verbal knowledge is increased (Park et al., 2002) and older adults may be better able to use context to extract meaning (Pichora Fuller, Schneider & Daneman, 1995) as everyday life experience compensates for the cognitive decline. The linguistic input children receive promotes learning and is crucial for pragmatic, grammatical and syntactic development (e.g., Huttenlocher, Vasilyeva, Cymerman & Levine, 2002). Another vital reason for enhancing our understanding on the communicative difficulties that adults with ASD experience is that they may potentially become parents and this may have important repercussions for the communicative development of their children. In fact, previous research on the speech of first-degree relatives of people with ASD has shown that their verbal skills are less pragmatically and grammatically complex compared to relatives of people with other psychiatric conditions (e.g., Landa et al., 1992). Thus, we suggest that it is critical to clarify the nature of the interplay between the roles of initial neurobiological abilities in children with ASD, their socio-behavioural experience and their linguistic environment in order to enhance our
understanding about how social communication deficits develop over time. We propose the possibility that although the delayed acquisition of linguistic features of language appears to develop in a typical fashion in children with ASD, it might not improve typically during adulthood or may even decline with age.

It is important to point out that we used self-reported questionnaires as measures of communication skills and auditory sensory behaviours, and there are often limitations to self-report data, as it relies on the participants’ ability to recall and verbalise their own experiences. However, in recent years self-reported data has become a common method for studies in adults with ASD (e.g., Crane et al., 2009; Robertson & Simmons, 2013; Woodbury-Smith, Robinson, Wheelwright & Baron-Cohen, 2005) especially of those with high-functioning ASD. Moreover, researchers have pointed out the need for integrating individuals with ASD in the process of research and the importance of taking into account evidence from the person’s own perspective (e.g., Mottron, 2011). Also, due to the nature of our study we were particularly interested in the subjective sensory experiences of our participants as they may have developed compensatory coping strategies, which could mislead observations of sensory sensitivities by third parties. Future research should utilize both self-reported and objective measures of sensory sensitivities and communication skills.

3.5.1 Conclusion

The current study provides the first behavioural evidence showing that the relationship between auditory perceptual processing and auditory sensory behaviours may contribute to the development of expressive pragmatic ability in ASD. Specifically, auditory sensory avoiding behaviours were associated with expressive pragmatic skills. Moreover, we proposed that atypical auditory sensory behaviours in ASD might stem
from idiosyncratic differences on low-level auditory perceptual sensitivity to intensity. We suggest that further research on the developmental relationships between domain-specific perceptual abilities and sensory processing sensitivities across modalities is essential in order to expand our understanding about the causal influence these associations may have on the genesis of autistic symptomatology. This study provides supporting evidence for the suggestion that auditory sensory behaviours persist well into adulthood and that linguistic aspects of structural language may be poorer in adults with ASD.
3.6 References


and 12 months. *Developmental Science, 9*(2), 13–21. doi:10.1111/j.1467-7687.2006.00468.x


4 THE RELATIONSHIPS AMONG AUTISTIC TRAITS, AUDITORY SENSORY BEHAVIOURS AND AUDITORY PROCESSING IN THE GENERAL POPULATION

4.1 Abstract

Although sensory processing atypicalities are part of the new diagnostic criteria for autism spectrum disorders (ASD), little is known about the underpinnings of this relationship and whether these sensory issues are part of the broader autism phenotype (BAP) in the typical population. Autistic traits, auditory sensory behaviours and auditory processing skills were assessed in 86 typically developing adults, using the Autism Quotient (AQ), the Adults/Adolescent Sensory Profile (AASP) and three low-level auditory discrimination tasks (intensity, frequency, duration). As predicted, the level of autistic traits was related to the degree of auditory sensory behaviours. Furthermore, our results indicate that the pattern of relationships among intensity discrimination, sensation avoiding behaviours and communication skills, previously found in individuals with ASD, also extends into the typical population with high levels of autistic traits. We suggest that this association may represent a specific developmental ASD phenotype.

4.2 Introduction

In the latest version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; APA, 2013), autism spectrum disorders (ASD) are defined in terms of qualitative atypicalities in social communication and interaction in the presence of restricted, repetitive patterns of behaviour, interests and activities (RRBs). In addition,
sensory atypicalities have also been included as part of the ASD diagnosis, although it remains unclear what precisely causes these atypicalities or how they are associated with the development of key autistic symptomatology such as social communication (e.g., Crane, Coddard & Pring 2009; Horder, Wilson, Mendez & Murphy 2014; Jones et al., 2009; Leekam Prior & Uljarević, 2011; Mayer, Hannent, & Heaton, 2014; Robertson & Simmons, 2013).

Despite the growing recognition by researchers and clinicians of the crucial role that sensory processing plays in learning, attention, cognitive and brain maturation, emotional regulation, and social communication development in humans (e.g., Ahn, Miller, Milberger & McIntosh, 2004; Bundy, Shia, Qi & Miller, 2007) and reports indicating that over 90% of children and adults with ASD exhibit diverse sensory behaviours (e.g., Chang et al., 2014, see also Crane et al., 2009; Dunn, 1997; Kern et al., 2007; Tomcheck, Huebner & Dunn, 2014), little is known about the relationship between autistic traits and sensory behaviours. While this relationship has been studied in people with ASD (e.g., Crane et al., 2009; Jones et al., 2009; Kargas, López, Reddy, Morris & Sarriá, under review), to date only two studies have investigated these relationships in the general population (Horder et al., 2014; Robertson & Simmons, 2013). Both studies reported that levels of autistic traits are associated with atypical sensory behaviours, suggestive of the existence of a dimensional link between these two factors, even after controlling for family history of ASD, mental illness, anxiety and migraines (Horder et al., 2014). Furthermore, it is reported that sensory behaviours appear to be particularly prevalent in the auditory domain (Roberson & Simmons, 2013), which is consistent with clinical reports on sensory behaviours for people with ASD (e.g., Hermelin & O’Connor, 1970; Ornitz, 1974; Dahlgren & Gillberg, 1989; Rosenhall, Nordin, Sandström, Ahlsen, & Gillberg, 1999).
To date, there is considerable evidence showing that relatives of people with ASD exhibit mild autistic-like behaviours, as for example difficulties in social communication skills (e.g., Piven et al., 1994; Piven & Palmer, 1997; Piven, Palmer, Jacobi, Childress & Arndt, 1997; Constantino et al., 2006) and sensory issues (Marche, Steyaert, & Noens, 2012). In addition, these autistic type tendencies have been suggested to be present in the general population (e.g., Constantino & Todd, 2003; Frith, 1991; Le Couteur et al., 1996). This pattern of findings has stimulated the idea of the existence of a broader autism phenotype (BAP), which suggests that autistic traits are substantially heritable and normally distributed throughout the general population, with clinical cases representing an extreme on a continuous dimension (e.g., Baron-Cohen & Hammer, 1997; Constantino & Todd, 2003; Dawson et al., 2002; Happé, Briskman & Frith, 2001; Le Couteur et al., 1996; Lord, Cook, Leventhal & Amaral, 2000; Piven & Palmer, 1999).

The most widely used questionnaire to assess the degree of autistic traits in the general population is the Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001). The AQ is a short, easy to use self-administered questionnaire designed to measure the degree to which adults with average or above average intelligence present traits similar to those observed in people with ASD. Although, the AQ is not a diagnostic tool, its use as a screening measure has been clinically tested and is found to be highly reliable and valid in discriminating between people with and without an ASD diagnosis (Hurley et al., 2007; Woodbury-Smith, Robinson, Wheelwright & Baron-Cohen, 2005). Furthermore, previous research shows that autistic traits, as measured by the AQ, are heritable (Hoekstra, Bartels, Verweij & Boomsma, 2007) and stable cross-culturally (Wakabayashi, Baron-Cohen, Wheelwright & Tojo, 2006).
Support for the BAP continuum has been gathered from findings showing that individuals with high-scores on the AQ, relative to low AQ scorers, demonstrate different patterns of correlations with social functioning (Elsabbagh et al., 2011), speech perception (Stewart & Ota, 2008; Yu, 2010), perspective-taking ability (Brunye et al., 2012), cortical structure and functions important for the processing of socially relevant stimuli (von dem Hagen et al., 2011), brain hyper-activity to auditory novel targets (Gomot, Belmonte, Bullmore, Bernard & Baron-Cohen, 2008), neural responses to eye gaze (Nummenmaa, Engel, von dem Hagen, Henson & Calder, 2012), personality traits (Austin, 2005) and with a variety of visual processing tasks (Bayliss & Kritikos, 2010; Grinter, Van Beek, Maybery & Badcock, 2009; Grinter et al., 2009; Stewart, Watson, Allock & Yaqoob, 2009; Sutherland & Crewther, 2010). Investigating how individual variation in autistic traits in the typical population predicts differences in perceptual, cognitive, neural and social functions could assist in identifying factors that contribute to the development of ASD as well as the categorization of the BAP (e.g., Austin, 2005; Stewart et al., 2009; Nummenmaa, et al., 2012; von dem Hagen et al., 2011).

To our knowledge, the association between autistic traits and low-level auditory discrimination skills in the typical population remains unexplored. This information is of great importance for two main reasons. The first reason is based on evidence indicating links between auditory processing abilities and other developmental variables in ASD. For instance, the degree of RRBs significantly correlates with intensity and frequency discrimination skills in adults with ASD (Kargas, López, Reddy & Morris, 2014) and a link between primary auditory processing and auditory sensory behaviours is suggested in the literature (Jones et al. 2009; Kargas, et al., under review). For example, sensation avoiding behaviours are related to coping with loud (intensity) sounds in adolescents and adults with ASD (Jones et al., 2009; Kargas et al., under
review) whereas an association of these two variables with pragmatic communicative
skills is reported in adults with ASD (Kargas et al., under review). Furthermore, several
studies have found important associations of enhanced frequency perception with good
language skills (Heaton, Davies & Happe, 2006), intelligence (e.g., Heaton, Williams,
Cummins, & Happé, 2008; Jones et al., 2009; Kargas et al., 2014) and delay onset of
first words in ASD (Jones et al., 2009). In addition, atypical sensory experiences are
associated with the development of language and socio-communicative ability in infants
and children with ASD (e.g., McCleert, Elliott, Sampanis & Stefanidou, 2013; for a
review see Watson et al., 2011) whereas primary auditory processing abilities are linked
to language acquisition and communicative ability in typical development (e.g., Cutler,
Oahan, & van Donselaar, 1997; Matychuk, 2005; Mehta & Cutler, 1988; Murray, 1992;
It is therefore important to investigate whether the relationship between autistic traits
and auditory perceptual sensitivities extend into the typical population and if they are
indicative of a specific BAP phenotype.

The second reason for studying auditory processing skills in relation to autistic
traits is based on the fact that the current literature on low-level auditory perception in
ASD presents a complex picture, characterized by contradictory reports (for reviews on
behavioural and neurophysiological findings see Haesen, Boets & Wagemans, 2011;
O’Connor, 2012; Samson, Mottron, Jemel, Belin, & Ciocca, 2006). For instance, there
are reports of individuals with ASD outperforming (e.g., Bonnel et al., 2003; Heaton et
al., 2008), matching (e.g., Bonnel et al., 2010; Jones et al., 2009) or demonstrating
poorer frequency discrimination skills (Kargas et al., in press) than comparison groups.
These inconsistencies are suggested to stem from the variability in the populations
studied (e.g., Heaton et al., 2008; Jones et al., 2009), the considerable variation in
auditory tasks (e.g., Marco, Hinkley, Hill & Nagarajan, 2011; Samson et al., 2006) and the high variability of primary auditory perceptual skills in people with ASD (Kargas et al., 2014). Investigating how low-level auditory processing abilities are represented in the typical population could potentially help us clarify previous inconsistencies in the findings on auditory processing abilities in ASD and shed some light about the role that auditory perception plays in the expression of key autistic behaviours.

Concisely, despite the fact that atypical auditory processing abilities are frequently found in the literature of ASD (for reviews see Haesen et al., 2011; O’Connor, 2012; Samson et al., 2006) and reports indicating that atypical sensory experiences are particularly prevalent in the auditory domain both in individuals with and without ASD (e.g., Rosenhall et al., 1999; Robertson & Simmons, 2013), the relationships among autistic traits, auditory perception and related sensory behaviours and communicative ability in the general population remain unexplored. This information is of great importance because it will contribute to our understanding about the development of autistic symptoms as well as in the characterisation of the BAP (e.g., Austin, 2005; Stewart & Ota, 2008). Therefore, the primary goal of the current paper is to explore whether the aforementioned associations are represented in the general population using a large sample of typically developing adults.

In the current study the associations among autistic traits, auditory perception and related sensory behaviours were investigated using the AQ (Baron-Cohen et al., 2001) and the Adolescent/Adult Sensory Profile (AASP; Brown & Dunn, 2002) questionnaires together with three low-level auditory discrimination tasks (ADTs) for intensity, frequency and duration (Kargas et al., 2014; Leong, Hämäläinen, Soltész & Goswami, 2011). Based on previous relevant findings, it was hypothesized that typically developing adults with high scores on the AQ would report more auditory
sensory behaviours relative to low AQ scorers (Horder et al., 2013; Robertson & Simmons, 2013). Furthermore, given previous findings in ASD (Kargas et al., under review), it was predicted that communicative ability as measured by the AQ would significantly correlate with auditory sensory avoiding behaviours and good performance on the intensity task in the high-scorers AQ group. Finally, in an attempt to clarify previous inconsistencies across findings of low-level auditory processing abilities in ASD, the relationship between autistic traits and low-level auditory discrimination abilities in the general population was explored.

4.3 Methods

4.3.1 Participants

Eighty-six typically developing adult participants were recruited from the general population through the University of Portsmouth participant pool and local social groups. Ethical approval was sought from the University of Portsmouth, Psychology Department Ethics Committee. The participants included 53 females ($M = 28$ years 3 months, $SD = 9.9$ years) and 33 males ($M = 32$ years 4 months, $SD = 11.2$ years). In total, there were more female participants (61.6%) than males (38.4%) in the sample. Chronological age did not differ between genders ($M$ males = 29 years; $M$ females = 32 years; $t(84) = -1.74, p > .1$). The exclusion criteria included psychiatric or developmental diagnoses and pharmacological treatments. Also, participants received a short hearing test for the standard range of frequencies (250-8000 Hz) using an audiometer to confirm that they had normal auditory acuity (i.e. hearing thresholds in the range of 0 to 25 dB). Furthermore, only participants who self-reported no prior formal musical training were included in the study. Finally, all participants completed
the AQ (Baron-Cohen et al., 2001) and the AASP (Brown & Dunn, 2000) questionnaires as well as three low-level ADTs.

4.3.2 Materials

4.3.2.1 Autism-spectrum quotient

The AQ (Baron-Cohen et al., 2001) consists of 50 self-descriptive statements where participants are required to indicate the degree to which they agree or disagree on a four-point Likert scale (i.e., definitely agree, slightly agree, slightly disagree, definitely disagree). Responses are coded as 1 for the autistic-like behaviours and as 0 in the non-autistic direction with total scores ranging from 0 to 50. In the original AQ study, people within the autistic spectrum (80%) produced a total score of 32 or more whereas the mean AQ score for the typically developing participants was 16.4 (Baron-Cohen et al., 2001). Hence, in the current study the value of 16 was chosen to differentiate between ‘high’ and ‘low’ scorers. As a result there were 33 participants who produced a score between 17 and 32 (high-scorers’ group) and 53 individuals who scored between 0 and 16 (low-scorers’ group).

The test is also designed to assess five different components associated with the BAP: communication (e.g., “I frequently find that I don’t know how to keep a conversation going”), social skills (e.g., “I would rather go to a library than a party”), attention switching (e.g., “I frequently get so absorbed in one thing that I lose sight of other things”), attention to detail (e.g., “I usually notice car number plates or similar strings of information”) and imagination (e.g., “When I’m reading a story, I find it difficult to work out the characters’ intentions”). Thus, the AQ’s subscale of
communication was used to investigate the relationship among auditory discrimination ability, auditory sensory behaviors and communicative abilities in the present sample.

4.3.2.2 Auditory sensory behaviours

All participants completed the AASP (Brown & Dunn, 2002). The AASP is a 60-item self-report questionnaire measuring levels of sensory processing in daily life across sensory modalities (e.g., auditory, visual, olfactory). However, due to the nature of our investigation only the auditory items were included. The AASP is based on Dunn’s (1997) model of sensory processing, which suggests that the perceptual process is characterized by four sensory processing patterns, that is two dimensions of neurological thresholds (high – low) and two dimensions of self-regulation strategies (active – passive). Neurological thresholds are defined as the amount of auditory sensory input (high – low) the neuron system requires for producing a response, whereas, self-regulation strategies refer to the individual’s style of behavioural response (active, passive). Participants are required to indicate the frequency of their behaviours to specific sensory experiences on a five-point Likert scale (i.e., almost never, seldom, occasionally, frequently and almost always).

The AASP consists of four orthogonal measures. First the ‘Low registration’ quadrant (e.g., “not noticing when your name is called”) reflects a high neurological threshold, and a passive behavioural response for detecting and responding to auditory sensory input. Second, the ‘Sensation seeking’ quadrant (e.g., “making noises such as humming, signing or whistling”) denotes a high neurological threshold and an active self-regulation strategy. Third, the ‘Sensory sensitivity’ quadrant (e.g., “I am distracted if there is a lot of noise around”) refers to a low neurological threshold and a passive behavioural response. Finally, the ‘Sensation avoiding’ quadrant (e.g., “I stay away
from noisy settings”) is indicative of a low neurological threshold and an active self-regulation strategy. The maximum scores are 10 for sensation seeking and 15 on the other three quadrants. Also, a high score is suggestive of a higher amount of auditory sensory behaviours.

4.3.2.3 Auditory discrimination tasks

The three ADTs (intensity, frequency and duration) were based on previous studies in ASD (Kargas et al., 2014; Kargas et al., under review) and developmental dyslexia (Leong et al., 2011). The auditory stimuli in all three ADTs were presented binaurally through headphones at a hearing level comfortable for the participants (74 dB). Discrimination thresholds were measured using a two-interval forced-choice (2IFC) with 500 ms inter-stimulus interval between tones and 2000 ms inter-trial interval and a combined 2-up 1-down and 3-up 1-down adaptive staircase procedure (Levitt, 1971). Correct items were randomized across positions (first/second tone). Full details of the auditory parameters of all ADT’s are presented in Table 4-1. The standard stimulus in all ADTs was a pure tone with a frequency of 500 Hz. In the intensity discrimination task, the intensity of the second tone ranged from 55 dB to 73.5 dB and the participants were asked to discriminate which tone was ‘louder’. In the frequency discrimination task the maximum pitch difference between the stimuli presented was 60 Hz and the participants were asked to decide which tone was ‘higher’ in frequency. In the duration discrimination task the standard stimulus had 400 ms duration and the other tones ranged between 600 ms to 410 ms. In this task participants were required to decide which tone was ‘longer’. It is worth pointing out that a low threshold (i.e., a score close to 0) is indicative of optimal performance.
Table 4-1. Parameters of the three auditory discrimination tasks (ADTs).

<table>
<thead>
<tr>
<th></th>
<th>Intensity</th>
<th>Frequency</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard stimuli</td>
<td>74 dB</td>
<td>500 Hz</td>
<td>400 ms</td>
</tr>
<tr>
<td>Starting probe</td>
<td>55 dB</td>
<td>560 Hz</td>
<td>600 ms</td>
</tr>
<tr>
<td>Lowest difference between probes</td>
<td>.5 dB</td>
<td>.8 Hz</td>
<td>5 ms</td>
</tr>
<tr>
<td>Intensity</td>
<td>Variable</td>
<td>74 dB</td>
<td>74 dB</td>
</tr>
<tr>
<td>Frequency</td>
<td>500 Hz</td>
<td>Variable</td>
<td>500 Hz</td>
</tr>
<tr>
<td>Duration</td>
<td>200 ms</td>
<td>200 ms</td>
<td>Variable</td>
</tr>
<tr>
<td>ISI</td>
<td>500 ms</td>
<td>500 ms</td>
<td>500 ms</td>
</tr>
</tbody>
</table>

4.3.3 Experimental procedure

The study was carried out in an approximately one hour testing session. Initially, participants were tested individually on the three ADTs. Testing took place in a quiet room and the stimuli were presented via closed cup headphones (HD-3030). The order of the ADTs was counterbalanced across participants. After each experimental procedure participants were given rest breaks in order to ensure that performance was not reduced due to tiredness and fatigue or loss of interest. To ensure that participants were familiar with each task, five practice trials representing different levels of difficulty were given prior to formal testing. All participants understood the procedure at the end of the practice and reported that they had no problems performing the tasks. After completion of the ADTs participants were asked to complete the AQ and AASP questionnaires. A trained experimenter was available to answer participants’ questions. Finally, participants were informed that they could terminate their participation at any
time without any negative consequences and they also received five pounds as a thank you for their participation.

4.4 Results

4.4.1 Sample characteristics

Scores on the AQ, AASP’s quadrants and auditory discrimination thresholds were explored to test that assumptions of normality were met. Shapiro-Wilk’s tests and a visual inspection of their histograms, normal q-q plots and box plots showed that with the exception of duration discrimination, scores on the relevant variables were not normally distributed (all $p < .05$). Thus, non-parametric methods were employed to explore group differences and associations between variables. However, it is worth noting that the same pattern of results was obtained using parametric analyses.

4.4.2 Associations of AQ full scale scores with AASP scores and ADTs thresholds.

Consistent with the predictions, Spearman correlation analysis revealed positive moderate correlations between scores on the full scale AQ and scores in Low registration ($r = .37, p < .001$), Sensory sensitivity ($r = .44, p < .001$), and Sensation avoiding ($r = .38, p < .001$), indicating that high levels of autistic traits were associated with more sensory behaviours reflecting hypo/hyper sensitivities. Also, a negative significant correlation was revealed between autistic traits and Sensation seeking ($r = -.25, p < .05$), indicating that high scores on AQ were associated with lower scores on Sensation seeking. Furthermore, the same pattern of correlations (albeit weaker) was found between the AQ’s subscale of communication and the AASP’s quadrants: Low
registration ($r = .30, p < .01$), Sensation sensitivity ($r = .22, p < .05$), Sensation avoiding ($r = .28, p < .01$) and Sensation seeking ($r = -.19, p < .05$).

In terms of the relationships between AQ scores and auditory threshold scores in the three ADTs, only duration discrimination was significantly negatively correlated with AQ full scale scores ($r = -.27, p < .05$) and with the AQ’s communication subscale ($r = -.16, p < .05$), indicating that individuals with high AQ scores demonstrated better performance on detecting temporal differences between auditory stimuli. However, it is worth pointing out that the levels of these correlation coefficients represent a weak association.

4.4.3 Relationship between ADTs and AASP’s quadrants

Spearman’s correlations were performed between low-level auditory thresholds and auditory sensory profiles. These correlations revealed significant negative relationships between duration discrimination and two of AASP’s quadrants, Low registration ($r = -.25, p < .05$) and Sensation avoiding ($r = -.24, p < .05$), indicating that good performance on duration discrimination was associated with higher scores in these two quadrants. The correlations between AASP’s quadrants and intensity or frequency discrimination did not reveal any significant relationships.

4.4.4 AQ subgroups sample characteristics

In order to discern which ranges of AQ scores were driving the aforementioned correlations, AQ scorers were divided into two groups (Low-scorers = 0 – 16, $n = 53$; High-scorers = 17 – 32, $n = 33$). Although, they were more female than male participants in the whole sample, the ratios of gender differed between the two AQ subgroups, indicating that in contrast to female participants, males were more likely to
produce a high AQ total score (17+) (Low-scorers: M = 32%, F = 68%; High-scores: M = 49%, F = 51%). Consistent with previous reports (e.g., Baron-Cohen et al., 2001) a series of Mann-Whitney $U$ tests revealed that the difference in the degree of autistic traits in males, compared to females was significant ($U = 625, z = -2.21, p < .05, r = .44$). Also, consistent with previous research (Horder et al., 2014; Roberston & Simmons, 2013), there were no significant differences between males and females on self-reported auditory sensory behaviours (all $p > .1$). Chronological age did not differ between the two AQ subgroups (Low-scorers $M = 30$ years; High-scores $M = 31$ years; $t(84) = -.618, p > .5$).

4.4.5 AQ subgroup differences

A series of Mann-Whitney $U$ tests was conducted to explore group differences in the AASP’s quadrants and the three ADTs (see Figure 4-1). Consistent with the hypothesis, the results demonstrated that the group of high AQ scorers reported more auditory sensory behaviours across all AASP quadrants, Low registration ($U = 581, z = -2.64, p < .01, r = .58$), Sensation seeking ($U = 636, z = -2.16, p < .05, r = -.51$), Sensory sensitivity ($U = 521, z = -3.14, p < .001, r = .67$) and Sensation avoiding ($U = 637, z = -2.12, p < .05, r = .51$), compared to the group of low AQ scorers (with substantial effect sizes). In terms of auditory discrimination abilities the results did not reveal any significant differences between subgroups on performance in the ADTs (i.e., intensity ($p = .92$), frequency ($p = .80$ and duration ($p = .47$)).
Figure 4-1. Mean scores on the auditory Adolescent/Adult Sensory profile quadrants (AASP) in the two AQ subgroups.

4.4.6 Associations of AQ communication scores with AASP auditory quadrants and ADT performance in the two AQ subgroups.

Based on the findings of Kargas et al (under review), Spearman’s correlations were performed in each AQ subgroup among scores on AQ’s communication composite, auditory sensory quadrants and the three ADTs to explore whether there was a different pattern of correlations between high and low AQ scorers. As can be seen in Table 4-2,
in the high-scorers’ AQ subgroup the correlations revealed significant positive relationships between AQ communication and AASP Sensation avoiding measures \( (r = .34, p < .05) \) and Low registration \( (r = .37, p < .05) \). Specifically, higher scores on the AQ’s communication composite (indicative of poor communication skills) were associated with higher scores on sensation avoiding behaviours (indicative of hypersensitivities) and Low registration (indicative of hyposensitivities). Interestingly, in the low AQ scorers there were no significant correlations between the AQ’s communication measure and the AASP’s quadrants. These results are consistent with previous findings indicating that high AQ scorers report more atypical reactions (both hyper/hyposensitivities) to sensory input than low AQ scorers (Robertson & Simmons, 2013).

Spearman’s correlations between AQ’s communication composite and the three ADTs revealed significant negative relationships with intensity \( (r = -.34, p < .05) \) and duration \( (r = -.56, p < .001) \), indicating that poor communication skills are associated with lower threshold scores (indicative of good performance and greater sensitivity) on intensity and duration discrimination. In contrast, there were no significant correlations between the three ADT’s, in the AQ subgroup of low-scorers.
Table 4-2. Spearman’s correlations among AQ’s communication and social skills composites and AASP’s quadrants and ADTs across groups.

<table>
<thead>
<tr>
<th>AQ Communication</th>
<th>High-group</th>
<th>Low-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low registration</td>
<td>.37*</td>
<td>.001</td>
</tr>
<tr>
<td>Sensation avoiding</td>
<td>.34*</td>
<td>-.047</td>
</tr>
<tr>
<td>Intensity</td>
<td>-.34*</td>
<td>.113</td>
</tr>
<tr>
<td>Duration</td>
<td>-.51**</td>
<td>.052</td>
</tr>
<tr>
<td>Frequency</td>
<td>-.03</td>
<td>.10</td>
</tr>
<tr>
<td>Sensation Seeking</td>
<td>-.30</td>
<td>.24</td>
</tr>
<tr>
<td>Sensory Sensitivity</td>
<td>.06</td>
<td>-.03</td>
</tr>
</tbody>
</table>

* Correlation significant at $p < .05$

** Correlation significant at $p < .01$

4.4.7 Relationships between ADTs and AASP’s quadrants in the two AQ subgroups

To further explore whether there was a different pattern of correlations between ADTs and AASP’s quadrants in each AQ subgroup, Spearman’s correlations were performed separately for high and low AQ scorers. These correlation analyses revealed that in the high AQ subgroup, only duration discrimination was significantly correlated with Low registration ($r = -.44, p < .01$) and Sensation avoiding ($r = -.32, p < .05$). Also, it is worth mentioning that there was a non-significant trend for an intensity discrimination and Sensation avoiding correlation ($r = -.23, p = .09$). In contrast, in the low AQ subgroup the only significant relationship found was a negative correlation between duration discrimination and Sensory sensitivity ($r = -.26, p = .05$), indicating that good
performance on duration discrimination is associated with more behaviours reflecting the ability to notice sounds in the environment.

4.4.8 Regression analyses

In order to examine the extent to which the variables identified as AQ Communication correlates in the high AQ group accounted for the variance in the scores in the two AQ subgroups, separate multiple linear regressions were performed on the two groups. The dependent variable was the AQ Communication scores and the predictor variables were the participants’ score on the low registration and sensation avoiding quadrants of AASP and their threshold scores on intensity and duration discrimination.

The results revealed a significant linear relationship between AQ Communication scores in the high AQ group and the predictor variables \[ F = (4, 28) = 3.995; \ p = .011; \ \text{adjusted } R^2 = .272 \]. This indicates that approximately 27% of the variability in the high AQ group on their AQ communication scores was predicted by the model. In contrast, there was no significant linear relationship between AQ Communication scores in the low AQ group and the predictor variables \[ F = (4, 48) = .231; \ p = .920; \ \text{adjusted } R^2 = -.063 \]. Finally, none of the predictor variables individual scores significantly predicted scores on AQ Communication in either AQ subgroups.

Discussion

The findings of the current study confirmed previous reports that autistic traits are associated with self-reported sensory experiences in the typical population (Horder et al., 2014; Robertson & Simmons, 2013). Specifically, it was found that in comparison with individuals scoring low on the AQ (Baron-Cohen et al., 2001), high AQ scorers reported more frequent and extreme auditory sensory behaviours across all measures of
the AASP (Brown & Dunn, 2002). Our study extends previous research by providing evidence about the associations among autistic traits, low-level auditory discrimination abilities and auditory sensory behaviours. These correlations revealed that only good performance on duration discrimination was associated with higher levels of autistic traits and more auditory sensory behaviours reflecting both hypo-sensitivities (i.e., Low registration) and hyper-sensitivities (i.e., Sensation avoiding) responses to sensory input. In addition, as predicted, AQ subgroup analyses showed that communicative ability in the high AQ subgroup was significantly correlated with good performance on intensity discrimination and greater degree of auditory sensory avoiding behaviours (Kargas et al., under review). However, unlike in ASD samples, we also found a significant correlation between duration discrimination and AQ communication scores. In contrast, we did not observe any significant correlations in the low AQ subgroup. To our knowledge, this is the first direct demonstration indicating that the relationships among autistic traits, primary auditory perception, sensation avoiding behaviours and communicative ability extend in the typical population.

In terms of the relationships between auditory processing abilities and auditory sensory behaviours our results support previous relevant findings in ASD (Jones et al., 2009; Kargas et al., under review). The current study utilized the similar auditory paradigms and assessed auditory sensory behaviours using the same questionnaires as in Jones et al. (2009) and Kargas et al. (under review), however we found a moderately different pattern of associations. Specifically, consistent with previous findings (Jones et al., 2009; Kargas et al., under review) we did not observe any significant associations between frequency discrimination and auditory sensory behaviours in both high and low AQ scorers (although Kargas et al. reported an association with under-responsiveness to auditory information in their ASD group only). Combined, these results suggest that
frequency perception is not an important contributor to more extreme responses to auditory sensory input observed in people with ASD and in general population.

Similar to the two previous relevant studies (Jones et al, 2009; Kargas et al., under review), we found that intensity discrimination abilities did not relate to the degree of auditory sensory behaviours in typically developing individuals. However, both previous studies reported an association between intensity discrimination and sensation avoiding behaviours in the ASD population. Interestingly, although we failed to find this relationship in the whole sample, there was a non-significant trend of a correlation in the high AQ scorers’ subgroup but not in the low AQ scorers. The fact that we observed a connection between intensity discrimination and sensory behaviours associated with coping with loud sounds in the high-scores AQ subgroup, albeit non-significant, indicates that a similar but more substantial relationship could be found in ASD. Therefore, we suggest that this association appears to be normally distributed throughout the general population and to represent an important BAP characteristic.

In the current sample only duration discrimination was correlated with AASP’s Low registration and Sensation avoiding quadrants in the high-scorers’ AQ subgroup and with sensory sensitivity in the low-scorers’ AQ subgroup. Interestingly, the latter association was also found in Kargas et al.’s (under review) typically developing control group. However, in Jones et al. (2009) it was found that good performers on duration discrimination reported more auditory sensory behaviours across all measures of the AASP whereas in Kargas et al. (under review) there were not any significant correlations between duration discrimination and auditory sensory behaviours in the ASD. Therefore, our results of correlations in the high AQ scorers partly contrast with both studies. Taken together, the findings of the aforementioned studies represent a
complex picture of the associations between time perception and auditory sensory behaviours in people with ASD or autistic traits.

One possible explanation for these dissimilarities in the findings may be that these relationships are mediated by other factors. For example, they might relate to the way that duration information is processed at the neurological level. Specifically, in contrast to intensity and frequency auditory input that are both represented in the auditory cortex (Lockwood et al., 1999), duration is processed in the basal ganglia, an area highly important for both perceptual and motor timing that requires the intervention of different memory modes (for reviews see Coull, Cheng & Meck 2011; Jones & Jahanshahi, 2009; Meck, Penney & Pouthas, 2008; Nayate, Bradshaw & Rinehart, 2005). Thus, performance on duration discrimination may be influenced by memory ability. To date, the literature on memory functioning in ASD has produced a complex picture (e.g., Bowler & Boucher, 2008; Mayes & Boucher, 2008; Minshew & Goldstein, 2001). However, several studies indicate that individuals with ASD exhibit memory difficulties when processing temporal-contextual information (e.g., Boucher, 2001; Bowler & Boucher, 2008; López & Leekam, 2003; Poirier, Martin, Gaigg & Bowler, 2011). Interestingly, although several studies in ASD, using a variety of auditory temporal processing paradigms, have reported findings for diminished abilities in time perception (e.g., Alcántara, Cope, Cope, & Weisblatt, 2012; Alcántara, Weisblatt, Moore, & Bolton, 2004; Groen et al., 2009; Lepistö et al., 2006; Kargas et al., 2014; Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011), others have failed to replicate these findings (e.g., Jones et al., 2009; for review see O’Connor, 2012). We suggest that future studies on time perception and its associations with auditory sensory behaviours could benefit from including measures of memory ability. Finally, although
speculative, we suggest that the current findings are in line with the time processing deficit hypothesis in ASD (see also Poirier et al., 2011).

Interestingly, it has previously been suggested that in contrast to non-ASD groups, communicative ability in ASD groups is associated with sensation avoiding behaviours and intensity discrimination skills (Kargas et al., under review). The present study replicated this finding using a normative sample. Specifically, it was shown that in the high-scorers’ AQ subgroup, but not in the individuals with low AQ scores, poor communicative skills as measured by the AQ were significantly correlated with more sensation avoiding behaviours and better performance on intensity discrimination. In addition, in contrast to low-scores’ AQ subgroup, in the high AQ subgroup we found a significant relationship between duration discrimination and AQ communication scores. However, this latter relationship was not observed in Kargas et al. (under review). To our knowledge this is the first empirical evidence showing that the associations of autistic-like communication skills with sensory avoiding behaviours and sensitivity to loudness levels also extends into the typical population, indicating that they may represent a specific ASD phenotype. Also, we suggest that further research is needed to clarify whether the association between duration discrimination and communication also extends into the clinical cases of ASD or an exclusive characteristic of people with high levels of autistic traits.

The aforementioned findings have also important implications for research methodologies in ASD. To date, research in ASD has been predominately investigating behaviours and abilities independently from each other. However, the developmental nature and heterogeneity of autistic symptomatology calls for the utility of interactive multimodal developmental research approaches. For example, it is possible that initial idiosyncratic auditory sensory processing sensitivities (i.e., hyper and hypo) could have
important repercussions to social behaviour, which develop over time into fixed neural and behavioural patterns that influence the development of language and communication abilities. In fact, it has been proposed that conceiving perceptual abilities and sensory behaviours in ASD as static over time rather than being developmentally changing, could also result in contradictory findings (Kargas et al., 2014; Kargas et al., under review). Specifically, Karmiloff-Smith (2009) impressively demonstrates the necessity for understanding the developmental trajectories in specific domains in order to discern the nature of autistic behaviours (see also Valla & Belmonte, 2013). For instance, the developmental trajectory of pitch discrimination ability between individuals with and without ASD differs markedly (Mayer et al., 2014). Specifically, although pitch discrimination ability becomes better over time and correlates with language skills in typical development, in ASD pitch discrimination is enhanced in early development with relative small change over time and it does not correlate with language scores (Mayer et al., 2014). In addition, López, (2013) has emphasized the need of developing theoretical and methodological approaches that take into account socio-environmental factors that influence the developmental trajectories of neurological, cognitive and behavioural autistic symptoms. Therefore, longitudinal studies are needed to assess the interaction among the development of cognitive abilities, sensory behaviours and socio-communication experience across the lifespan in people with ASD.

The present study also explored whether the discrimination abilities of low-level auditory information may be different between high and low AQ scorers. In the current sample, low-level auditory discrimination abilities did not differ between the two AQ subgroups. This finding supports previous studies reporting similar discrimination abilities in low-level ADTs between adolescents or adults with and without ASD.
(Bonnel et al., 2010; Jones et al., 2009). However, overall the literature on auditory processing in ASD is characterized by contradictory findings (for a review see Haesen et al., 2011; O’Connor, 2012; Samson et al., 2006). For example, although there are several behavioural reports indicating that individuals with ASD demonstrate enhanced frequency perception, other studies report intact (Bonnel et al., 2010; Jones et al., 2009) or diminished performance (Kargas et al., 2014) compared to controls. Furthermore, a similar pattern of inconsistent results is found in electrophysiological studies. For instance, studies in individuals with ASD report that mismatch negativity event-related responses of frequency detection are enhanced (Ferri et al., 2003), intact (Ceponiene et al., 2003; Kamner, Verbaten, Cuperus, Camfferman & van Engeland, 1995) or reduced (Gomot et al., 2006; Seri, Cerquiglini, Pisani & Curatolo, 1999).

A possible explanation for these inconsistencies in the results among previous studies that explored the associations between auditory processing and auditory sensory behaviours in people with ASD or ASD traits might be due to the considerable variability of skills that is frequently reported in several domains in ASD (Valla & Belmonte, 2013). For instance, great variability is reported in low-level auditory discrimination abilities (Kargas et al., 2014), sensory behaviours (e.g., Bogdashina, 2003), RRBs (e.g., Leekam et al., 2011) and in language and communication skills (e.g., Kjellmer, Hedvall, Fernell, Gillberg & Norrelgen, 2012).

Another possible explanation may relate to the suggestion that individual differences in auditory processing skills may reflect differences in other abilities. With respect to ASD, there is evidence indicating that auditory performance relates to intelligence levels (e.g., Heaton et al., 2008; Jones et al., 2009; Kargas et al., 2014) and to language or communicative ability (Heaton, Davies & Happe, 2006; Kargas et al., under review). Although, the current study did not assess intelligence and language
skills, due to the majority of the participants being either university students or staff, it seems reasonable to argue that our sample had relatively high IQ and linguistic ability. Thus, the results of similar auditory discrimination skills between high and low AQ subgroups may be linked to the specific characteristics of our sample. Therefore, we propose that participant grouping in research on auditory processing in ASD should give further consideration to the IQ and communicative characteristics of the samples. The investigation of homogeneous subgroups based on these variables, rather than on ASD diagnosis, might be more helpful to clarify the role of auditory processing in ASD (see also Bertone, Bonnel & Burack, 2009; Kargas et al., 2014; Valla & Belmonte, 2013).

A number of limitations in the current study deserve attention. Autistic traits and auditory sensory behaviours were assessed using self-report questionnaires, which means that the quality of the data relies on the participants’ ability to accurately recall their own experiences. However, self-report data, particularly from the AQ and AASP questionnaires, are common practices in the ASD literature (e.g., Horder et al., 2014; Gomot et al., 2008; Jones et al., 2009; Kargas et al., under review). Also, we were particularly interested in the subjective sensory experiences of participants because it is possible that although some adults experience more sensory disturbances than others, they might have developed compensatory coping strategies that could mislead observations by third parties (see also Robertson & Simmons, 2013; Kargas et al., under review). Another limitation is that we did not formally assess participants’ IQ and comprehension skills. The AQ is not designed for individuals with low IQ, since it assumes reading comprehension skills (Baron-Cohen et al., 2001). To address this issue, an experimenter was available to answer any questions participants might have. Furthermore, frequency discrimination abilities appear to correlate with levels of IQ in
ASD. Thus, it is suggested that future investigations of auditory processing in ASD should include an IQ measure.

4.4.9 Conclusion

The present study replicated previous findings indicating that autistic traits are linked to autistic-like sensory behaviours in the typical population. Our findings add to previous research that linked sensory experience differences to socio-behavioural differences (e.g., Cosbey, Johnston, & Dunn, 2010, 2010; Hilton et al., 2010; Horder et al., 2014; Robertson & Simmons, 2013) by demonstrating that there is also a strong connection between auditory perceptual abilities, and in particular intensity and duration, auditory sensory behaviours (sensation avoiding and low registration) and socio-communicative skills in typically developing adults with high levels of autistic traits. Specifically, it is suggested that the relationship among intensity discrimination, sensation avoiding behaviours and communication skills found in ASD also extents to the typical population and may be indicative of a specific phenotype. Furthermore, it is suggested that further research is needed to clarify whether the relationship between duration discrimination and communication skills observed in typically developing adults with high levels of autistic traits is of clinical significance.

In terms of auditory processing, high and low AQ scorers demonstrated similar performance in all three ADTs. It was argued that auditory processing might be linked to intelligence and communication skills. We suggest that future investigations on auditory processing in ASD should give more consideration on these measures when designing grouping criteria. Finally, it is suggested that longitudinal studies are needed to investigate the relationship between auditory perception and related sensory
behaviours in order to fully understand their contribution to the expression of autistic symptoms.
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Chapter 5

RELATIONS AMONG DETECTION OF SYLLABLE STRESS, SPEECH ABNORMALITIES AND COMMUNICATIVE ABILITY IN ADULTS WITH AUTISM SPECTRUM DISORDERS.

5.1 Abstract

To date the literature on perception of affective, pragmatic and grammatical prosody abilities in autism spectrum disorders (ASD) has been sparse and contradictory. Interestingly, the primary perception of syllable stress that is crucial for all prosody functions remains unexplored in ASD. Thus, a same-different syllable stress perception task using pairs of identical four-syllable words was delivered to 42 adults with/without high-functioning ASD, matched for age and IQ, to investigate primary speech perception ability in ASD. We also explored the relationships among stress perception sensitivity, speech production abnormalities and communicative ability in ASD. As predicted, the results showed that adults with ASD were less sensitive in making judgments about syllable stress relative to controls. Also, partial correlations revealed a key association of speech abnormalities with stress perception sensitivity, rather than communicative ability per se. Our findings provide the first direct evidence for deficits on primary syllable stress perception in ASD and its role on socio-communicative atypicalities in ASD.

5.2 1. Introduction

Disordered prosody has been linked to difficulties in interpreting abstract language (e.g., metaphors) and conversational features of language (e.g., Sahlen & Nettlebladt, 1993; Samuelsson, Nettleblat & Lofqvist, 2005), which are common symptoms in autism
spectrum disorders (ASD). In fact, atypical prosody production is one of the most noted deviant characteristics of language in individuals with ASD (for a review see McCann & Peppé, 2003). Previous research suggests that atypical prosody is predictive of reduced social and communicative competence in high-functioning people with ASD (Paul et al., 2005b) and it may be related to difficulties in understanding facial expressions and unresponsiveness to non-verbal feedback such as nodding (Grossman, Edelson & Tager-Flusberg, 2013; Lindner & Rosén, 2006; Nolen-Hoeksema, 2004; Tager-Flusberg, Joseph & Folstein, 2001). Furthermore, it appears that receptive and expressive prosodic deficits are closely related (e.g., Diehl & Paul, 2013; McCann & Peppé, 2003; Paul, Augusyn, Klin & Vlokmar, 2005a; Peppé, McCann, Gibbon, O’Hare & Rutherford, 2007).

Conceivably, the difficulties that people with ASD experience with social communication and interaction might stem from impairment in comprehension and production of communicative messages (e.g., Diehl, Bennetto, Watson, Gunlogson & McDonough, 2008; Diehl & Paul, 2013; Paul et al., 2005a; Peppé et al., 2007; Shriberg, et al., 2001). Despite the overwhelming evidence showing that many individuals with ASD demonstrate atypical-sounding prosody, a speech element that could become a stigmatising barrier to social acceptance (Shriberg, et al., 2001), perceptive prosodic ability in autism is an under-researched area (see McCann & Peppé, 2003; O’Connor, 2012 for reviews). Thus, the focus of this paper is first, to explore the relationship between basic speech perceptual skills and speech production abnormalities and second, to explore whether their relationship contributes to the socio-communicative difficulties observed in individuals with high-functioning ASD. This research is of importance because it could provide useful information for understanding the receptive and
expressive prosodic abilities of people with ASD and could help to identify factors that may contribute to the development of social communication and interaction deficits.

Speech perception has multiple functions. In particular, speech sounds may convey information on the content, the emotional connotation and the identity of the speaker (e.g., Blake & Sekuler, 2006). In linguistics, the term prosody refers to the suprasegmental properties of the speech signal and plays an important role in a range of communicative functions that have been categorized as affective, pragmatic and grammatical (Roach, 2000; Panagos & Prelock, 1997; Shriberg et al., 2001). These functions help the speaker to enhance or change the meaning of what is said (Couper-Kuhlen, 1986; Cruttenden, 1997), hence facilitating communication. Acoustically, prosody is defined by variations in loudness (amplitude), duration, pitch (fundamental frequency), intonation (changes in pitch over time), rhythm (duration, rate and pauses) and stress (the relative prominence of particular units within the speech signal) (Lehiste, 1970; Shriberg, Kwiatkowski & Rasmussen, 1990; Stephens, Nickerson & Rollins, 1983).

Affective prosody refers to changes in the speech register used in different social situations or communicative partners (e.g., speech towards children or work colleagues) and to convey general emotional states (e.g., relaxed or annoyed) (Bolinger, 1989; Hargrove, 1997). Pragmatic prosody refers to different ways an utterance is expressed to deliver the intentions of the speaker and to provide additional social information that goes beyond the syntax of the sentence (e.g., Bates & McWhinney, 1979; Winner 1988). For example, stress can be used pragmatically to emphasize the unit of information within an utterance that requires the receiver’s focus of attention. Grammatical prosody is used to indicate whether someone makes a question or a statement and to highlight syntactic information within utterances or sentences (e.g., Gerken, 1996; Warren, 1996).
Grammatical stress, for instance, indicates whether a word is a noun (e.g., PREsent) or a verb (e.g., preSENT).

Literature on prosody ability in ASD has focused predominantly on prosodic expression, indicating deficiencies in vocal quality that are characterized by inappropriate use of stress (i.e., atypical placement of stress cues within the utterance), pitch variation (i.e., ‘robotic or exaggerated intonation), phrasing and rhythm (e.g., Baltaxe, 1984; Baltaxe & Guthrie, 1987; Bonneh, Levanon, Dean-Pardo, Lossos, & Adini, 2011; DePape, Chen, Hall, & Trainor, 2012; Diehl & Paul, 2013; Kujala, Lepistö, & Näätänen, 2013; McCann & Peppé, 2003; Paul et al., 2005a, 2005b; Paul, Bianchi, Augustyn, Klin, & Volkmar, 2008; Shriberg et al., 2001). These verbal behaviours are present at infancy and highly persistent with relatively little change over time (Kanner, 1971; Simmons & Baltaxe, 1975). In comparison to prosodic expressive abilities, little is known about the processing skills of receptive prosody in individuals with ASD (see McCann & Peppé, 2003; O’Connor, 2012 for reviews). Most of the studies in this area have focused primarily on the perception of pragmatic/affective prosody (Baron-Cohen, Hill, & Rutherford, 2007; Chevallier, Noveck, Happé, & Wilson, 2011; Golan, Baron-Cohen, & Hill, 2006; Golan, Grossman, Bemis, Plesa Skwerer, & Tager-Flusberg, 2010; Heikkinen et al., 2010; Järvinen-Pasley, Wallace, Ramus, Happé, & Heaton, 2008b; Jones et al., 2011; Kleinman, Marciano, & Ault, 2001; Lindner & Rosén, 2006; Peppé et al., 2007; Rutherford, Baron-Cohen, & Wheelwright, 2002). Several of these studies using complex vocal expressions (i.e., where an understanding of mental states is needed for making a judgment) or complex experimental paradigms (i.e., tasks that demand enhanced cognitive load), reported findings for atypical perception of pragmatic and affective prosodic cues in individuals with ASD (e.g., Chevallier et al., 2011; Golan et al., 2006, 2007; Kleinman et al., 2001; Rutherford et al., 2002). In
contrast, the processing of basic voice expressions and vocalizations (e.g., laughing-happy, crying-sad) appear to be intact in children, adolescents and adults with ASD (Grossman et al., 2010; Heikkinen et al., 2010; Jones et al., 2011), although some studies failed to replicate these findings (Lindner & Rosén, 2006; Mazefsky & Oswald, 2007; Philip et al., 2010).

Research on the perceptual abilities of grammatical prosody is scarce in ASD and the findings are contradictory. Specifically, some research groups reported that individuals with ASD exhibited deficits in the comprehension of grammatical cues of word stress (Paul et al., 2005a; Peppé et al., 2007), whereas others have not (Chevallier, Noveck, Happé, & Wilson, 2009; Crossman et al., 2010; Järvinen-Pasley, Peppé, King-Smith, & Heaton, 2008a). A similar pattern of inconsistencies in the results is evident in studies exploring the ability to use stress to perceive phrase structures in individuals with ASD. Specifically, some studies have reported evidence for impaired performance in individuals with ASD relative to controls (Diehl et al., 2008; Järvinen-Pasley et al., 2008a), while other studies have not found significant group differences on performance (Paul et al., 2005a; Peppé et al., 2007).

In summary, current research on prosody perception and comprehension in ASD presents a complex picture, characterized by contradictory findings in all areas of prosodic function. Two main potential explanations for these inconsistencies are suggested in the literature. One explanation is that these contradictions are the result of differences among prosodic paradigms (e.g., Diehl et al., 2008; McCann & Peppé, 2003) and the other explanation suggests that previous inconsistencies reflect heterogeneity in ASD samples (e.g., Järvinen-Pasley et al., 2008a; McCann & Peppé, 2003). For example, research shows that there is considerable variability in skills found
in several domains in people with ASD (e.g., Kargas, López, Reddy, Morris, 2014; Valla & Belmonte, 2013).

Overall, pragmatic, affective and grammatical stress perception and production are suggested to represent an area of particular difficulty for people with ASD (e.g., Diehl & Paul, 2013; Paul et al., 2005a; 2008; Shriberg et al., 2001). However, to our knowledge, previous studies on prosody perception in ASD have not investigated primary detection of syllable stress within the word structure independent of meaning. Based on previous related findings reporting impaired perception of pragmatic, affective and grammatical prosody cues in ASD (see McCann & Peppé, 2003; O’Connor, 2012; Kujala et al., 2013 for reviews), is predicted that the group with ASD would exhibit reduced performance on our syllable stress perception task compared to the comparison group. Deficits in the primary perception of syllable stress could have negative consequences in learning how different acoustic versions of utterances convey different meanings, which in turn could result in atypical receptive and expressive prosodic abilities, communication skills and overall language acquisition (Cutler, Oahan, & van Donselaar, 1997; Mehta & Cutler, 1988; Pierrehumbert, 2003, Wood & Terrell, 1998). In addition, this study aimed to investigate the associations between stress perception and communicative abilities in individuals with ASD. Based on related findings showing a relation between receptive and expressive prosodic skills in higher level experimental tasks (see O’Connor, 2012 for a review), we predicted a similar relation between primary perceptive skills of syllable stress and speech production abnormalities in ASD (e.g., Paul et al., 2005a; Peppé et al., 2007). Finally, it was also hypothesized that both speech perception and production skills would be related to communicative abilities in individuals with ASD (Diehl & Paul, 2013; Paul et al, 2005b).
5.3 2. Methods

5.3.1 Participants

Forty-two native adult English speakers participated in this study. Participants’ details are shown in Table 5-1. The participants were 21 individuals with ASD and 21 typically developing (TD) adults (3 females in each group). Participants with ASD were recruited from the database of the Autism Research Network (ARN, Portsmouth) and through a local adult support group for people with ASD. All participants in the ASD group had a formal diagnosis of ASD according to standard clinical criteria (APA, 1994, 2000). In order to confirm their diagnoses and to ensure consistency across participants, the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) was administered. The comparison group was selected through the university’s participant pool and local social groups. Ethical approval was sought by the university’s Research Ethics Committee. Based on self-reports, it was confirmed that all participants in the comparison group did not have a psychiatric or developmental diagnosis.

All participants completed the Wechsler Adult Intelligence Scale-Third Edition (WASI; Wechsler, 1999). Verbal IQ (VIQ), performance IQ (PIQ), full-scale IQ (FIQ) and chronological age characteristics of the participants in the ASD and TD group did not differ significantly (all p >.1). Participants received a short hearing test for the standard range of frequencies (250-8000 Hz) using an audiometer. All of the participants had normal auditory acuity, which was a condition for being included in the study.
Table 5-1. Participants’ mean scores and standard deviations (SD) for chronological age and IQ scores across groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Chronological age</th>
<th>Verbal IQ</th>
<th>Performance IQ</th>
<th>Full IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASD</td>
<td>Mean 30.3</td>
<td>109.8</td>
<td>107.2</td>
<td>109.5</td>
</tr>
<tr>
<td></td>
<td>SD (10.4)</td>
<td>(18.2)</td>
<td>(15.7)</td>
<td>(18.3)</td>
</tr>
<tr>
<td>TD</td>
<td>Mean 29.5</td>
<td>113.9</td>
<td>114.2</td>
<td>115.9</td>
</tr>
<tr>
<td></td>
<td>SD (11.4)</td>
<td>(9.2)</td>
<td>(10.7)</td>
<td>(10.6)</td>
</tr>
</tbody>
</table>

5.3.2 Materials

5.3.2.1 Syllable stress perception task

A stress perception task was used to test the hypothesis that primary detection of syllable stress will be reduced in the group with ASD. The task was based on 10 four-syllable words with lexical templates that have first syllable stress, such as ‘delicacy’ and ‘dandelion’, and 10 four-syllable words with lexical templates that have second syllable stress, such as ‘capacity’ and ‘discovery’. Full details about the selection criteria for the words and the experimental paradigm can be found in Leong and colleagues (Leong, Hämäläinen, Soltész, & Goswami, 2011). The selection criteria for the words included written and spoken frequency, familiarity and syllable structure and were drawn from the linguistics databases of MRC Psycholinguistic Database and CELEX. The list of the words used in this task is provided in the Appendix (5-A-1).

All words were produced by a native female speaker of British English and recorded using Audacity software. Two samples for each word were made, one with
stress emphasis on the first syllable position such as *AUiditory* (i.e., SUUU) and another one with stress emphasis on the second syllable position such as *auDitory* (i.e., USUU). This factor was labelled as First/Second stress position. Generally, in English language stress syllables are louder, longer and higher in pitch than unstressed syllables. The two word samples were matched for total duration and the first two syllables were analysed for mean intensity, fundamental frequency (f0) and duration using Praat software. The total duration of the two tokens among the word pairs ranged from 800 ms to 1200 ms. Mean values for stressed and unstressed first syllables stress such as *AU* or *au* in *AUiditory* and *auDitory* and stressed and unstressed second syllables as for example *di* in *AUiditory* and *DI* in *auDitory* are shown in Table 5-2. Pair samples t-test was used to confirm that the auditory parameters differed between stressed and unstressed syllables and among words. Word pairs were matched in all four possible ways (SUUU - SUUU, USUU - USUU, SUUU - USUU, USUU - SUUU), producing two different types of judgments, Same and Different (e.g., Same: *Auditory* – *AUiditory*, *auditory* – *auDitory*; Different: *Auditory* – *auDitory*, *auditory* – *AUiditory*). This factor is referred to as Discrimination type. Therefore, by combining the two factors together, two blocks of 40 trials were created. The experimental design is shown in Fig. 5-1.
<table>
<thead>
<tr>
<th></th>
<th>Syllable Stress (First/Second)</th>
<th>Response (Same/Different)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>First Syllable</td>
<td>Same</td>
<td>AUditory – AUditory</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>auDitory – auDitory</td>
</tr>
<tr>
<td>2</td>
<td>Stress (SUUU)</td>
<td>Different</td>
<td>AUditory – auDitory</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AuDitory – AUditory</td>
</tr>
<tr>
<td>3</td>
<td>Second Syllable</td>
<td>Same</td>
<td>deMOcracy – deMOcracy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DEmocracy – DEmocracy</td>
</tr>
<tr>
<td>4</td>
<td>Stress (USUU)</td>
<td>Different</td>
<td>deMOcracy – DEmocracy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DEmocracy – deMOcracy</td>
</tr>
</tbody>
</table>

Figure 5-1. Schematic illustration of the experimental design.
Table 5-2. Acoustic parameters of stressed and unstressed syllables (mean across 20 words).

<table>
<thead>
<tr>
<th></th>
<th>Stressed</th>
<th>Unstressed</th>
<th>t(19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First syllable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.g. AU in</td>
<td></td>
<td>E.g. au in</td>
<td></td>
</tr>
<tr>
<td>Manipulated</td>
<td>AUditory</td>
<td>AuDitory</td>
<td></td>
</tr>
<tr>
<td>Mean intensity in dB</td>
<td>78.4</td>
<td>69.4</td>
<td>10.0*</td>
</tr>
<tr>
<td>SD</td>
<td>2.7</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td>Mean f0 in Hz</td>
<td>222.3</td>
<td>182.8</td>
<td>5.23*</td>
</tr>
<tr>
<td>SD</td>
<td>27.0</td>
<td>36.3</td>
<td></td>
</tr>
<tr>
<td>Mean duration in ms</td>
<td>288.2</td>
<td>148.7</td>
<td>6.91*</td>
</tr>
<tr>
<td>SD</td>
<td>78.0</td>
<td>38.1</td>
<td></td>
</tr>
<tr>
<td>Second syllable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.g. DI in</td>
<td></td>
<td>E.g. di in</td>
<td></td>
</tr>
<tr>
<td>Manipulated</td>
<td>auDitory</td>
<td>AUditory</td>
<td></td>
</tr>
<tr>
<td>Mean intensity in dB</td>
<td>77.1</td>
<td>72.4</td>
<td>5.97*</td>
</tr>
<tr>
<td>SD</td>
<td>3.5</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>Mean f0 in Hz</td>
<td>235.4</td>
<td>182.5</td>
<td>11.6*</td>
</tr>
<tr>
<td>SD</td>
<td>19.0</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>Mean duration in ms</td>
<td>236.3</td>
<td>162.4</td>
<td>4.52*</td>
</tr>
<tr>
<td>SD</td>
<td>63.3</td>
<td>52.9</td>
<td></td>
</tr>
</tbody>
</table>

* p < .001

Word pairs were presented one after the other (500 ms ISI) with 2000 ms ITI. Participants were requested to make same-different judgments about the position of syllable stress in the pair, (e.g., Same: SUUU - SUUU or Different: SUUU - USUU).
Moreover, participants were asked to give their response as accurately and quickly as possible after a question mark appeared on the computer screen (at the end of the second word of each pair). During presentation of the stimuli the computer screen remained blank. Their responses were given by pressing left or right buttons via a computer keyboard with the preferred hand. Finally, the experimenter clarified to the participants that their task was to decide whether the word pairs sound the ‘same or different’ and not whether they were correctly or incorrectly pronounced (Leong et al., 2011). All participants reported that the instructions were clear. Prior to testing participants were given four practice trials and feedback of the correctness of their responses (text on the screen and verbally) and they did not appear to have any problems executing the task.

5.3.2.2 Speech abnormalities and communication skills

The ADOS (Lord et al., 2000) was used to measure speech abnormalities and communication skills in the group with ASD. ADOS Module 4 provides accurate assessment and diagnosis of autism for verbally fluent adolescents and adults suspected of having ASD and is commonly used by clinicians and in research. An ADOS assessment takes approximately 40 minutes to complete. The ADOS consists of semi-structured situations and standardized activities, which allow the examiner to observe behaviours important to the diagnosis of ASD such as communication, social interaction and play or imaginative use of materials. ‘Language and Communication’ (LC) is one of the five ADOS measures. ADOS LC assesses the participant’s language production skills and style of communication and comprises 10 items. Ratings of item 2 of ADOS LC reflect speech abnormalities or in other words atypical vocal characteristics, which are specific to autism. For example, coding involves elements of speech that is unusually slow, rapid, odd-intonation and/or inappropriate stress. Thus, we used the
ADOS LC total scores (excluding item 2) to measure communicative ability and ADOS LC item 2 as a measure of speech abnormalities in ASD.

5.3.3 Experimental procedures

The study was carried out in a three hour testing session. Initially, participants were seen individually by the first and second authors in order to complete the ADOS interview and the WASI test. After administration of the ADOS and WASI, each participant was tested individually on the syllable stress perception task and spoken stimuli were presented via closed cup headphones (HD-3030). Testing took place in a quiet room. Between each experimental procedure rest breaks were given in order to ensure that performance on the tasks was not reduced due to tiredness and fatigue or loss of interest. Moreover, all participants reported that they had no problems performing the tasks and they also appeared to be interested and motivated. Finally, participants were informed that they could terminate their participation at any time and without any negative consequences.

5.4 Results

Sensitivity and response bias in making judgements about syllable stress were measured using d-prime ($d'$) and criterion ($c$). Calculated $d'$ and $c$ values as well as mean percentage of correct responses in each condition are shown in Table 5-3.
Table 5-3. Mean % correct, $d'$, $c$ and standard deviations (in parentheses) for performance of both groups in the syllable stress task.

<table>
<thead>
<tr>
<th></th>
<th>ASD</th>
<th>TD</th>
</tr>
</thead>
<tbody>
<tr>
<td>First syllable stress (SWWW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same judgement</td>
<td>95.0% (11)</td>
<td>98.5% (2.8)</td>
</tr>
<tr>
<td>Different judgement</td>
<td>91.6% (18)</td>
<td>98.1% (2.9)</td>
</tr>
<tr>
<td>Second syllable stress (WSWW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same judgement</td>
<td>93.3% (7.4)</td>
<td>98.3% (2.8)</td>
</tr>
<tr>
<td>Different judgement</td>
<td>90.9% (14)</td>
<td>98.8% (2.1)</td>
</tr>
<tr>
<td>$d'$ sensitivity</td>
<td>2.2 (0.7)</td>
<td>2.7 (0.1)</td>
</tr>
<tr>
<td>$c$ response bias</td>
<td>0.0 (0.3)</td>
<td>0.0 (0.1)</td>
</tr>
</tbody>
</table>

Independent sample $t$-tests revealed significant group differences for sensitivity ($d'$) but not for criterion bias. Specifically, the group with ASD demonstrated significantly lower sensitivity on detecting lexical stress than the TD group task ($t(40) = 2.7, p = .01$). This finding indicates that individuals with high-functioning ASD have difficulties in the detection of acoustic prominence in speech. However, no significant group differences were observed in the response bias, suggesting that participants in both groups were equally biased toward giving a same or different response.

A mixed factorial ANOVA, 2 (First/Second syllable stress) x 2 (group), using $d'$ as the dependent variable, was conducted to statistically test the effects of varying the syllable template. This revealed a significant main effect of group ($F(1, 40) = 6.9; p = .012; \text{partial } \eta^2 = .147$) but no significant main effect of First/Second syllable stress ($p = .235$) and no significant interaction between group x First/Second syllable stress ($p = .114$). Moreover, the same pattern of results was observed even after controlling for
FIQ and VIQ. Overall, the aforementioned results indicate that the participants with ASD made significantly less accurate judgements about shared syllable stress, regardless of the syllable template (i.e., SUUU or USUU).

Due to the heterogeneity of the ASD and previous findings suggesting considerable variability in performance on acoustic discrimination paradigms (e.g., Jones et al., 2009; Kargas et al., 2014), we further explored the mean scores of $d'$ to assess whether there were concealed subgroups with either exceptionally good or poor sensitivity performance on stress perception in the ASD group. As a higher $d'$ value is indicative of better performance, the criteria for good and poor sensitivity performance were defined correspondingly as 2 SDs above and below the mean of the TD group. There were 2 exceptional good performers in each group. However, 7 (33%) individuals in the ASD group had sensitivity values 2 SDs below the comparison mean compared to 2 (10.5%) individuals in the TD group. This difference in distribution was significant ($X^2 (df = 2) = 3.53; p < .05$). All other individuals in both groups performed within 2 SDs.

5.4.1 Associations among stress perception, speech production and communication skills in ASD.

In order to explore whether sensitivity in making judgements about shared syllables is associated with the quality of speech production in individuals with ASD, Spearman’s correlations were performed between $d'$ average values on performance in the stress perception task and ADOS LC speech abnormalities scores. These results revealed significant negative correlations ($r = -.75; p < .001$), indicating that lower $d'$ values, that is, less sensitivity on syllable stress, were associated with higher scores in the ADOS LC speech abnormalities item, or in other words with atypical quality of vocal
production. Also, the correlations remained significant even after partialling out all three measures of IQ. However, in contrast to predictions, the correlations between performance on the stress perception task and ADOS Communication total scores were not significant, indicating that impaired sensitivity on stress perception cannot fully account for communication deficits in the group with ASD. Finally, consistent with our hypothesis, there was a moderately large, significant positive correlation between ADOS speech abnormalities scores and ADOS Communication total scores ($r = .39; p < .05$), indicating that atypical speech production was associated with lower communication skills in ASD. Further, their relationship remained significant even after controlling for VIQ.

To investigate the contribution that sensitivity on syllable stress perception and communicative ability had on speech production abnormalities in ASD, two partial correlations were calculated (see figure 5-2). First, a partial correlation between ADOS LC speech production abnormalities scores and performance on the syllable stress perception task, controlling for ADOS Communication total scores. These correlations revealed that the relationship between syllable stress perception sensitivity and quality of speech production remained highly significant ($r = -.68; p < .001$) even when controlling for communicative ability. The second partial correlation was between ADOS speech production abnormalities scores and ADOS Communication total scores partialling out performance on the syllable stress perception task. Interestingly, the correlation between communicative ability and speech production abnormalities after partialling out performance on speech perception task was no longer significant ($r = .36; p > .05$). This pattern of results suggests that it is impairments in detecting syllable stress rather that communicative ability per se that influence quality of speech in ASD.
Figure 5-2. Illustration of patterns of bivariate and partial Spearman’s correlations for syllable stress perception sensitivity and communicative ability associations with speech production atypicalities in ASD.

5.5 Discussion

The principle aim of the present study was to investigate whether the perception of primary acoustic prominence in speech is intact in individuals with high-functioning ASD. A secondary aim was to explore the relations among perception of syllable stress, quality of speech production and communicative ability in ASD. Four main findings emerged from the study. First, it was found that the ASD group was significantly less sensitive in the detection of syllable stress relative to controls. To our knowledge, this finding is the first direct demonstration of primary syllable stress perception
impairments within the word structure in ASD. Second, even within a relatively homogeneous group with ASD (i.e., autism diagnosis and level of IQ), performance on the syllable stress perception task varied considerably across individuals. Third, correlational analyses revealed that poor perceptual sensitivity of syllable stress was associated with atypical quality of speech production in ASD. Fourth, performance on the stress perception task was not related to communicative ability in ASD, indicating that perceptual difficulties in primary prosodic information cannot fully account for differences in overall language and communication skills. However, it was shown that perception of syllable stress, rather than communicative ability *per se*, influences quality of speech production in ASD.

Our results on the syllable stress perception task adds to previous research reporting impaired receptive abilities across a wide range of prosody functions in ASD (e.g., Chevallier et al., 2011; Diehl et al., 2008; Jarvinen-Pasley et al., 2008a; Paul et al., 2005a; Peppé et al., 2007) and are consistent with previous findings indicating that stress is an area of particular difficulty (e.g., Diehl & Paul, 2013; Paul et al., 2005a; 2005b; 2008; Shriberg et al., 2001). The prosody impairments in ASD are predominantly thought to stem from either increased attention to perceptual cues of the speech signal (e.g., Mottron, Dawson, Soulières, Hubert, & Burack, 2006), which results in decreased attention to linguistic information (e.g., Happé & Frith, 2006), or due to higher-order processing impairments at the level of interpretation, such as understanding mental or affective states of others (e.g., Baron-Cohen, Leslie & Frith, 1985). These explanations postulate that low-level perceptual processes are to a great extent intact in ASD. However, early prosodic deficits have been suggested to be a possible explanation for the later impairments in the comprehension of the pragmatic and socio-emotional meanings and prosody production observed in individuals with
ASD (e.g., McCann & Peppé, 2003; Diehl et al., 2008; Diehl & Paul, 2013; Ploog, Banerjee, & Brooks, 2009). For example, correct perception of syllable stress is necessary for the development of cognitive reconstructions that link different acoustic versions of an utterance with different affective, pragmatic and grammatical functions and social meanings. Therefore, the current findings showing that the primary perception of syllable stress is impaired in ASD suggest that basic perceptual acoustic deficits may impact negatively on all prosody functions, at least partly, and consequently might limit the repertoire of higher-order socio-communicative skills.

Another potential explanation for the inconsistencies in previous findings on prosody perception abilities in ASD might lie in the considerable variability in skills that is frequently reported in several domains (Valla & Belmonte, 2013), such as in low-level auditory discrimination ability (Kargas et al., 2014), language and communication skills (e.g., Kjellmer, Hedvall, Fernell, Gillberg & Norrelgen, 2012), and sensory behaviours (e.g., Bogdashina, 2003). Autism is a heterogeneous neurodevelopmental condition. Therefore, conceiving of ASD as a homogeneous group of disorders and conceptualizing perceptual abilities and socio-communicative skills as stable over time, seems unjustified and may also lead to contradictory findings (see also Kargas et al., 2014; Valla & Belmonte, 2013). For example, even within the relatively homogeneous sample in our study (i.e., autism diagnosis and levels of IQ) we found a meaningful subgroup with ASD (33%) (see also Heaton, Williams, Cummins & Happé, 2008; Jones et al., 2009; Kargas et al., 2014; Kargas, López, Morris, Reddy & Sarriá, submitted) that exhibited markedly poor sensitivity to syllable stress perception (above 2 SDs from the control mean) and clear atypical speech.

Interestingly, in the current study performance on perception of syllable stress was associated with speech production abnormalities in ASD also at the group level,
supporting previous evidence showing a correlation between receptive and expressive prosodic skills (e.g., Diehl & Paul, 2013; McCann & Peppé, 2003; Paul, et al., 2005a; 2008; Peppé, et al., 2007). However, it is worth pointing out that perception of syllable stress was not associated with communicative ability in ASD, indicating that factors other than perceptive prosody sensitivities may contribute to the development of communication deficits. Previous studies show that children with ASD do not emulate the speech of their peers like typically developing children do (Baron-Cohen & Staunton, 1994; Paul et al., 2008). For example, their stress production ability is not qualitatively comparable to the level of their peers (Diehl & Paul, 2013; Paul et al., 2005a). This lack of speech emulation is thought to be an important contributing factor to the social communication deficits observed in speakers with ASD (Baron-Cohen & Staunton, 1994; Paul et al., 2008). Receptive prosody precedes and influences the development of expressive prosody. In fact, in typical development, prosody processing ability is associated with early language acquisition and the development of communication and social skills (e.g., Demuth & Morgan, 1996; Jusczyk, 2003; Pierrehumbert, 2003). Again, the correct perception of the acoustic prominence in speech is necessary for the precise emulation of speech. Therefore, based on our findings we propose the possibility that atypical sensitivity to acoustic cues of speech may influence the development of the speech production in people with ASD. If this suggestion has any kernel of truth, it could facilitate the development of easy to implement and effective interventions for speech and language therapy in ASD (see also Diehl & Paul, 2013; Paul et al., 2005).

On the other hand, previous research has also highlighted that interest in socio-communicative cues plays a crucial role on language acquisition in typically developing infants (e.g., Frenald, 1985; Fernald & Kuhl, 1987). Studies on infants and children
with ASD have shown that interest to social cues is significantly less salient relative to typically developing individuals (e.g., Dawson, Meltzoff, Osterling, Rinaldi & Brown, 1998; Klin, 1991). For example, pre-school children with ASD prefer to attend to non-speech stimuli than to child-directed speech and their cortical mechanisms responsible for speech processing are underdeveloped (Kuhl, Coffey-Corina, Padden & Dawson, 2005; see also Boddaert et al., 2004; Gervais et al., 2004; Lepistö et al., 2005).

Therefore, social motivational reasons may also account for the failure to emulate the speech of peers and the speech production abnormalities observed in children with ASD. Thus, at least to some extend, lack of typical social communication and interaction experiences in ASD could have detrimental effects in learning significant linguistic and prosodic features important for effective communication.

Partial correlations revealed a key association of speech abnormalities with stress perception sensitivity, rather than communicative ability *per se* in ASD. This pattern of results is consistent with accounts emphasizing the important role of prosody perception in language acquisition and the development of communication and social skills (e.g., Demuth & Morgan, 1996; Jusczyk, 2003; Pierrehumbert, 2003). These findings indicate that atypical speech perception is the primary contributing factor for speech abnormalities in ASD, such as inappropriate use of stress, which in turn could hinder the development of communication skills. Specifically, we propose that initial atypicalities in the perception of primary acoustic cues in speech may be responsible for speech production abnormalities that contribute to atypical social communication and interaction experiences, which result in the communication deficits observed in ASD. Future research is needed in order to test this hypothesis and to develop adequate theories mapping the development of social communication and interaction skills in ASD.
It is worth mentioning the limitations for assessing speech abnormalities in ASD in the current study. The ADOS speech abnormalities score is a composite of different types of vocal atypicalities and does not differentiate between subtypes of speech features, thus is not the best measure for speech abnormalities. Therefore, although our principal aim was to explore whether there is an association between syllable stress perception and speech production, we were not able to determine in what way individual differences in sensitivity on primary acoustic cues of syllable stress may impact differentially upon subtypes of speech abnormalities. Furthermore, future studies are needed to assess the extent to which different prosody functions are influenced by individual differences in primary perception of speech. Moreover, future research should attempt to utilize a battery of experimental paradigms in which the linguistic and perceptual dimensions of syllable cues are independently manipulated. Also, more research is needed to understand the role that atypical low-level auditory discrimination abilities in ASD (e.g., O’Connor, 2012; Kargas et al., 2014) play on prosody perception. This information would be of great significance for assisting speech and language therapists to identify particular targets for intervention.

5.5.1 Conclusion

To our knowledge, this is the first study to provide a direct demonstration for impaired basic perception of acoustic cues for syllable stress within the word structure, regardless of meaning, in ASD and the first empirical evidence showing an association between primary detection of syllable stress and speech production atypicalities. However, it should be noted that this may relate to high variability of perceptual abilities that is frequently reported in several domains in ASD (e.g., Kargas et al., 2014; Valla & Belmonte, 2013). Furthermore, the current study provides the first behavioural evidence
indicating that the relationship between perception of syllable stress and speech abnormalities may contribute to the development of communication deficits observed in ASD. However, it is suggested that perceptual atypicalities cannot fully account for the social communication and interaction impairments in ASD.

Our results support previous reports indicating that studies on basic speech perception could help us to better understand in what way verbal information is processed in individuals with ASD. This information could lead to a better comprehension of the social communication and interaction difficulties individuals with ASD encountered (e.g., Alcántara, Cope, Cope, & Weisblatt, 2012; Diehl & Paul 2013; McCann & Peppé, 2003; Paul et al., 2005b), which could facilitate the development of effective interventions for speech and language therapy and social communication interventions.
5.6 References


Heikkinen, J., Jansson-Verkasalo, E., Toivanen, J., Suominen, K., Väyrynen, E.,


### Table A 5.1. Word list for the syllable stress task.

<table>
<thead>
<tr>
<th>First Syllable Stress</th>
<th>Second Syllable Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory</td>
<td>Botanical</td>
</tr>
<tr>
<td>Categorize</td>
<td>Capacity</td>
</tr>
<tr>
<td>Dandelion</td>
<td>Curriculum</td>
</tr>
<tr>
<td>Difficulty</td>
<td>Debatable</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Democracy</td>
</tr>
<tr>
<td>Mercenary</td>
<td>Manipulate</td>
</tr>
<tr>
<td>Military</td>
<td>Maternity</td>
</tr>
<tr>
<td>Organizer</td>
<td>Necessity</td>
</tr>
<tr>
<td>Punishable</td>
<td>Remarkable</td>
</tr>
<tr>
<td>Voluntary</td>
<td>Ridiculous</td>
</tr>
</tbody>
</table>
6  GENERAL DISCUSSION

6.1  Overview

The studies presented in the current thesis explored the impact of auditory perception on the expression of RRBs, atypical auditory sensory behaviours and communicative ability in adults with ASD or with varying levels of autistic traits. In addition, the associations among speech perception and production, and communication were investigated. Taken together, the outcome of these investigations highlight three main findings: 1) the importance of considering the development of core autistic symptoms as an interactional multi-developmental process, which extends into the general population, 2) the crucial role of auditory processing in the expression of autistic-like sensory behaviours, communication and RRBs, 3) the need to clarify to what extent, and how, atypicalities in speech perception and production, as well as in social experience, contribute to the emergence of social communication and interaction impairments in ASD, and 4) that primary auditory discrimination abilities are characterised by high variability in ASD.

Chapter 2 reports empirical evidence showing a relationship between low-level auditory processing and RRBs and also provides evidence for diminished low-level auditory discrimination abilities across a range of auditory parameters in adults with ASD. Furthermore, Chapter 3 reports evidence showing that the relationship between auditory processing of loudness levels and auditory sensory behaviours may contribute to the development of expressive pragmatic ability in ASD. Moreover, these findings were expanded by the study reported in Chapter 4. Specifically, it is suggested that the relationship among intensity discrimination, sensation avoiding behaviours and
communication skills found in ASD also extends to typically developing adults with high levels of autistic traits. Lastly, Chapter 5 provides a direct demonstration for impaired basic perception of acoustic cues for syllable stress within the word structure in ASD and empirical evidence showing an association between primary detection of syllable stress and speech production atypicalities.

Concisely, the findings of the current thesis contribute to our understanding of where the complex and heterogeneous autistic symptoms stem from and highlight the need for future studies to investigate the development of autistic symptoms under an interactional multimodal lens using a mixed-methods approach.

### 6.2 Summary of the main findings and implications

#### 6.2.1 Auditory processing and RRBs in ASD

To date, there are mixed findings regarding low-level auditory processing abilities in ASD (i.e., enhanced or intact; for reviews see Haesen, Boets, & Wagemans, 2011; O’Connor, 2012; Samson, Mottron, Jemel, Belin, & Ciocca, 2006). Furthermore, it has been suggested that RRBs are linked to sensory features (for a review see Leekam, Prior, & Uljarević, 2011), therefore, the paucity of information on the association between distinctive auditory perceptual features and RRBs is surprising given their elements could potentially help us to discern the aetiology or function for some types of RRBs. Therefore, the study reported in Chapter 2 had two aims: 1) to investigate auditory discrimination abilities in ASD across all three basic auditory parameters (intensity, frequency, duration) and 2) to explore the relationship between different auditory parameters and RRBs.
The participants were 21 adults with high-functioning ASD and 21 typically developing adults. The results showed that the group with ASD demonstrated poorer discrimination skills compared to the control group across all three ADTs. Also, it was found that auditory discrimination ability is characterized by high variability in ASD. Specifically, similar to previous studies (Heaton, Williams, Cummins, & Happé, 2008; Jones et al., 2009) some participants with ASD demonstrated enhanced performance on the frequency discrimination task (around 9.05%) whereas some other exhibited reduced performance (around 24%). Further, it was found that intensity and frequency discrimination ability correlated with the amount of RRBs, indicating that the expression of these behaviours may be influenced by the degree to which sounds are detected or missed in the environment.

It was suggested that further research on the developmental relationship between individual differences in low-level auditory perception and different subclasses of RRBs is essential to enhance our understanding of how RRBs initially emerge (e.g., coping with loudness) and change over time in ASD. Understanding the role of auditory perception in ASD could contribute to identifying behaviours that may have a negative functional impact, and consequently facilitate the development of the autistic syndrome.

6.2.2 Auditory processing, auditory sensory behaviours and communication skills

Although, social communication difficulties have been widely documented in ASD (e.g., Baron-Cohen, Baldwin & Crowson, 1997; Boucher, 2012a; Eigsti, de Marchena, Schuh & Kelley, 2011; Tager-Flusberg, Paul & Lord, 2005), the role that atypical sensory behaviours play in the manifestation of deficits in social communication remains unclear. This is of great importance due to the fact that researchers have consistently reported how atypical sensory sensitivities in people with ASD interfere with functions
of daily life such as parent-child interaction, learning, work and the ability to explore and interact with the social environment (e.g., Bogdashina, 2005; Loftin, Odom, & Lantz, 2008), as for instance avoiding noisy social settings, which could in turn hinder the development of communicative skills. Furthermore, due to the significant role that acoustic features play in children’s linguistic, cognitive, emotional and social development (e.g., Kempe, 2009; Matychuk, 2005; Murray, 1992) and evidence of atypical primary auditory processing abilities in ASD (for reviews see Haesen et al., 2011; O’Connor, 2012; Samson et al., 2006) it is crucial to investigate low-level auditory perception in relation to communicative ability as well as sensory behaviours in people with ASD.

In the study reported in Chapter 3 the main aim was to investigate whether communicative abilities in ASD may be explained by low-level auditory perceptual ability and related sensory behaviours. The participants were 20 adults with high-functioning ASD and 20 adults without ASD. All participants completed three low-level ADTs (intensity, frequency, duration) and two self-reported questionnaires, one about auditory sensory behaviours and one about communication skills.

The results showed that the perception of intensity (loudness) and auditory sensation avoiding behaviours were correlated with atypical expressive pragmatic ability in ASD. Partial correlations revealed that auditory sensory avoiding behaviours rather than intensity discrimination \textit{per se} influenced pragmatic ability. Furthermore, the findings provide supporting evidence for the suggestion that auditory sensory behaviours persist well into adulthood and that linguistic aspects of structural language may be poorer in adults with ASD.
It was concluded that initial hypersensitivity to loudness may contribute to the development of auditory sensory behaviours associated with avoiding loud contexts, which result in atypical social experiences and thus in the expressive pragmatic difficulties observed in ASD. Also, it is suggested that further research on the developmental relationships between domain-specific perceptual abilities and sensory processing sensitivities across modalities is essential in order to expand our understanding about the causal influence these associations may have on the genesis of autistic symptomatology.

6.2.3 Autistic-like behaviours and communication in the typical population

Following up the results from the study reported in Chapter 3, I explored whether the associations across auditory perception, auditory sensory behaviours and communication skills could also be part of the Broader Autism Phenotype (BAP). To do this, I delivered the same material for assessing auditory sensory behaviors (i.e., AASP; Brown & Dunn, 2002) and low-level auditory discrimination skills (i.e., intensity, frequency and duration) as in study presented in Chapter 3 to a sample of 86 typically developed adults. In addition, the Autism Quotient (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) was used to measure autistic traits and autistic-like communication tendencies. Finally, participants were divided into two subgroups based on their AQ scores (high: 17 -32; low: 0 - 16).

The results replicated previous findings indicating that autistic traits are related to autistic-like behaviours sensory experiences in the general population (Horder, Wilson, Mendez & Murphy, 2014; Robertson & Simmons, 2013). Moreover, individuals with high levels of autistic traits relative to low AQ scores reported significantly more auditory sensory behaviours. Furthermore, it was found that in
contrast to the low AQ subgroup, the relationships previously found in the ASD sample among intensity discrimination, sensation avoiding behaviours and communication were present in the high AQ subgroup. Interestingly, moderate significant correlations were observed between autistic-like communicative skills and duration discrimination as well as Low registration auditory behaviours (indicative of hyposensitivities) in the high AQ subgroup. However, these relationships were not found in the ASD samples (see Chapter 3).

Based on the aforementioned findings it was concluded that the relationship among communicative ability, perception of loudness levels and related sensory behaviours appears to extent to the general population and might represent a specific ASD phenotype. Furthermore, it was proposed that further research is required to clarify whether the associations of duration discrimination with auditory sensory behaviours and communication skills is of clinical significance.

6.2.4 Speech and communication in ASD

Atypical prosody production is one of the most noted deviant characteristics of language in individuals with ASD (for a review see McCann & Peppé, 2003). In addition, atypical prosody is a speech element that could become a stigmatising barrier to social acceptance (Shriberg, et al., 2001) and is also predictive of reduced social and communicative competence in high-functioning people with ASD (Paul, Augustyn, Klin & Volkmar, 2005). Therefore, the social communication and interaction impairments observed in ASD might stem from atypicalities in comprehension and production of communicative messages and/or atypical socio-communicative experiences.
To date, research on prosody perception in ASD presents a complex picture, characterized by contradictory findings in all areas of prosodic function (i.e., pragmatic, affective, grammatical) (see Elgsti et al., 2011; McCann & Peppé, 2003; O’Connor, 2012 for reviews). However, the primary perception of syllable stress within the word structure that is crucial for all prosody functions remains unexplored in ASD. Conceivably, the focus of the study reported in Chapter 5 was first, to explore the relationship between basic speech perceptual skills and speech production abnormalities and second, to investigate whether their relationship contributes to the socio-communicative difficulties in adults with ASD.

A same-different syllable stress perception task using pairs of identical four-syllable words was delivered to a 42 adults with/without high-functioning ASD matched for chronological age and IQ. As predicted, the results showed that adults with ASD were less sensitive in making judgments about syllable stress relative to controls. Also, partial correlations revealed a key association of speech abnormalities with stress perception sensitivity, rather than communicative ability per se.

Based on these results it was suggested that basic perceptual acoustic deficits in ASD may have a negative effect on all prosody functions and consequently might limit the repertoire of higher-order socio-communicative skills. However, perception of syllable stress was not associated with communicative ability in ASD, indicating that factors (e.g., atypical social-communicative experience) other than perceptive prosody sensitivities may contribute to the development of communication deficits.

These findings could facilitate the development of language and communication intervention programmes in ASD. Furthermore, they have important implications for explanations of ASD that are suggesting that the social communication and interaction
difficulties observed in ASD are due to higher-order processing impairments at the level of interpretation (e.g., Baron-Cohen, Leslie & Frith, 1985), rather due to atypicalities in the processing of the basic acoustic perceptual features of the speech. Finally, it was proposed that further research is needed to investigate how atypical acoustic perceptual processing of the speech signal influences the development of social communication and interaction skills in ASD.

6.3 Implications: The need for an interactive model of autistic development

Scientists in ASD attempt to discern the multifarious factors that contribute to the expression of autistic symptomatology, mainly by searching for single potential precursors, thus overlooking the complexity that is inherent in human development. In fact, most theories in ASD currently stand upon data measuring abilities in specific perceptual (e.g., Enhanced Perceptual Functioning; Mottron, Dawson, Soulières, Hubert, & Burack, 2006), cognitive (e.g., Executive Functioning; Turner, 1999) or social (e.g., Theory of Mind; Baron-Cohen, Leslie & Frith, 1985) domains. However, research shows that there is considerable variability in skills found in several domains in people with ASD and findings are often contradictory (e.g., Kargas et al., 2014; Valla & Belmonte, 2013). It is therefore suggested that employing an interactive specialisation multi-developmental approach, in which different contributing factors are side-by-side interacting with each other, might be a more precise and valid method to examine the influence of each factor to autistic symptoms. After all, the developmental nature of autistic symptomatology necessitates the understanding of how initial abilities through their interaction with the social environment develop over time into fixed neural and behavioural patterns (see also Kargas et al., 2014; Valla & Belmonte, 2013). Moreover, it is suggested that interpretations of specific impairments differ when developmental
changes are taken into account (López, 2013) and that understanding the developmental trajectories in any specific domain is essential for identifying the nature of these impairments (e.g., Karmiloff-Smith, 2009; López, 2013; Mayer, Hannent, & Heaton, 2014).

Although the patterns of interaction of sensory and cognitive processes with the social environment change across the course of typical development, these can be categorised into specific developmental milestones (e.g., Piaget, 1926). However, ASD is characterized by atypical developmental trajectories. For instance, auditory and speech perception (Mayer et al., 2014), visual reception (Landa & Garrett-Mayer, 2006), motion processing (Annaz et al., 2010) and neural representation of, and attention to, language (Kujala, Lepistö, & Näätänen, 2013) develops differently in toddlers, children and adults with ASD than in neurotypical individuals. The patterns of associations among certain abilities in specific domains (e.g., visual, auditory and motion processing and social communication) as well as the importance each ability plays in their developmental interactional relationship may differ significantly across developmental stages (e.g., infancy vs. adolescence). Therefore, it is vital to gather and compare evidence from different age groups.

Speech perception involves the integration of visual-motor (e.g., mouth movement and gestures) and auditory information (speech and vocal sounds) whereas meaningful language requires the integration of various real life experiences (e.g., with people or objects) (e.g., McCleery, Elliot, Sampanis & Stephanidou, 2013). Thus, language connects speech and vocalizations with the concrete reality of the speaker. Most importantly, effective communication occurs only when the speaker and the receiver have a comparable cognitive reconstruction of the reality, which is based on their real life experiences (see also Wertsch, 1985; Bogdashina, 2005). Over time, the
primary communicative interactions present in the early development (e.g., infant-mother) emerge into more complex and sophisticated socio-constructive interactions. Therefore, understanding how initial atypical abilities (e.g., hyper/hypo sensory sensitivities) influence the way each individual interacts behaviourally and cognitively with the social environment and how real life experience influences the development of abilities (e.g., language and speech) across the course of development, would assist in comprehending the nature of the socio-communicative impairments and RRBs observed in ASD (see also Bogdashina, 2005; López, 2013; VanDalen, 1995).

The studies reported in the present thesis utilized a mixed methods approach (e.g., observational, experimental and self-report data on perception and behaviour) to investigate key autistic symptoms (i.e., social communication and RRBs). It is suggested that using this type of experimental approach to study developmental trajectories in ASD could potentially help us identify distinctive subclasses of developmental paths across the spectrum. Specifically, previous research shows that variability of abilities in ASD samples is typical in several domains (e.g., Kargas et al., 2014; Valla & Belmonte, 2013). Drawing from the findings of the present thesis indicating the existence of distinctive subgroups with high-functioning ASD that share particular characteristics (e.g., Kargas et al., 2014; Chapter 3), and the heterogeneous nature of the disorder, it is argued that developmental trajectories in ASD may be characterised by high variability. Therefore, it is possible that there are subgroups of people with ASD that share common developmental pathways. If this hypothesis has any kernel of truth it could aid in the classification of ASD and facilitate the development of rational and effective early therapy and intervention programmes.
6.4 Limitations and future directions

The current thesis revealed a number of important findings that warrant further investigation. First, in Chapter 2 the outcome of associations between auditory discrimination abilities and the degree of RRBs in ASD indicated that the perception of intensity and frequency acoustic parameters play an important role in the manifestation of RRBs. However, in this study RRBs were assessed using ADOS SBRIs total score (Lord et al., 2004), which is a composite of different classes of behaviours and does not differentiate between subtypes of RRBs. Interestingly, distinctive subclasses of RRBs have been identified in the literature (for reviews see Leekam et al., 2011). Therefore, future research is needed to clarify whether specific auditory parameters are significant contributing factors to particular subclasses of RRBs. In addition, ADOS is a short assessment that depends on what the individual does within a 40 min session under controlled conditions (within an interview room) and therefore might not represent the true extent of RRBs in the individuals assessed. Thus, it is not the best measure of RRBs as it lacks ecological validity. One potential method that can resolve this issue is to gather additional information on RRBs from people (e.g., parents, caregivers and friends) who are familiar with the developmental history and current behaviour of the individual assessed, as for instance with the Autism Diagnostic Interview Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994) or the Repetitive Behaviours Questionnaire (RBQ-2; Leekam et al., 2007). Despite of these limitations the high correlations between auditory discrimination skills and the degree of RRBs, as measured by ADOS, suggest that this association is of a great importance.

The unexpected findings of diminished low-level auditory discrimination abilities across a range of auditory parameters in ASD reported in Chapter 2, indicate that future studies should give further consideration on the design of auditory
experimental findings. For example, differences in the adaptive methodologies (e.g., step size and tracking algorithm) may lead to different results (Leek, 2001). These variables have not been consistent in the studies investigating auditory processing in ASD. For example, frequency discrimination in the studies of Heaton and colleagues (e.g., Heaton, Hermelin & Pring, 1999; Heaton 2005; Heaton et al., 2008) participants had to make judgments on musical stimuli (semitones) whereas Jones et al. (2009) used a wide frequency range (600 Hz to 982 Hz, difference between probes 10 Hz) representative of environmental sounds. In this thesis, the frequency discrimination task was designed on parameters important for speech perception (500 Hz to 560 Hz, difference between probes .07 Hz). Thus, the discriminations that our participants had to make were fundamentally different from previous related studies. Therefore, it is suggested that future studies should incorporate three different types of auditory tasks (e.g., using music and speech related stimuli) to clarify whether the results of diminished frequency discrimination abilities was a specific characteristic of our sample or it relates to differences in the adaptive methodologies. This information is of a great importance because could potentially change fundamentally our current understanding about the auditory and speech perception abilities in ASD.

It is worth mentioning that both studies in Chapters 3 and 4 used self-reported questionnaires to assess auditory sensory behaviours and communication skills in adults with and without ASD and there are often limitations to self-report data. However, both the Adolescent/Adult Sensory Profile (AASP; Brown & Dunn, 2002) and the Communication Checklist-Self Report (CC-SR; Bishop, Whitehouse & Sharp, 2009) questionnaires are frequently used in clinical practice and in research on ASD and are found to be highly reliable and valid in discriminating between people with and without ASD (e.g., Horder et al., 2014). Moreover, due to the nature of the study I was
particularly interested in the subjective sensory and communication experiences of the participants. Future research is now needed to explore the aforementioned associations using both self-reported and objective measures of sensory sensitivities and communication skills.

The findings presented in Chapter 5 indicating that basic syllable stress perception is impaired in adults with high functioning ASD has important implications for theories in ASD, as well as provide useful information for the development of effective interventions for speech and language therapy in ASD. Specifically, it was suggested that the impairments observed across all prosodic functions in individuals with ASD might be due to primary deficits in speech perception. Further research should attempt to clarify the extent to which different prosody functions are influenced by individual differences on primary perception of speech. This hypothesis can be investigated by using a battery of prosody paradigms to assess different prosodic abilities (e.g., affective, grammatical and basic prosody) and in which the linguistic and perceptual dimensions of syllable cues are independently manipulated (e.g., Järvinen-Pasley, Pasley, & Heaton, 2008a; Järvinen-Pasley, Wallace, Ramus, Happé & Heaton, 2008b). Finally, deficits in the processing of the ‘low-level’ auditory speech signal are thought to represent early markers for phonological impairments in developmental dyslexia (e.g., Goswami et al., 2002). Thus, more research is needed to investigate the impact that atypical low-level auditory discrimination abilities have on prosody perception in ASD (e.g., O’Connor, 2012). This information would be of great significance for assisting speech and language therapists to identify particular targets for intervention.

This study had some limitations. First, speech production abnormalities were assessed using observational data drawn from a diagnostic interview (i.e., ADOS).
Future research can benefit from also incorporating acoustic analyses of speech. However, currently there is no standard acceptable range of human speech (Diehl & Paul, 2013), thus even if acoustic differences are found, it is not possible to determine what these differences indicate without relating them to subjective observational ratings.

It is necessary to acknowledge that the findings of the present thesis were based on adult samples, thus it is not possible to confirm developmental issues in ASD. In fact, it has been suggested that only longitudinal studies can provide reliable information about developmental processes (e.g., Kraemer, Yesavage, Taylor, & Kupfer, 2000). However, I believe that the current thesis provides important inferences that could contribute to the rationale and design of new studies for investigating developmental processes in longitudinal studies.

Finally, I would like to stress the need for more studies using a developmental approach in adults with ASD. Human development involves four main processes that occur across the life span: 1) physical (e.g., sensorimotor and nerve development), 2) mental (e.g., learning how to make judgments and deal with various situations), 3) emotional (e.g., learning and dealing with feeling, as for example happiness and stress) and 4) social (e.g., learning how to interact and develop relationships with others). To my knowledge, the developmental literature in ASD has been focused exclusively on infants, children and adolescence, or in other words up to the age that the neurophysiological maturation of the brain is complete. However, ASDs are characterised by social communication and interaction impairments. These abilities develop across the life span and become more complex and sophisticated with age in typical adults (see also Chapter 3, p. 63-64). Unfortunately, little is known about how the socio-communicative abilities develop in adults with ASD or about the factors that influence their development. Similarly, we have limited information on whether the
social communication and interaction skills of people with ASD become better or poorer across different adult age groups (e.g., early, middle and late adulthood). Understanding the socio-communicative difficulties people with ASD experience throughout their lives could facilitate the development of strategies that aim to improve their communication, and consequently their overall quality of life.

6.5 Conclusions

Human communication is a complex process that involves the integration of several physiological, psychological and socio-cultural environmental influences. Furthermore, sensory experience is critical to emotional, cognitive and brain maturation. For example, sensory awareness and sensory processing play a crucial role in the development of language and communication, influence self-expression and form the basis of human reality (e.g., Bion, 1963). Effective communication requires people to follow key socio-cultural rules. In fact, in the new criteria for ASD (DSM-5; APA, 2013) the domains of the qualitative impairments in communication and social interaction found in DSM-4 have been merged into a single set of symptoms, due to the fact that impairments in communication are closely associated with social deficits (DSM-5).

Although ASD is characterized by social communication and atypical sensory sensitivities, little is known about the role of sensory issues in the manifestation of the communicative impairments observed in ASD. The current thesis attempted to explore these associations in the hope of better understanding the multifaceted factors that contribute to the autistic symptomatology. Overall, it was shown that exploring the interactional relationships between auditory perceptual abilities and related sensory behaviours could enormously enhance our understanding of how social communication
impairments and RRBs emerge and change over time in ASD. Finally, the need for studying ASDs under an interactional multimodal developmental lens was highlighted.
6.6 References


Antonio: Psychological Corporation.


Horder, J., Wilson, C. E., Mendez, M. A., & Murphy, D. G. (2014). Autistic traits and


6.7 Appendix

6.7.1 Additional information on participant recruitment and procedures.

Participant recruitment is one of the most challenging stages of a research study. Particularly, in ASD research, due to the heterogeneity of autistic symptoms (e.g., social communication, persistence to change) there are many potential pitfalls in recruiting a sample that adequately represents the ASD population. In my opinion, information on participant recruitment in the ASD literature is seldom reported adequately. Therefore, in this section I would like to provide background information about the recruitment strategies and experimental procedures that were employed for collecting the data of the current thesis.

Participants in both groups were matched as closely as possible on an individual basis in terms of education, music experience, demographics (e.g., English speakers from the same geographical area, age) and intelligence. In order to ensure that the data collected from the participants with ASD was not influenced by secondary factors (e.g., anxiety) relating to their autistic symptoms, the following strategies were employed. First, all participants were drawn from the local area through the Autism Research Network and the university's participant pool as well as local support groups for adults with ASD. Thus, all individuals were familiar with the area in which the study took place. It is worth pointing out that the principal investigator of the current thesis had already established a relationship with 17 out of 21 participants involved in the studies through his involvement as an active member in social clubs for adults with ASD. Based on participants’ reports the fact that the experimenter was familiar with each individual’s idiosyncratic autistic behaviours made them feel more secure, confident and relaxed. Second, each participant had an informal interview with the experimenter
prior to his or her visit at the university. The information gathered from each individual was used for making appropriate adjustments during their testing session (e.g., light conditions in the testing room, time of testing). In addition, participants with ASD were given the opportunity to visit and familiarise themselves with the building, room and experimenter prior to testing sessions.

It is also worth pointing out that the ADOS interview took place in the first testing session. The participants with ASD completed the psychoacoustics tasks in a second testing session that took place within the same week. Eight of the participants with ASD also completed the syllable stress task during their second testing session whereas another 8 completed it in a third session within the next following two weeks. Full details for the scores of the 16 participants that completed all three ASD studies of the present thesis are given in Table A1.
Table A 6-1. Participant data scores for the ASD group from all studies.

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