Cross-modal Selective Attention and Perceptual Load in Autism Spectrum Disorder

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Declaration

I, Julian Tillmann confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

J. Tillmann

Abstract

This thesis investigated cross-modal selective attention in children and adolescents with Autism Spectrum Disorder (ASD) and typically developing (TD) individuals using the Load Theory of Selective Attention and Cognitive Control (Lavie, 1995). Perceptual load theory states that perception of irrelevant stimuli depends on the perceptual load of the task (the amount of task relevant information). At low levels of perceptual load, when finite perceptual capacity is not reached, remaining resources 'spill over' and irrelevant stimuli are automatically processed; when perceptual load exhausts capacity, irrelevant stimuli are no longer processed.

In ASD, there is some evidence that on visual attention tasks, individuals with ASD continue to process visual information at higher levels of perceptual load than controls, indicative of an increased perceptual capacity (Remington, Swettenham, & Lavie, 2012; Remington, Swettenham, Campbell, & Coleman, 2009; Swettenham, Remington, Murphy, Feuerstein, Grim, & Lavie, 2014).

This thesis tested novel predictions derived from these findings for contexts of cross-modal selective attention. Using behavioural measures, the extent to which participants were able to attend to auditory information was examined as a function of the perceptual demands of a visual task. It was shown that individuals with ASD continued to report awareness of auditory information at higher levels of visual perceptual load than matched typically developing individuals. This was evident on tasks that measured both awareness for an unexpected, as well as expected auditory stimulus. Together, these findings suggest that individuals with ASD are characterised by an increased perceptual capacity that operates across sensory modalities.

For Eva and Ilya

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Chapter 1 Autism

Autism Spectrum Disorders (ASD) are a set of life-long, neurodevelopmental conditions that were first described by Leo Kanner (1943) and Hans Asperger (1944), who independently of each other observed a group of individuals unable to form normal relationships with their peers, had a desire for sameness and revealed peculiar patterns of communication. Although both authors differed in their description of autism, they acknowledged that these individuals shared certain features that were not part of other known child psychiatric disorders. Confirmation that the syndrome they observed was indeed a distinct psychopathological entity was provided on the basis of a large epidemiological study in Camberwell, London by Wing and Gould (1979). They found a history of 'typical, Kanner-type autism' in 4 out of 10,000 children, which increased to 21.2 in 10,000 children when a broader definition of impaired reciprocal social interaction was used. As a result of this study, the syndrome described by Kanner was considered a particular manifestation of a spectrum of conditions, with individuals on this spectrum sharing common impairments in social, imaginative and symbolic functioning, as well as repetitive/restrictive behaviour, yet the individual expression of these symptom domains can differ substantially from one subject to another (Diagnostic and Statistical Manual of Mental Disorders, DSM-V: American Psychiatric Association, 2013).

Diagnosis

Deficits in social communication can include deficits in reciprocity (inability to interact appropriately with others using social norms), as well as atypical nonverbal communication (such as eye contact and gestures) and a difficulty building and maintaining relationships. Restrictive and repetitive patterns of behaviour or interests in individuals with ASD are often reflected in over-dependence on routines, an insistence on sameness, focussing on very specific objects or topics, or a high sensitivity to changes in the environment (American Psychiatric Association, 2013). Within the category of restrictive/repetitive interests, sensory symptoms were recently introduced as a new diagnostic criterion which have long been observed in individuals with autism but were not part of the diagnostic criteria under DSM-IV (American Psychiatric Association, 1994). This new criterion describes hypersensitivity or hyposensitivity to sensory input or an unusual interest in sensory cues. To receive a diagnosis of autism, symptoms must be present in early childhood (they may however not manifest themselves until later life), should cause significant impairment in everyday functioning, and should not be attributable to any other medical or neurological condition or be explained by intellectual disability (DSM-V; American Psychiatric Association, 2013). In the absence of established biomarkers, diagnosis of autism relies on behavioural assessments, reviews of a child’s history and interviews with family members and parents (Volkmar, Siegel, Woodbury-Smith, King, McCracken, & State, 2014).

Autism has previously been conceptualised as a range of separate disorders including autistic disorder, Asperger’s syndrome, childhood disintegrative disorder and Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS; DSM-IV, American Psychiatric Association, 1994) that share common core features of autism. However, as research was unsuccessful in validating these diagnoses as separate constructs (for a review see Grzadzinski, Huerta, & Lord, 2013; Lord et al., 2012), the introduction of the DSM-5 criteria (American Psychiatric Association, 2013) has replaced these diagnostic categories by a single umbrella disorder – Autism Spectrum Disorder (ASD). Throughout this thesis, the term ASD will therefore be used to include all autism spectrum conditions.

It has now also been proposed by some researchers that autistic traits are present in the general population, with these traits thought to lie on a continuum across the whole population with individuals with ASD forming the extreme end of this distribution (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Constantino & Todd, 2003). Consequently, some studies measure autistic traits in the population using questionnaire measures such as the Autism-spectrum Quotient (AQ, Baron-Cohen et al., 2001) and relate these differences in autistic traits to behaviour on a range of tasks. The view that the distribution of autistic traits is continuous in nature has been supported by genetic studies (Robinson, Munir, Munafò, Hughes, McCormick, & Koenen, 2011) and findings indicating that outcome measures for autistic traits in the general population map well onto ‘gold standard’ diagnostic tools such as the Autism Diagnostic Interview-Revised (ADI-R) (Constantino et al., 2003). Others in contrast have argued that AQ scores are an unreliable proxy for autism and therefore any conclusions derived from these studies should be taken with caution (Gregory & Plaisted-Grant, 2013).

Prevalence

Although current estimates vary across studies, autism spectrum disorders are considered to be one of the most common neurodevelopmental disorders, with an estimated prevalence rate of ~1% worldwide (CDC, 2014; Saemundsen, Magnússon, Georgsdóttir, Egilsson, & Rafnsson, 2013) and 1.1% in the United Kingdom (Baird et al., 2006; Baron-Cohen, Scott, et al., 2009; Brugha et al., 2009). It is more commonly diagnosed in males than in females with a reported sex ratio of approximately 4:1 (Baird et al., 2006; Fombonne, 2003). Females also often receive a diagnosis of autism later in life than their male counterparts (Begeer et al., 2013) and are less likely to be diagnosed than males even if they display the same level of autism severity (Russell, Steer, & Golding, 2011). It has been proposed that autism may be underdiagnosed in girls (Baird, Douglas, & Murphy, 2011), particularly in those at the higher end of the spectrum (Begeer et al., 2013).

Nonetheless, a male predominance in autism has important aetiological implications. For example, the presence of female-specific biological factors might reduce the risk in females to develop autism (Werling & Geschwind, 2013), whereas male-specific risk factors might heighten susceptibility to develop autism (Baron-Cohen, Lombardo, Auyeung, Ashwin, Chakrabarti, & Knickmeyer, 2011).

Theories on ASD

A great body of research has attempted to identify the underlying causes of autism. Biological theories point towards a range of factors that are associated with autism. For example, it is now widely accepted that autism has a strong genetic component (Bailey et al., 1995; Folstein & Rutter, 1977). Twin studies (Hallmayer et al., 2011), recurrence rates in siblings (Constantino, Zhang, Frazier, Abbacchi, &

Law, 2010) and high-risk infant sibling studies (Ozonoff et al., 2011) all point towards important genetic factors in the aetiology of autism. However, which particular genes are implicated in autism remains controversial (O'Roak, 2008; Scherer et al., 2003). Physical brain abnormalities such as macrocephaly (Webb, Nalty, Munson, Brock, Abbott, & Dawson, 2007), abnormal dopamine metabolism (Ernst, Zametkin, Matochik, Pascualvaca, & Cohen, 1997) and neuroanatomical abnormalities in the prefrontal cortex (Prior & Hoffmann, 1990), parietal lobes (Courchesne, Press, & Yeung-Courchesne, 1993), prefrontal cortex medial temporal lobe structures (Salmond, Ashburner, Connelly, Friston, Gadian, & Vargha‐Khadem, 2005) and the cerebellum (Courchesne, 1997) have also been associated with the condition. However, no accepted biological aetiology has emerged from this work.

Findings from structural magnetic resonance imaging (MRI) for example indicate that toddlers with ASD (aged 2 – 4 years) demonstrate on average larger brain volumes than typically developing children (Carper & Courchesne, 2005; Courchesne, 2002; Courchesne et al., 2001), although with development, this difference in brain volume between subject groups seems to decline (Courchesne, Campbell, & Solso, 2011). These findings, among others, suggested that brain maturation is atypical in ASD and involves a period of early overgrowth in both white matter and grey matter (Courchesne et al., 2001; Ecker, Bookheimer, & Murphy, 2015), followed by a stagnating growth phase and possibly decline in older ages (Courchesne et al., 2011). The finding of increased brain volume also converges with reports of larger head circumference in ASD (Lainhart et al., 1997), increased brain weight in post-mortem brains of individuals with autism (Bailey et al., 1998) and an increase in cortical thickness, particularly in temporal and parietal cortices in children with ASD compared to controls (Hardan, Muddasani, Vemulapalli, Keshavan, & Minshew, 2006). A wide variety of brain regions have been reported to be structurally abnormal in individuals with ASD. This includes a reduction in cell size and cell density in the limbic system, Purkinje cells in the cerebellum and enlargement of the amygdala (see Amaral, Schumann, & Nordahl, 2008 for a review).

Studies using diffusion tensor imaging (DTI) have also shown atypical patterns of white matter circuitry in individuals with ASD (Keller, Kana, & Just, 2007), with these abnormalities already observable in early development (Wolff et al., 2012). Wolff et al. (2012) for example showed that those infants that later went on to develop autism had accelerated white matter development at 6 months compared to unaffected infants. This pattern however reversed over time such that at 24 months, the infants with ASD showed decreased white matter fibre tracts (Wolff et al., 2012).

Apart from structural differences, functional brain connectivity also seems to be different in individuals with ASD. One prominent view suggests that ASD is characterised by local over-connectivity and long distance under-connectivity of the frontal cortex (Courchesne & Pierce, 2005). Evidence for this claim derived from an early study using positron emission tomography (PET) (Horwitz, Rumsey, Grady, & Rapoport, 1988), as well as later post-mortem (Vargas, Nascimbene, Krishnan, Zimmerman, & Pardo, 2005) and fMRI studies (e.g. Carper & Courchesne, 2005). While the finding of long-range under-connectivity seems to be generally supported in the literature (Abrams et al., 2013), only little evidence also points towards increased local connectivity in ASD (Vissers, Cohen, & Geurts, 2012). The reasons for differences between these studies could potentially be driven by developmental changes in individuals with ASD given the large variability in age of participants studied (Uddin, Supekar, & Menon, 2013), or in the oversampling of high-functioning individuals with ASD in some studies.

Psychological theories

The most influential psychological theories; theory of mind, executive dysfunction and weak central coherence aimed to provide a cognitive perspective of autism and associated core symptoms. I am now going to outline each of these theories separately.

Difficulties with Theory of Mind

The term “theory of mind” (ToM) was first coined by Premack and Woodruff (1978) and refers to the ability to attribute mental states to self and others. It relates both to the capacity to understand that other people know and understand the world differently than oneself, as well as to use these representations to predict and describe the behaviour and motivations of others (Brownell & Martino, 1998). An intact ToM mechanism allows individuals to make inferences about what another person feels, thinks, and desires. This process of “mentalising” describes the automatic attribution of mental states in order to predict and explain behaviour (Frith, 1989a). It has therefore been suggested that ToM is crucial in successfully engaging in social situations (Baron-Cohen, Leslie, & Frith, 1985) and an overarching deficit in ToM might account for the pattern of impairments seen in communication, socialisation and imagination that characterise ASD (Baron-Cohen et al., 1985; Frith, 1989a; Leslie & Frith, 1987).

The hypothesis that an impaired ToM is a fundamental deficit in ASD was first tested using false belief tasks. In these tasks, participants are required to predict the behaviour of another person who holds a false belief. Baron-Cohen et al. (1985) presented children with ASD with the ‘Sally Anne’ task, where two dolls, Sally and Anne acted out a scenario in which Sally hid a marble in a basket and then left the room. While Sally is absent from the room, Anne moves the marble into a box. The children are then asked where Sally will look for her marble. In order to pass this false belief task, the children need to understand that Sally’s beliefs of the location of the marble are false and different to one’s own, i.e. Sally would look in the basket for her marble and not in the box. It has been shown that typically developing (TD) children pass this test between the ages of 4 and 6 (Wimmer & Perner, 1983). Yet, Baron-Cohen et al. (1985) found that only 20 % of children with ASD predicted correctly Sally’s behaviour, even though they had an average verbal mental age of 5 years and 5 months. The authors also demonstrated that this was not due to their low IQ, as 80% of mental-aged matched children with Down’s syndrome also passed the test. An explanation in terms of a general mental handicap that could account for this difference in performance was therefore ruled out.

This study also inspired subsequent work investigating why some of the children with ASD who are able to pass first-order false belief tasks nonetheless fail second-order false belief tasks (e.g. Baron-Cohen, 1989; Happé, 1994). Whereas first-order false belief tasks require an understanding of the relationship between a person’s belief and reality, second-order false belief tasks measure the ability to understand the belief of one person about another person’s belief (e.g. “John thinks that Mary thinks X”). Baron-Cohen (1989) found that while most typically developing children (chronological age of 7.5) and children with Down syndrome (mean verbal mental age of 7.5) passed this task, none of the children with ASD (mean verbal mental age of 12.2) passed this second-order false belief task, although being able to successfully attribute first-order false beliefs. Happé (1994) further extended these findings using a more naturalistic test of theory of mind by embedding a test of theory of mind in a realistic context. She presented participants with a set of vignettes or stories that described everyday situations where people would say things which they do not literally mean (e.g. someone says a dress looks pretty although it is actually ugly to not hurt the other person’s feelings). Subjects were subsequently asked to describe what was being said and why. The results indicated that although passing first and second-order false belief tasks, individuals with ASD were still severely impaired at performing in these more naturalistic contexts. This provided further evidence that individuals with ASD continue to experience difficulties attributing mental states even after they are able to pass more traditional first and second-order beliefs tasks.

Deficits in the acquisition of a theory of mind in ASD, it was argued, provided a convincing explanation for the core symptoms seen in autism, particularly in relation to the impairments seen in social reciprocity and communication. The robustness with which these findings have been replicated over the years leaves little doubt that individuals with ASD experience difficulties attributing mental states to themselves and others.

However, the theory of mind hypothesis has also received criticism. Apart from methodological limitations in administering false belief tasks, particularly in respect to children (Birch & Bloom, 2003), questions about the universality of the theory of mind hypothesis have been raised (Tager-Flusberg, 2007). This concerns the idea that whilst a ToM deficit is able to account well for some of the core symptoms in autism, it cannot sufficiently explain the other areas of impairments in ASD, notably restricted and repetitive behaviours. Even within the domain of social-communication impairments, a ToM deficit can only account for a fraction of the behavioural phenotype seen in autism (Tager-Flusberg, 2007). One caveat of the theory of mind hypothesis is also that many individuals with ASD are still able to pass false belief tasks, suggesting that a theory of mind deficit is not universal in ASD. For example, Bowler (1992) found that adults with Asperger syndrome (AS) were as capable as typically developing adults at solving second-order false belief tasks, suggesting that an intact theory of mind mechanism does not shield against impairments in social communication and interaction. This indicated that deficits of individuals with ASD on ToM tasks may not be the only explanation for the social impairments in ASD, but may constitute one cause.

Executive Dysfunction

The second major theory seeks to explain the core cognitive symptoms in ASD according to an impairment in executive function. Executive function refers to the cognitive operations related to planning, working memory, inhibition, flexibility, as well as the initiation and monitoring of action (Duncan, 1986), and are thought to be controlled by the frontal lobes (Hill, 2004). This theory sees executive dysfunction as the primary deficit of ASD (Pennington & Ozonoff, 1996) that underlie many of the features of autism both in the social and non-social domain (Hill, 2004). For example, the restrictive and repetitive interests might be a result of poor mental flexibility that results in perseverative, stereotyped behaviours and impaired regulation of motor behaviour. Conversely, the social difficulties observed in ASD could reflect a deficit in regulating social behaviour and emotional reactions that in turn is the result of impaired functioning of the prefrontal cortex (Bennetto, Pennington, & Rogers, 1996).

As social interaction relies on the abilities of individuals to keep subtle verbal and non-verbal information in mind and then plan and respond in a flexible manner, disruption of executive function would make it difficult for individuals with ASD to interact appropriately in a social situation. One strength of this approach compared to the other theories therefore is that it is able to account for multiple core symptom domains in ASD. Early studies have revealed significant impairments in children, adolescents and adults with ASD on a range of tasks that are considered to tap into executive function. For example, the Wisconsin Card Sorting Test (WCST) is regarded to be a test of mental flexibility or set shifting and requires participants to sort cards according to three possible dimensions (colour, number, shape) and an unknown rule. Participants receive direct feedback whether a card was sorted according to the correct rule, although without being told the exact rule. At some point, and without the knowledge of the participant, the rule is changed and the number of perseverative errors (i.e. sorting by the old criterion) is measured. A high number of errors is indicative of a failure to shift set to a new sorting rule. Individuals with ASD have generally been observed to perform worse than controls on the WCST, reflected by increased rates of perseveration and shifting between different sorting criteria (Bennetto et al., 1996; Ozonoff & McEvoy, 1994; Prior & Hoffmann, 1990; Rumsey & Hamburger, 1990). Similar findings have been reported for the Tower of Hanoi (Bennetto et al., 1996; Ozonoff & McEvoy, 1994), and Tower of London test (Ozonoff & Jensen, 1999; Ozonoff, Pennington, & Rogers, 1991).

However, one problem with this account is that executive function deficits are not consistently reported in individuals with ASD (Geurts, Corbett, & Solomon, 2009). For example, Griffith, Pennington, Wehner, and Rogers (1999) showed that children with ASD did not differ from mental-age matched controls on eight different executive function tasks, thereby questioning the specificity of executive function to explain the underlying causes of this condition. Adding to this study, Lopez, Lincoln, Ozonoff, and Lai (2005) also showed that only some aspects of executive functions (i.e. working memory, cognitive flexibility, and response inhibition) were related to repetitive behaviours in ASD and not others such as mental planning and fluency. While it has been claimed that executive dysfunction is universal within the ASD population (Ozonoff et al., 1991), is has been shown that it is not specific to ASD but is also associated with ADHD (Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004) and Tourette’s syndrome (Channon, Pratt, & Robertson, 2003). This led some to suggest that strong skills in executive functions might reduce the susceptibility of at-risk individuals to develop autism or other neurodevelopmental disorders by compensating for brain atypicalities in other domains (Johnson, 2012).

Weak Central Coherence

The third theory, weak central coherence, attempts to account for the behaviour patterns in ASD in terms of an atypical cognitive style that involves higher-level processes (Frith, 1989a). According to Frith, autism is characterised by weak central coherence, which relates to the weakness of higher-order cognitive systems to integrate component parts to form a coherent whole, resulting in a tendency or cognitive bias to process local parts of information at the expense of the overall context or “Gestalt”. The evidence to support this theory derived from observations that described impairments in contextual processing at the “Gestalt” level in individuals with ASD (Brosnan, Scott, Fox, & Pye, 2004), yet advantages to process local, low-level information or scene-detail in stimuli.

For example, individuals with ASD perform exceptionally well on the embedded figures task (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983) where participants are required to locate a hidden shape (e.g. triangle) within a complex drawing. Similarly, individuals with ASD consistently outperform controls on the block design sub-test of the Wechsler intelligence scale (Happé, Briskman, & Frith, 2001; Shah & Frith, 1993). According to the weak central coherence account, superior performance of individuals with ASD on these tasks (e.g. shorter latencies to find the target stimulus) reflects a tendency to process information at the local level.

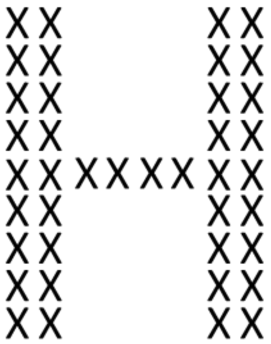
Conversely, people with ASD are less susceptible to visual illusions that require global processing (Happé, 1996), and show a deficit in grouping according to the gestalt (Brosnan et al., 2004). Superior local and impaired global performance on these tasks has also been found in neurotypical individuals with higher autistic traits, suggesting that this cognitive style may be observable across the autism spectrum (Grinter, Maybery, Van Beek, Pellicano, Badcock, & Badcock, 2009; Sutherland & Crewther, 2010).

A local processing style has also been suggested to contribute to the exceptional abilities in individuals with ASD that are occurring disproportionally in this population (Baron-Cohen, Ashwin, Ashwin, Tavassoli, & Chakrabarti, 2009; Mottron et al., 2013). For example, in the auditory domain, a local processing style could be reflected by a higher incidence of perfect pitch (e.g. Heaton, 2003) and enhanced frequency discrimination skills, at least in a subgroup of those with ASD (Bonnel et al., 2010; Jones et al., 2009).

It has also been suggested that weak central coherence is associated with the behaviour patterns seen in ASD, particularly in relation to the social and language deficits (Happé & Frith, 2006). For example, a deficient ability to integrate local parts into a coherent role and attribute meaning could impede the ability to understand mental states of other people and their behaviour. Without central coherence, the multitude of verbal and non-verbal cues and emotional reactions that make up social situations are not integrated successfully and are instead processed in a 'piecemeal' approach. Weak central coherence may also be responsible for the pragmatic difficulties experienced by individuals with ASD. This was demonstrated in both children (Frith & Snowling, 1983) and adults with ASD (Jolliffe & Baron-Cohen, 1999), who were less likely than controls to use the context of a sentence to determine the meaning and therefore pronunciation of a word.

However, not all studies investigating weak central coherence in ASD have produced the same pattern of observations. On a range of tasks including the embedded figures task and Block design task (Ropar & Mitchell, 2001), as well as the Navon task (Ozonoff, Strayer, McMahon, & Filloux, 1994), individuals with ASD can show intact central coherence under certain conditions. Plaisted, Swettenham, and Rees (1999) for example examined these findings further by presenting participants with two versions of the Navon task. In the Navon task, participants are presented with a compound stimulus that is comprised of a large shape made up of small shapes, with the smaller shapes being either compatible (e.g. a large H made up of small H's) or incompatible (e.g. a large 'H' made up of small 'X's', see Figure 1.1) to the larger shape. As soon as the stimulus is shown, participants are required to indicate the identity of the letter at either the global and/or local level (Navon, 1977). On this task, subjects typically show a 'global advantage', i.e. faster and more accurate responses to the global form compared to the local form, as well as a 'global interference' effect. The latter effect relates to the finding that when required to respond to the local but not global form, slower target responses in incompatible conditions are observed that indicate response interference from processing of the global shape.

Figure 1.1 Illustration of stimuli used in the Navon task (incompatible condition)



Plaisted et al. (1999) observed that in a divided attention condition (participants were required to focus on both the local or global form to detect the target), children with ASD demonstrated a local advantage compared to controls as predicted by weak central coherence. In the selective attention condition however (focus on either the local or global form), children with ASD showed the same global advantage and global interference effect as typically developing children. These results supported earlier findings by Ozonoff et al. (1994) and demonstrated that global processing is generally intact in autism, at least when being overtly primed.

A related theory to weak central coherence in autism is the Enhanced Perceptual Functioning (EPF) account (Mottron & Burack, 2001; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). This model proposes that individuals with ASD also show a more locally biased perceptual style (as posited by weak central coherence). In contrast to the weak central coherence account however, the EPF model does not predict a weakness in global processing in individuals with ASD. Instead, the EPF account proposes that lower-order cognitive processes take precedence over the development of higher-order processes. According to this theory, superior performance in individuals with ASD is the result of enhanced low-level perception rather than a weak global processing style.

In summary, unlike the two theories (ToM and executive function) mentioned above, the weak central coherence account of ASD attempts to explain not only the deficits but also the superior performance of individuals with ASD on some behavioural tasks. Some of these phenomena that inspired the development of weak central coherence have also led to a great body of research investigating atypical attentional and perceptual processes in this population, which is going to be the focus of the next chapter.

Chapter 2 Selective attention and perceptual load theory

Our ability to effectively select those aspects of the environment which are important in guiding our behaviour whilst ignoring other potentially distracting information is a fundamental component of human information processing. This ability is crucial given that we only possess limited processing systems (Broadbent, 1958), yet are constantly bombarded with a multitude of information, often originating from different senses. Selective attention is the generic term used to describe the cognitive mechanisms responsible that allow us to focus on what is relevant and ignore what is irrelevant (Portas, Rees, Howseman, Josephs, Turner, & Frith, 1998). Indeed, without this ability, the experience of our world would be quite different, maybe even to the point of being chaotic.

In individuals with ASD however, self- and parent reports point to a distinctively different phenomenological experience of the world. These observations led some to suggest that perceptual and attentional atypicalities are a central feature in individuals with ASD (Allen & Courchesne, 2001). Patterns of attention and perception have also been the subject of some of the earliest and most influential experimental research in autism. In a series of meticulously controlled experiments, Hermelin, O'Connor and colleagues studied the psychophysical aspects of sensation and perception in individuals with ASD and revealed cross-modal information processing deficits in ASD. This included deficits in cross-modal integration, low-level sensory and perceptual impairments, as well as problems with associative thinking and deriving meaning from language (Hermelin and O'Connor, 1970). Interestingly, these deficits were less pronounced on tasks that used proximal sensory input (i.e. smelling or touching) than those that involved distal sensory input (i.e. vision or hearing), suggesting that cross-modal processing is intact in some situations. These by-now classic experiments used paradigms from mainstream experimental psychology to further understand underlying cognitive patterns in individuals with ASD. Mottron, Dawson and Soulières (2008) made an interesting point in this respect by drawing on findings in memory research, relating descriptions of the cognitive profile of individuals with autism to 'normocentrism'. This term describes the tendency to evaluate autistics in relation to the performance profile of non-autistics (i.e. impaired/spared, reduced/increased). Criticising normocentrism, the authors suggested using a ‘difference’ rather than a ‘deficit’ approach to describe autistic patterns of behaviour and accept autism as a variant within human species and not as a defect.

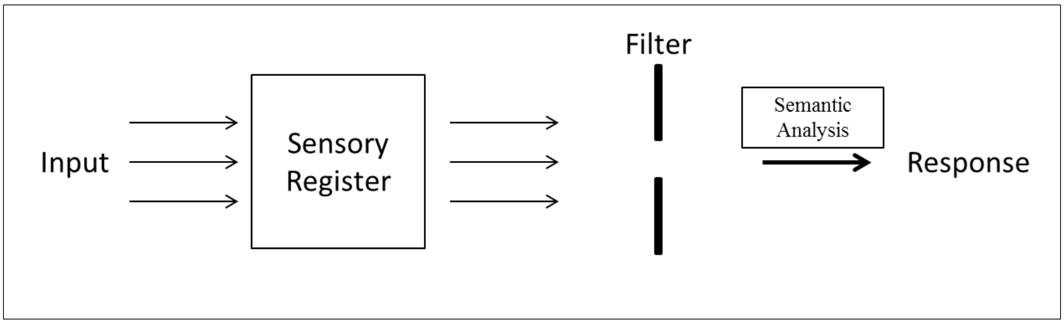
While a great deal of subsequent research has investigated attentional abnormalities in ASD, particularly in the visual domain, relatively little work has focused on selective attention or indeed cross-modal selective attention in ASD. Based on recent advances in research on visual selective attention in ASD that applied Lavie’s perceptual load theory of attention (Lavie, 1995), this thesis seeks to investigate cross-modal selective attention in ASD. The relevant mainstream literature on selective attention and perceptual load theory will first be discussed, before considering the issues of attentional abnormalities in individuals with ASD.

Early selection vs. late selection

A central question that has pervaded research on selective attention concerns the locus of attentional selection. This pertains to the idea that at some stage in the information processing stream, irrelevant information needs to be disregarded. Decades of research have shaped two opposing views about the locus of attentional selection, that is, whether selection of attended items occurs at an early or late processing stage. Proponents of the early selection view argue that attention is characterised by a limited capacity system that restricts processing to attended items only. As a result, unattended items are filtered out at an early processing stage (e.g. Broadbent, 1958; Treisman, 1969). The opposing late selection view posits that perception is an automatic process in which all incoming stimuli are processed regardless of relevance, with selective attention proceeding thereafter (Deutsch & Deutsch, 1963). According to this theory, selection of the most relevant stimuli occurs relatively late in the processing stages after full perception and identification is completed.

The early selection view was mainly formed by data from dichotic listening tasks that found that focusing attention on one auditory stream over another can impair perception and identification of information in the unattended stream. In a classic study by Cherry (1953), participants were presented with different auditory streams (spoken words) played to each ear via headphones and were asked to shadow the input to one ear only (i.e. verbally repeating those words aloud) whilst ignoring the other stream. After completing the task, participants were asked about the information presented in the unattended channel. Interestingly, participants were only aware of the physical properties of the unattended message (e.g. pitch, volume), but not the semantic content of the unattended message even if the language was changed (from English to reversed speech), or when single words were frequently repeated. On the basis of these findings, Broadbent (1958) proposed that selection of information occurs at an early temporal sequence within information-processing stages in order to account for the observation that participants were only able to report drastic physical changes in pitch and volume, but not the actual content of the unattended message. Broadbent proposed that stimuli undergo a two-stage model of processing. In the first stage, stimuli are extracted and processed in terms of their physical properties in a 'parallel' fashion, and are subsequently filtered out according to particularly salient physical properties. He argued that the second processing stage for semantic identification has a much smaller capacity than the first processing stage, and therefore not all stimuli can be processed simultaneously. Instead, any incoming sensory information has to pass a bottleneck to not overload processing at the second stage. Only stimuli passing this bottleneck are further passed on to extract semantic meaning (see Figure 2.1). This explanation was able to account well for the finding that on dichotic listening tasks, participants experienced limited awareness of semantic information in the unattended message, yet were able to distinguish between physical properties of the unattended auditory stream. According to the early selection view, physically distinct information is selected early in the information processing stream, whereas semantic information in the unattended stream is not processed beyond the first processing stage (i.e. the sensory register).

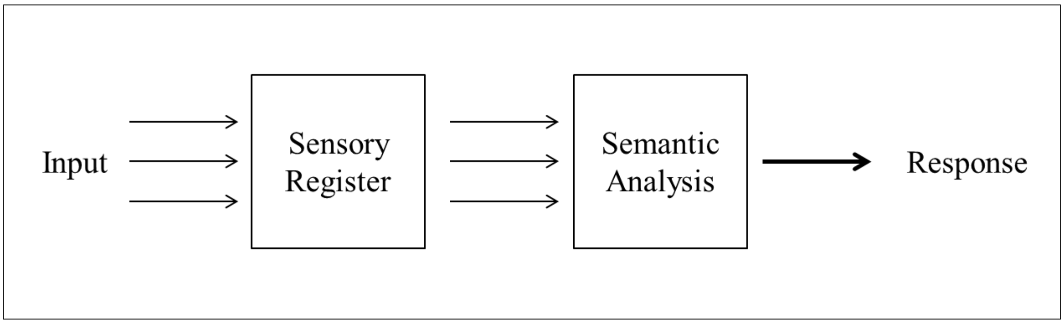
Figure 2.1 Filter theory according to the early selection view (Broadbent, 1958)



However, not all observations could be reconciled with this early selection account of attention. Moray (1959) for instance found that participants showed own-name recognition in the unattended channel, suggesting that the semantic content of words in the unattended stream is processed even if it is not physically salient. In a related finding, Treisman (1960) presented participants with a dichotic listening task that featured two sentences, one in each ear, with participants being asked to shadow one of two sentences. When the content of the shadowed channel changed to the other ear, participants would continue to repeat the same sentence, although it was now being presented in the to-be-ignored channel. The tendency of participants to track the sentence across channels based on syntactic structure and semantic content suggested that the message in the unattended channel was processed at a semantic level rather than just being restricted to its physical features-only as predicted by Broadbent's early selection theory. Finally, Corteen and Dunn (1974) demonstrated that conditioning for feared words elicited a galvanic skin response even if they were played to the non-shadowed ear. It was also claimed that this effect generalises to synonyms of the conditioned words (Von Wright, Anderson, Stenman, Rabbitt, & Dorric, 1975), indicating that the meaning of the fear-conditioned words was processed to some extent. Together, this evidence therefore directly contradicted the predictions of the early selection theory.

Deutsch and Deutsch (1963) took on these results and proposed a late selection model, directly opposing the early selection model advanced by Broadbent. According to this view, all incoming stimuli are analysed in terms of their semantic meaning but only the most relevant stimuli are selected to be passed on to further processing (see Figure 2.2).

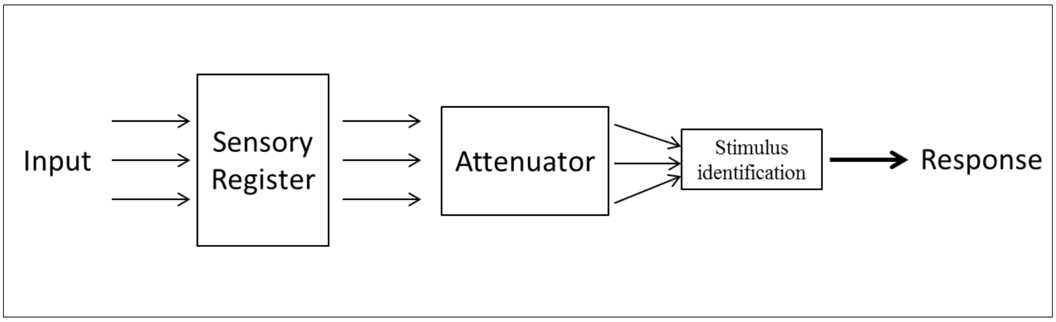
Figure 2.2 Late-selection theory of attention (Deutsch and Deutsch, 1963)



If the late selection model holds, then it would predict that detection rates for target words in the attended and unattended channel would be similar, as the semantic meaning is fully processed across the two income streams before selection occurs. However, this was shown to not be the case, as detection rates for target words in the shadowed message reached 87% and only 8% for the unattended message (Treisman & Geffen, 1967, as cited in Treisman, 1969).

Treisman (1960, 1964) in turn, offered a less drastic version of Broadbent's filter theory in her 'Filter Attenuation Model' (Treisman, 1964) to account for some of the findings that indicated that unattended information is processed to a deeper semantic level than predicted by the early selection theory. While adopting the early selection view of a perceptual filter mechanism that selects stimuli based on physical properties, the theory proposes that this filter does not completely discard irrelevant information, but rather attenuates it. Although these attenuated stimuli only have a weak perceptual trace, they can for example be activated if participants are primed to a sufficient extent (e.g. as in fear conditioning studies, Corteen & Dunn, 1974) or if the words hold a special personal significance (e.g. your own name, Moray, 1959). According to Treisman, these attenuated stimuli in the unattended channel activate detector units, which in turn lower the threshold for recognition, and thus selection of information originating from the unattended channel.

Figure 2.3 Filter Attenuation Theory of Attention (Treisman, 1964)



Although these theories were mainly based on research within the auditory modality, they were also influential in providing the theoretical framework for selective attention research in the visual domain. Neisser (1969) for example used the selective reading paradigm that was closely modelled on the original dichotic listening tasks to measure visual information processing for unattended content. In this task, participants were required to read the lines of text consisting of one colour whilst ignoring alternating lines of text printed in a different colour. The results indicated that as in the dichotic listening paradigms, little content presented within the unattended text could be retained. Furthermore, Sperling (1960) showed that when presented with many letters in a set (e.g. four rows of three letters each) for a very short period of time (50ms), participant’s recall of the whole set was generally poor, suggesting a limited processing capacity. Yet when cued to a particular row (e.g. the top row), recall was much improved. This suggested that only relevant letters able to pass through a filtering bottleneck were processed at the semantic level, therefore providing support for the early selection model of attention. Further work by Von Wright (1970) that used a similar experimental design presented subjects with a display of eight characters and asked them to recall a subset of four items according to varying criteria. It was shown that performance was excellent when selection was based on location, colour, size or brightness, yet was considerably impaired when asked to select according to identity (e.g. orientation, letter vs. digit, vowel vs. consonant). This finding again suggested the presence of a filter mechanism that allows physical attributes to be passed on for further processing, possibly as a result of selecting this information early on in the information-processing stream.

Other work however found evidence for the late selection theory. Tipper (1985) for example showed that using a priming paradigm, participants are still processing the unattended visual content. In this study, participants were shown superimposed images of two objects, of which one object was the target and the other a distractor. Following this display, a third picture (the probe) was presented and participants had to name the probe. Response latencies for naming the probe were shown to be longer when the probe was identical or semantically related to the distractor compared to when it was unrelated to the distractor. This indicated that the to-be-ignored prime object (the distractor) was processed to a semantic level in order to have this effect on reaction times. Studies using the Stroop paradigm (Stroop, 1935) have also provided strong evidence in favour of the alternative late selection view. In the classic Stroop colour-word task (e.g. Stroop, 1935), participants are presented with a colour word printed in a conflicting hue (e.g. the word 'Blue' printed in red: Blue) and asked to name the colour of the ink whilst ignoring to read the word. Response latencies as measured by reaction times in this condition (i.e. incongruent condition) are typically longer compared to control conditions in which, for example, the written text is congruent with the colour ink (e.g. the word 'Blue' printed in blue: Blue). The fact that the ignored dimension (the colour of the word) has an influence on participant's reaction time suggests that although being irrelevant to the task, it is nonetheless processed to a semantic level. This therefore provides evidence for late selection.

Taken together, the debate whether early or late selection determines selective attention still remained unsolved, as several streams of research provided convincing evidence for both accounts.

Perceptual load theory

Nilli Lavie (1995, 2000) put forward a model that can potentially resolve the ‘early’ vs. ‘late’ selection debate. Based on the observation that evidence for the early selection view was generated throughout the 1950’s, 60’s and early 70’s, whereas from the mid-70’s most research supported the late selection model, she inferred that these diverging conclusions are a result of differences in methodologies (Lavie & Tsal, 1994). Lavie and Tsal (1994) noted that earlier studies mainly employed filtering paradigms in form of dichotic listening tasks (e.g. Cherry, 1953) that typically presented a more demanding task with multiple stimuli to participants. These experiments were designed to overload attention of participants to see which specific stimuli are processed or ignored. In contrast, later studies used tasks such as the ‘selective set paradigm’ that confronted participants with only a limited amount of information (e.g. a single target and distractor), which was presumably less demanding on attention.

Lavie (1995) concluded from this observation that it is the level of ‘perceptual load’ of the task that determined these findings. She proposed that early selection occurs (i.e. unattended items are not perceived) under conditions of high perceptual load that exhaust capacity, yet late selection (i.e. perception of unwanted information) proceeds in less capacity-taxing low perceptual load conditions. Crucial to the perceptual load model is the assumption that selective attention is limited in capacity as proposed by the early selection view, yet perception proceeds automatically and involuntarily on all stimuli falling within this limit even if they are not relevant to the task (reflecting the late selection view). This implies that when attentional capacity is available, as in low perceptual load conditions, any spare capacity of the processing of task-relevant stimuli automatically “spills-over” into processing of irrelevant information. The implication of the perceptual load model is that one cannot refrain from processing items if the relevant capacity is not consumed. In tasks of high perceptual load however, all processing capacity is engaged in the primary task, leaving no additional capacity to process irrelevant information (Lavie, 1995).

The perceptual load of a task is operationally defined as either (i) an increase in the number of relevant items/units in a display for the same task, or (ii) an increase in the complexity of perceptual operations/perceptual processing requirements involved in the relevant task for the same number of items (Lavie, 1995). Attentional capacity is therefore consumed by the additional processing of these items or by imposing additional and/or more complex perceptual processing requirements on participants.

In a series of studies, Lavie (1995) and Lavie and Cox (1997) provided preliminary support for the perceptual load theory of attention. These studies used the Eriksen response competition paradigm (Eriksen & Eriksen, 1974) to assess the extent to which visual distractors were processed under different levels of perceptual load via interference effects on target reaction times (RTs). The general design involved participants identifying a relevant target letter (e.g. X or Z) presented within a central display of letters. On the periphery, either a compatible (i.e. X when the target in the ring was X), incompatible (e.g. X when the target in the ring was Z, or vice versa) or neutral (e.g. P) distractor letter was also presented. The perceptual load of the task was subsequently manipulated by adding non-target letters to the central display (e.g. K, S, V, M, and N). This meant that participants either performed a low perceptual load condition with a search set size of one (only target letter was presented) or a high perceptual load condition with a set size of six (target letter + five non-target letters). The extent to which distractors were processed at different levels of perceptual load was measured by comparing trials that featured an incompatible distractor compared to a neutral distractor. If the distractor was indeed processed, then a slowing of response times would be observed on incompatible trials that activated the opposite response category. Lavie found that when the perceptual load of the task was low, that is, when the display featured fewer attended objects, distractors were processed (evidence for late selection). In contrast, in high perceptual load conditions, distractor interference was eliminated, indicating that they were not processed (early selection) (Lavie, 1995).

Figure 2.4 Example of displays used by Lavie & Cox, 1997

Note: Participants were required to make a speeded target letter response (X or N) in either a low perceptual load condition (left box) or high perceptual load condition (right box) with, as in this example, an irrelevant incompatible distractor shown in the periphery

Note that it is not just the number of units in a task-relevant display (e.g. extra non-target letters) which constitutes perceptual load. Perceptual load is also conceptualised in terms of variations in processing demands in the relevant task whilst maintaining identical displays across conditions. To examine distractor processing using this manipulation of perceptual load, Lavie (1995) presented participants with either a single feature search task (colour) or a conjunction feature search task (colour + shape). Other manipulations of perceptual load according to this definition of perceptual load involved a more demanding size and position judgment relative to a simple presence judgment. Using these manipulations of the perceptual load of the task, Lavie (1995) again found greater distractor effects on response times when the perceptual load of the task was low (e.g. single feature search task) than when the perceptual load was high (e.g. conjunction search task).

Since these initial observations, the theory that perceptual load affects attention has been supported by various behavioural and neuroimaging findings. For example, when distractors were presented in subsequent trials in a priming paradigm, a negative priming effect (i.e. slowing of responses on the subsequent trial) was observed in low perceptual load trials, but not in high perceptual load trials (Lavie & Fox, 2000). This suggests that distractors were processed in low perceptual load, but not high perceptual load displays. Evidence from neuroimaging studies also point to perceptual load effects at the neural level. Rees, Frith, and Lavie (1997) found that cortical responses in the visual cortex to motion distractors were only evoked in low perceptual load conditions whereas distractor words did not provoke a neuronal response when participants were engaged in a central picture task with high perceptual load. Other studies have shown that high perceptual load attenuates visual cortex activity in response to task-irrelevant checkerboards (Schwartz, Vuilleumier, Hutton, Maravita, Dolan, & Driver, 2005), and reduces parahippocampal activity related to images of places (Yi, Woodman, Widders, Marois, & Chun, 2004). In summary, over the past decade, the predictions of load theory have converged across a range of tasks and distractor measures suggesting that the extent of distractor processing is dependent on the level of perceptual load in the relevant task (for reviews see Lavie, 2005, 2010).

In an important experiment for perceptual load theory, Lavie and de Fockert (2003) also delineated the boundary conditions of perceptual load effects on attention by contrasting these effects with the effects of task difficulty on attention. Perceptual load can be manipulated by increasing the number of task-relevant items or by increasing perceptual processing requirements, thereby placing higher attentional demands on available resources (i.e. increasing data "resource limits" (Lavie, 2005, 2010). Task difficulty on the other hand can be increased by manipulations of extreme sensory degradation, altering sensory "data limits" (e.g. by manipulating contrast or size of a target) without increasing perceptual load (Lavie & de Fockert, 2003). Lavie and de Fockert (2003) demonstrated that whereas an increase in perceptual load resulted in reduced distractor processing, task difficulty (as defined above) disrupts task performance while having no effect on distractor processing. The effect of perceptual load on attention can therefore not simply be attributed to general task difficulty and instead reflect load-specific effects on perceptual resources.

Conscious awareness and perceptual load theory

The majority of studies that were published following the initial proposal of perceptual load theory (Lavie, 1995; Lavie & Tsal, 1994), including the ones mentioned above, have typically investigated the effects of visual perceptual load on distractor processing via response interference effects. In these studies, the extent to which a distractor was processed was reflected in the RT costs associated with the presence of a response-incongruent distractor (requiring the opposite target response). Conversely, the absence of RT differences between incompatible compared to neutral or compatible trials was taken as evidence that distractors were not processed. Although these studies clearly demonstrated that distractor processing is reduced or even eliminated in conditions of high perceptual load, this cannot provide information on the effects of perceptual load on conscious awareness of those distractors. Perceptual load theory would suggest that the elimination of interference effects seen at high levels of perceptual load is a result of a reduction in distractor perception. By extension, this may then indicate that there is no conscious perception of distractors at high levels of perceptual load. Alternative explanations are however also viable. For example, greater reaction time costs incurred on incompatible versus compatible trials could reflect post-perceptual processes such as response selection. Alternatively, distractors may never enter awareness regardless of load, but activate more strongly unconscious recognition processes of distractor-/target-response associations under low perceptual load. The effects of reaction times can therefore potentially be attributed to a range of mechanisms and cannot provide clear evidence whether distractors were actually consciously perceived and thus entered awareness.

Specific evidence that perceptual load can determine unconscious processing was provided by several studies (Bahrami, Carmel, Walsh, Rees, & Lavie, 2008; Bahrami, Lavie, & Rees, 2007). Bahrami et al. (2007) for example presented participants with a rapid serial visual presentation (RSVP) task that featured a central stream of letters presented at fixation whilst measuring V1 responses (neural response in the primary visual cortex) to invisible irrelevant stimuli that participants did not consciously perceive (using the continuous flash suppression method). Although these stimuli were invisible in both perceptual load conditions, V1 responses to these invisible gratings were significantly diminished under higher perceptual load of the task. These findings indicate that increasing perceptual load can reduce unconscious processing at very early stages of visual input. Clearly, any evidence from studies on the neural effects of perceptual load on processing irrelevant information cannot provide information on conscious experience.

Several studies have now begun to investigate how the level of perceptual load of a visual task affects perception and awareness of an additional visual stimulus using the inattentional blindness paradigm. Inattentional blindness refers to the phenomenon that participants often fail to notice an unexpected visual stimulus on a critical trial when their attention is engaged in the primary task, yet report awareness on a following control trial when they are told not to engage in the primary task (Mack & Rock, 1998; Neisser, 1979). The term awareness in this context refers to the conscious and perceptual awareness of an additional visual stimulus that is accessible for report by an individual (Lavie, Beck, & Konstantinou, 2014). In a typical inattentional blindness task, participants perform a task (e.g. judging which line of a cross is longer) for some trials (Mack & Rock, 1998). On a ‘critical trial’ (also known as the ‘inattention trial’), an unexpected, additional visual stimulus (the critical stimulus, e.g. a shape) is presented together with the cross stimulus. Once participants have responded to the primary task on this critical trial, participants are asked whether they have noticed anything else. The critical trial is followed by a control trial (referred to as the ‘full attention trial’) that also features the critical stimulus, yet requires participants to not pay attention to the primary task and instead pay attention to anything else that might appear. The term ‘inattentional blindness’ was coined by the observation that on the critical trial, most participants were not aware of the critical stimulus, yet reported awareness of the critical stimulus on a subsequent fully-attended control trial. The difference in awareness, or ‘blindness’ in relation to the critical stimulus between the critical and control trial must therefore be a result of a lack of attention towards it, hence the term inattentional blindness.

Cartwright-Finch and Lavie (2007) investigated whether the level of perceptual load modulated the incidence of inattentional blindness. The general design involved participants performing a central task featuring a cross stimulus for a short number of trials. The cross target was characterised by two arms of different colour (blue and green) and of different length. Perceptual load of the task was manipulated by presenting the same cross display across load conditions, yet depending on the condition, participants had to perform a different perceptual judgment task. In the low perceptual load condition, participants were required to make a simple judgment of colour (indicate which arm of the cross is blue), whereas in the high perceptual load condition, participants had to indicate which arm of the cross was longer, requiring a more subtle discrimination judgment. On a critical trial, together with the central cross stimulus, an unexpected visual stimulus in form of a black square appeared at the periphery of the screen and participants were subsequently asked whether they had noticed any other stimulus. The results indicated that performing in the high perceptual load condition resulted in higher failure rates of detecting the additional visual stimulus than in the low perceptual load condition, suggesting that attention and thus awareness of the critical stimulus was dependent on the level of perceptual load. The authors also demonstrated reduced awareness on a critical trial at higher levels of perceptual load in a task intermixing low- and high-load trials, and in a letter search task manipulating perceptual load by adding similar items to the display (Cartwright-Finch & Lavie, 2007).

Apart from these effects of perceptual load on awareness when the additional stimulus was unexpected, Macdonald and Lavie (2008) also measured awareness for a critical stimulus that participants expected and were instructed to detect. This design allowed measuring detection sensitivity for the critical stimulus, which has the advantage that its value does not depend upon the response criterion the subject is adopting, thereby providing a true measure of a subject’s sensitivity. Participants were required to perform a visual search task in form of a letter identification task (identify whether an X or N is present in the central display) at varying levels of perceptual load. Perceptual load of the central letter task was manipulated by varying the similarity between target letters (X or N) and non-target letters. The low perceptual load condition featured apart from the target letter other small letters that were not similar to the target (i.e. small *o’s)*, whereas in the high perceptual load condition, similar letters to the target (e.g. H, K, M, V, and Z) were presented. On each trial, participants also had to report the presence of a grey meaningless shape presented in the periphery (the critical stimulus). The results showed that despite participants anticipating and actively trying to detect the additional shape, performing the task at a high level of perceptual load resulted in a reduction in sensitivity, while having no effect on response bias. The same findings were also reported in an experiment in which participants had to make the detection response prior to the letter search task response, therefore ruling out the possibility of rapid forgetting or poorer encoding into memory during prolonged response times in the high perceptual load condition.

Carmel, Saker, Rees, and Lavie (2007) further extended these findings by measuring conscious flicker perception using the same manipulation of perceptual load in a visual search task. The results suggested that performing the task at a high perceptual load level reduced the detection of a flicker stimulus presented at fixation. Similar findings were also observed on a task that manipulated the processing requirements of the relevant task that either involved a simple feature discrimination task (low perceptual load) or a task requiring discrimination along a conjunction of features (high perceptual load) (Carmel, Thorne, Rees, & Lavie, 2011). In summary, various streams of research provided evidence for the role of perceptual load for conscious awareness in the visual domain, both when the additional stimulus was unexpected as in inattentional blindness paradigms, and when it was expected and repeated on multiple trials as in variants of a response competition (Eriksen flanker paradigm) and visual search task.

Cross-modal selective attention and perceptual load

Several studies have now also begun to examine whether the level of visual perceptual load modulates the extent to which participants can attend to additional auditory information. These studies have contributed to the much wider debate in attention research on whether there exist a central processing capacity for both vision and hearing that distributes processing resources across sensory modalities (Broadbent, 1958), or whether perceptual capacity is modality specific (Allport, Antonis, & Reynolds, 1972; Duncan, Martens, & Ward, 1997). This debate concerns the question of whether performing in one modality can affect performance in another modality.

In favour of a shared attentional capacity between senses, Sinnett, Costa, and Soto-Faraco (2006) showed that recognition memory for task-irrelevant words presented to both ears was reduced while monitoring either a rapid stream of pictures or sounds. This was the case for both within- (target and cue were presented in the same modality) and between modality conditions. These findings clearly show that word recognition depends on a capacity-limited resource common to vision and hearing. Santangelo, Olivetti Belardinelli, and Spence (2007), using a peripheral cuing paradigm, also found that a high perceptually demanding task of focusing attention on a central stream of visual characters reduced cuing effects for auditory peripheral cues relative to a less demanding spatial cuing task that served as a control condition. The authors concluded that performing the perceptually more demanding task of focussing on the central stream exhausted processing resources and reduced auditory cueing effects.

While the above studies hinted at an effect of visual demands on auditory processing, the level of visual perceptual load has also been specifically manipulated in a range of studies. For example, there is some evidence that the level of perceptual load in a visual task determines the incidence of inattentional deafness. Inattentional deafness is the auditory equivalent of the inattentional blindness phenomenon described earlier and relates to the failure to notice an unexpected auditory stimulus on a critical trial. Macdonald and Lavie (2011) adopted the inattentional blindness paradigm used previously by Cartwright-Finch and Lavie (2007) to show that awareness rates for an unexpected pure tone were significantly reduced under high visual perceptual load compared to low perceptual load (Macdonald and Lavie, 2011). Importantly, these effects remained when high- and low perceptual load trials were intermixed, therefore ruling out other explanations in terms of top-down factors such as load anticipation (c.f. Handy & Mangun, 2000; Murray & Jones, 2002; Theeuwes, Kramer, & Belopolsky, 2004). This suggested to the authors that vision and hearing share a common attentional resource, as performing a visual task with high perceptual load exhausted all available attentional capacity and led to reduced awareness. In the low perceptual load task however, attentional resources were not fully depleted and available resources automatically spilled-over into processing of the auditory stimulus.

Apart from these cross-modal effects on awareness for an unexpected auditory stimulus, Raveh and Lavie (2015) demonstrated that visual perceptual load can also modulate detection sensitivity for an expected auditory stimulus. In this study, participants were presented with a dual-task paradigm that involved a speeded visual classification task (i.e. indicate whether an ‘X’ or ‘N’ is present in a central ring) whilst also indicating whether an auditory stimulus was played simultaneously. The extent to which participants were able to also attend to the auditory stimulus was manipulated by adding non-target letters to the central task display. The results indicated that detection sensitivity for the auditory stimulus was significantly reduced under high visual perceptual load (featuring five non-target letters + target letter), both when the detection response was made prior to or after the visual target response and when the auditory stimulus was presented frequently (presented on 50% of all trials). Across different task paradigms, these studies have demonstrated that visual perceptual load modulates the extent to which participants can attend to other additional auditory information, providing evidence for a shared attentional capacity between visual and auditory sensory modalities.

There are however also some conflicting findings. Tellinghuisen and Nowak (2003) found that searching for a target letter in a high perceptual load condition (set size six) did not reduce interference effects from simultaneously presented response-incongruent auditory distractor letters. This in turn would suggest modality-specific capacity resources. However, the auditory distractor was presented for a longer period than the search task, finishing 200ms after the offset of the search task, suggesting that the longer temporal overlap between visual and auditory stimuli in the high load condition (due to longer search times) could have offset any perceptual load effect.

Matusz, Broadbent, Ferrari, Forrest, Merkley, and Scerif (2015), in a recent study, provided evidence that at least in adults, a longer temporal overlap between visual and auditory stimuli cannot account for these findings. They asked participants to search for a coloured shape according to a conjunction of features (a red square or a green circle) amongst other non-target shapes (red and green triangles, circles, and squares). The perceptual load of the task was manipulated by either presenting the target shape alone (low perceptual load), or together with three non-target shapes (high perceptual load) in one of six possible locations. Distractors were either compatible or incompatible with the target response and participants performed in three distractor conditions: (1) visual (visual flanker presented in the periphery), (2) auditory (voice recordings of a person saying “red” or “green”), or (3) audio-visual (visual flanker + voice recording). When the presentation time of the auditory distractor and visual search display was equal, adults still displayed interference by auditory distractors at all levels of perceptual load. These results therefore indicated that visual perceptual load did not affect the extent to which auditory distractors were processed.

Using steady-state evoked potentials, a study by Parks, Hilimire, and Corballis (2011) examined how visual perceptual load can modulate the neural response to task-irrelevant auditory stimuli. Subjects were required to monitor a stream of crosses in a rapid serial visual presentation (RSVP) task according to either a single feature (colour) or a conjunction of features (colour and orientation). Simultaneously, irrelevant auditory distractors were also presented. The results indicated that auditory steady-state signals remained unchanged when the level of visual perceptual load increased. However, in an earlier study using a similar manipulation of visual perceptual load, reduced amplitude of an auditory-evoked microreflex was found at high perceptual load, suggesting the opposite effect of perceptual load on auditory processing (Parks, Hilimire, & Corballis, 2009).

Overall, the pattern of results for the cross-modal effects of perceptual load on attention is mixed. Whilst in some cases these effects may by study-specific, as in Tellinghuisen and Nowak (2003), the paucity of research in this area suggests the need for further investigation. In order to expand on the existing literature, the first experiment in this thesis examined how development affects the interaction between attention and awareness in cross-modal contexts of attention by adopting the framework of perceptual load theory.

Dilution theory

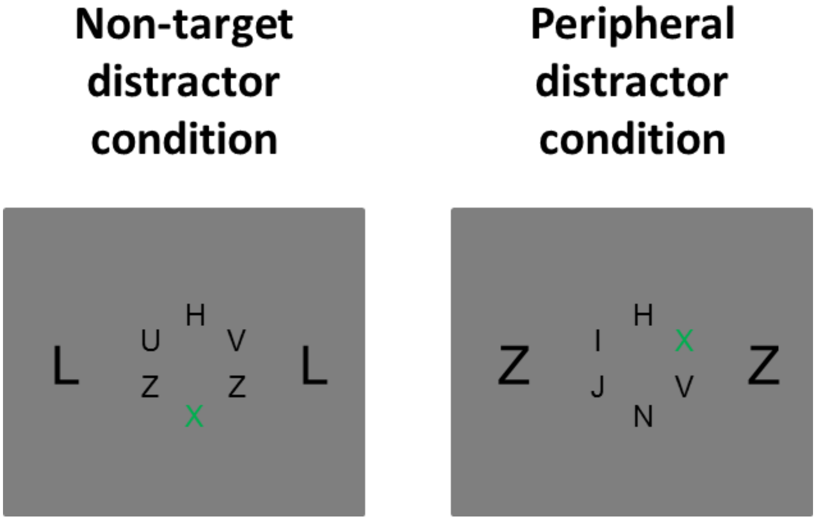
The main competing account to Load theory is Dilution theory (Tsal & Benoni, 2010a, 2010b). On this account, the reduction in distractor interference observed under high perceptual load (in tasks manipulating search set size) occurs as a result of the diluting effect of the distractor by neutral items. According to Tsal and Benoni (2010a, 2010b), the features of the non-target search items (e.g. neutral letters) competed with those of the distractor, thus degrading the quality of its visual representation and leading to reduced distractor processing. To demonstrate this, Tsal and Benoni (2010a) presented participants with a low perceptual load/high dilution search task, where the number of non-target items matched a typical high perceptual load display, but with these non-target items being clearly distinguishable from the target item (i.e. red target among white non-targets; see Figure 2.5).

Figure 2.5 Examples of stimulus displays used by Tsal and Benoni (2010a)

A low perceptual load in the relevant task was achieved by presenting the target letter in red among white non-target letters resulting in a stimulus ‘pop-out’ effect. In all conditions, participants had to identify a target letter (C or S) presented in the central array, whilst ignoring either a congruent (same response category as the target) or incongruent (opposite response category) peripheral distractor. The results revealed that in the low load/high dilution condition, although having a low perceptual load on attentional resources, the mere presence of non-target items (neutral letters) was sufficient to eliminate distractor processing. This dilution effect was subsequently replicated across other visual search paradigms (Fitousi & Wenger, 2011; Wilson, Muroi, & MacLeod, 2011).

Lavie however has countered this claim by demonstrating that in low perceptual load/high search set size displays, capacity in fact spills over into processing the non-target items in the search array, therefore ruling out an alternative explanation in terms of dilution (Lavie & Torralbo, 2010). They compared a high search set size condition with two peripheral distractors and a singleton colour target with a new non-target distractor condition. In this condition, two of the neutral non-target letters (e.g. V, H, U, J) were replaced with response competing distractor letters. These distractor letters were placed on either side of a green target letter (X or Z) and could be either response-congruent (e.g. target X, then distractor letters were X as well) or response-incongruent (e.g. target X, then distractor letters were Z) (see Figure 2.6 for an illustration).

Figure 2.6 Example of stimulus displays used by Lavie and Torralbo (2010)



Non-target distractor condition

Peripheral distractor condition

Note:
On the left, example of a non-target distractor condition (target X in green colour with adjacent non-target letters replaced by response incompatible distractor letters Z and response neutral peripheral letter L in black). On the right, example of a peripheral distractor condition (target X in green with adjacent neutral non-target letters and response incompatible peripheral distractor Z in black).

Whenever compatible or incompatible distractors were presented in the non-target distractor condition, the peripheral distractor was response neutral (e.g. letter L). The results indicated that in this new non-target distractor condition, participants recorded significantly slower RTs when response incompatible non-target letters were presented in the circle compared to response compatible letters. No RT compatibility effects were seen for the peripheral distractor condition. Together, this suggested to the authors that spare capacity is allocated to some of the non-target items in the display and not the peripheral distractor. Distractor interference effects are again restored when these can be measured via response interference effects on RTs once the non-target letters are response incongruent.

Lavie and Torralbo (2010) also point out that their interpretation of perceptual load effects in terms of dilution only pertain to one specific manipulation of perceptual load. That is, manipulating the relevant search set size and measuring its effect on distractor response competition effects. However, recall that apart from increasing the number of relevant items in a search task (e.g. by increasing the search set size), perceptual load can be manipulated by increasing the processing requirements of items in the relevant task (Lavie, 1995, 2005). The previous section outlined a number of published studies that have manipulated the perceptual load of a single-element display (e.g. line discrimination) and which have demonstrated reduced processing of task-irrelevant stimuli with increased perceptual load either behaviourally (Cartwright-Finch & Lavie, 2007; Macdonald & Lavie, 2011) or by reduced neural responses evoked by task-irrelevant information in high perceptual load single element displays (Carmel et al., 2011; Schwartz et al., 2005). The observation that the effects of perceptual load on attention has been robustly shown acrros a range of tasks, paradigms, and modalities suggests that perceptual load theory still remains the most plausible explanation for these findings.

Selective attention and autism

Lavie's perceptual load theory has recently been applied in a number of studies to examine visual selective attention in individuals with ASD (e.g. Remington, Swettenham, et al., 2012; Remington et al., 2009; Swettenham et al., 2014). The results obtained from these studies demonstrated that individuals with ASD continue to process other, additional information at higher levels of perceptual load than TD controls. Within the resource framework of perceptual load theory, this was interpreted as evidence that individuals with ASD are characterised by an increased perceptual capacity.

Before describing those studies, I will first outline the broader literature on selective attention in autism. Attentional atypicalities in individuals with ASD have been observed across a range of attentional components and the literature can be broadly divided on this basis. This includes arousal, sustained attention and shifting attention, as well as selectivity/filtering and visual search. It should be noted that a number of studies on attention and ASD have included a social component. Social attention in ASD will be discussed later in chapter five; therefore all studies presented here have only included socially neutral stimuli.

Arousal

A number of early studies proposed that the pattern in behaviour seen in individuals with ASD is related to a deficit in modulating arousal (see Bryson, Wainwright-Sharp, & Smith, 1990; Rogers & Ozonoff, 2005 for reviews). This literature however has yet to reach a consensus. While some have argued that individuals with ASD are characterised by hyperarousal (Hutt, Hutt, Lee, & Ounsted, 1964), others suggested that autism involves hypoarousal (Rimland, 1964). Evidence for hyperarousal was for example derived by the observation that children with ASD recorded elevated levels of desynchronised electroencephalography (EEG) (Hutt et al., 1964). Studies measuring skin conductance levels (SCL), frequency of skin conductance rate (SCR) (Palkovitz & Wiesenfeld, 1980) and differences in baseline heart rates (Ming, Julu, Brimacombe, Connor, & Daniels, 2005) further supported this hypothesis. However, others also reported normal or even reduced SCR levels and heart rate levels in high-functioning adults with ASD (Zahn, Rumsey, & Van Kammen, 1987), suggesting abnormal modulation of arousal. Rimland (1964) in fact proposed that individuals with ASD are characterised by hypoarousal, based on the observation that children with ASD preferred situations of greater stimulation. Others modified these two proposals by putting forward the idea of dysfunctional modulation of arousal (Ornitz & Ritvo, 1976). This theory attempts to account for the heterogeneity in reactivity often seen within the same individual with ASD by proposing that variability in response to sensory input is directly linked to the individual’s state of arousal. This means that in some situations, individuals would experience under-arousal and in other situation over-arousal. Support for this view also comes from Kinsbourne (1987), who observed both hyper-and hypo-responsiveness within the same child. Research into the role and influence of arousal in ASD has now however been largely abandoned, due to inconsistencies in findings (Burack, Enns, Stauder, Mottron, & Randolph, 1997; Goldstein, Johnson, & Minshew, 2001).

Sustained attention

Another important attentional component is sustained attention. This refers to the “capacity to maintain attentional focus on a task over an extended period of time” (Bowler, 2007, p. 115) and is typically measured using continuous performance tests (CPT, see Rosvold, Mirsky, Sarason, Bransome Jr, & Beck, 1956). On this task, subjects are required to respond to a pre-defined target presented within a stream of irrelevant stimuli. Casey, Gordon, Mannheim, and Rumsey (1993) for instance showed that autistic savants were less accurate (i.e. made more omission errors) than age-, and gender-matched controls at detecting visual and auditory target stimuli presented simultaneously in a continuous performance test (CPT). This suggested to the authors that autistic savants are impaired in their ability to respond to more than one task simultaneously. However, the small sample size in each group (n=10), substantially lower IQ scores in the ASD group, lower hearing thresholds than normal in 3 out of 10 autistic subjects, and ceiling performance of TD participants on both unisensory visual/auditory and cross-modal CPT tasks suggests that these results should be taken with caution. Indeed, when administering a visual CPT, Garretson, Fein, and Waterhouse (1990) found no difference between individuals with ASD and mental-age (MA) matched controls. Pascualvaca, Fantie, Papageorgiou, and Mirsky (1998) also demonstrated that when continuous shifts are required, as on continuous performance tasks, task performance between groups is similar. Yet when sudden shifts of attention are required, individuals with ASD experience more difficulty than controls. This literature on attention shifting will be considered next.

Orienting, Disengaging and Shifting attention

Orienting towards a new stimulus can be either exogenous (bottom-up, involuntary orienting) or endogenous (top-down, voluntary orienting) and can occur overtly, with corresponding head/eye movements or covertly, without these movements (Burack et al., 1997). Posner and Cohen (1984) proposed that orienting involves disengaging, shifting, and reengaging attention. In ASD, the functioning of some of these components, particularly voluntary endogenous orienting has been reported to be atypical (see Bowler, 2007 for a review; Townsend, Harris, & Courchesne, 1996; Townsend, Courchesne, & Egaas, 1996; Wainwright-Sharp & Bryson, 1993), while exogeneous orienting seems to be relatively spared (Burack & Iarocci, 1995; Iarocci & Burack, 2004). Generally, deficits in orienting present themselves as a larger RT difference between presentation of the cue and target response (Townsend, Harris, et al., 1996; Townsend, Courchesne, et al., 1996; Wainwright-Sharp & Bryson, 1993). Difficulties in endogenous shifts of attention in ASD have been suggested to be at the response selection level, where individuals with ASD have been found to be impaired in selecting the appropriate response and require more time than TD individuals to direct the shift of attention (Landry, Mitchell, & Burack, 2009).

Disengaging and shifting attention in individuals with ASD has also been specifically investigated. Courchesne and colleagues for example have demonstrated that individuals with ASD are slower at shifting attention between stimuli within a single modality, as well as between different sensory modalities (Courchesne, Townsend, Akshoomoff, et al., 1994; Courchesne, Townsend, & Saitoh, 1994). In one of their studies, Courchesne, Townsend, Akshoomoff, et al. (1994) presented subjects with ASD and a mental age and chronological age-matched TD group with a task that required shifting attention between visual and auditory modalities and a task that required focused attention. While the group with autism had no difficulties with the focused attention task, they were significantly slower and less accurate when they quickly had to shift attention between sensory modalities. Reed and McCarthy (2012) in a more recent study also found similar evidence. They demonstrated that children with ASD performed worse than TD controls on a visual-only switching task, but were particularly impaired when required to switch attention between an auditory and visual task.

Selectivity & filtering

Individuals with ASD are frequently observed to focus obsessively on certain items or details in their environment. One mechanism that was suggested to give rise to this behaviour is ‘stimulus overselectivity’ (Lovaas & Schreibman, 1971). This idea was based on the finding that individuals with ASD only used and responded to a limited number of stimuli in their environment. In their study, Lovaas and Schreibman (1971) trained autistic, developmentally delayed and typically developing children on a successive discrimination paradigm (similar to a go/no-go task) that involved responding to a complex stimuli made up of visual, auditory and tactile information. Once participants responded reliably to this compound stimulus, the individual components were presented separately (i.e. visual, auditory or tactile information alone), and responses were recorded. The authors found that children with ASD tended to only respond to one of the component cues, whereas control participants responded to each stimulus cue equally. From these findings it was concluded that individuals with ASD show overly selective attention, giving rise to behaviour patterns which are too restricted (Lovaas & Schreibman, 1971). While this initial study demonstrated overselectivity when all stimulus cues fell in different sensory modalities, subsequent studies confirmed this effect for situations in which multiple cues fall within the same sensory modality. For example, overselective response patterns in individuals with ASD have been shown for multicomponent visual stimuli (Fein, Tinder, & Waterhouse, 1979; Schreibman & Lovaas, 1973), dual-component auditory stimuli (Reynolds, Newsom, & Lovaas, 1974), and compound-tactile stimuli (Ploog & Kim, 2007).

Following on from these observations, Rincover and Ducharme (1987) proposed that stimulus overselectivity is second only to an overly selective gaze or “tunnel vision” in ASD – characterised by a focus of attention that is too narrow and that restricts processing to only some of the relevant information. This was based on the finding that the spatial distance between two visual cues determined the occurrence of overselectivity in ASD. When two features of a stimulus (colour and shape) were separated in space, children with ASD, but not controls, responded to only one stimulus feature (Rincover & Ducharme, 1987), suggesting that autism is characterised by an overly focussed attention. Mann and Walker (2003) however proposed that overfocus of attention in autism might be more readily explainable by a deficit in broadening the existing spread of visual attention. In their study, children with autism, in contrast to typically developing and intellectually impaired controls, were slower and less accurate to respond when a large crosshair was presented after a small crosshair, but not vice versa. This suggests that rather than having constant narrowed attention, the difficulty of individuals with ASD is to broaden visual attention again once it has been narrowed.

Other investigators suggested that the attentional abnormalities in autism reflect an inability to filter out irrelevant distractors (Burack, 1994). In Burack's study, participants were required to identify a target shape (O or +) that appeared in the same central location on each trial. Experimental conditions were varied according to the presence/absence of a spatial window narrowing the visual field, the number of distractors in the periphery and distance between the target stimulus and distractors. The results showed that while individuals with ASD benefited from a narrowing of the spatial window when no distractors were present, they performed worse than controls when distractors were present. Burack concluded from these findings that individuals with ASD have an "inefficient attentional lens", which impedes their ability to focus on a target stimulus and ignore other distracting stimuli. Similar evidence also comes from recent studies that found a selective deficit in filtering out, or inhibiting, distracting information in individuals with ASD compared to typically developing individuals. On variations of the flanker task (Eriksen & Eriksen, 1974), in which participants are required to detect a visual target surrounded by distractors, individuals with ASD consistently demonstrated larger degrees of interference in the presence of distractors than TD individuals (Adams & Jarrold, 2012; Christ, Holt, White, & Green, 2007; Christ, Kester, Bodner, & Miles, 2011).

These results have also received support from neurophysiological studies. Ciesielski, Courchesne, and Elmasian (1990) for instance recorded event-related potentials (ERP) from adults with ASD and controls as they performed a divided attention task (responding to a rare stimulus in either the auditory or visual modality whilst ignoring stimuli presented in the other modality). They demonstrated that individuals with ASD had some difficulty maintaining their focus of attention, and only attend to the relevant stimulus. ERP results confirmed the behavioural data and found that selective-attention related waves N270, Nc and P3b were attenuated within the ASD group but not in controls. Importantly, this was also the case for those individuals with ASD whose task performance (RT and accuracy) reached the level of controls. However, a later study from the same group did not find any differences between groups in behavioural performance, despite atypical activation pattern of event-related potentials (ERPs) in adolescents with high-functioning ASD (Ciesielski, Knight, Prince, Harris, & Handmaker, 1995). In TD participants, the ERP associated with voluntary attention as measured by the slow negative wave (SNW) gradually modulated in response to attentional demands, with the largest amplitude observed during focused auditory- and visual attention conditions, intermediate in response to the divided attention condition, and smallest in response to unattended stimuli. Such task related modulation of the SNW however was not found in autistic subjects, which was thought to indicate a deficit in selective inhibition and attention (Ciesielski et al., 1995). Nonetheless, individuals with ASD were able to perform the task as well as TD controls. This dissociation suggests that individuals with ASD did not need to deploy attention to the same extent as TD controls to be able to perform the task. Other subsequent studies also did not find a filtering deficit in ASD (Burack, Iarocci, Mottron, Stauder, Robaey, & Brennan, 1996; Iarocci & Burack, 2004).

Visual search

Visual search is one task domain in which selective attention has been studied extensively in both the typically developing population (Treisman & Gelade, 1980; Wolfe, 1998) and in ASD (O'Riordan, 2004; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998), and typically involves participants locating a specific target among non-targets. There are two types of visual search tasks: feature (where the target has a unique visual feature, i.e. red F target among green X and red T distractors) and conjunctive search (where the target has a unique combination of two or more features shared with the distractors, i.e. red X among red T and green X distractors). Research has shown that items are processed differently in these two search tasks (Treisman & Gelade, 1980). In conjunctive search tasks, target detection times generally increase linearly with increases in the number of distractors, indicative of serial search (one item is processed at a time until the target is found). Detection times in feature search tasks on the other hand do not increase at larger display sizes and the search is carried out in a parallel fashion with all items being processed at once. Both search tasks have been applied to investigate attentional abnormalities in ASD. Plaisted et al. (1998)

for instance have shown that while performance of individuals with ASD and controls did not differ on a feature search task (i.e. both groups demonstrated search times unaffected by array size), the pattern of search times for individuals with ASD on a conjunctive search task was markedly different to controls. In particular, reaction times (RTs) of individuals with ASD were not affected by increases in array size, whereas controls showed the usual linear increase in RT when the number of non-targets increased. Plaisted et al. (1998) interpreted these findings as evidence that individuals with ASD are using parallel search mechanisms as might be expected in feature search tasks, and that this may underlie their superior performance on tasks that require processing of unique features such as the Embedded Figures Task and the block design task (Shah & Frith, 1983, 1993). Other studies have also since reported superior visual search performance in both children (Jarrold, Gilchrist, & Bender, 2005; O'Riordan et al., 2001) and adults with ASD (O'Riordan, 2004).

O'Riordan et al. (2001) have put forward two processing mechanisms that could potentially explain superior visual search abilities in ASD: (1) enhanced memory for rejected distractor locations and (2) enhanced ability to discriminate between similar items. According to the first proposal, if individuals with ASD have an enhanced memory of already inspected distractor locations, search efficiency should improve and hence result in faster detection times. Joseph, Keehn, Connolly, Wolfe, and Horowitz (2009) tested this assumption by presenting a group of children with ASD and TD controls with a standard static search display or a dynamic search condition. In the latter condition, targets and distractors regularly changed positions, thus making memory of inspected locations of little value to the participant. Their results indicated that like TD children, children with ASD did not experience a deterioration of search performance in the dynamic display condition, suggesting that memory is not responsible for the superior search skills in ASD. The second possibility, enhanced discrimination, was tested by comparing the performance of children with ASD and IQ-matched controls on a visual search task where the similarity between targets and distractors was manipulated (O'Riordan & Plaisted, 2001). The authors demonstrated that while all children were affected by increases in target-distractor similarity, the control group was more adversely affected than the ASD group, thus supporting the hypothesis of enhanced discrimination in ASD.

Hence, while some studies on selectivity and filtering point to impaired selective attention in ASD thought to underlie increased distractibility (e.g. Burack, 1994), others have demonstrated enhanced performance of individuals with ASD on visual selective attention tasks.

In the next section, I am going to detail how Remington et al. (2009) attempted to account for this discrepancy in findings on visual selective attention in ASD by applying Lavie's Load theory of attention and cognitive control (e.g. Lavie, 1995; Lavie, 2005).

Perceptual load theory & selective attention in ASD

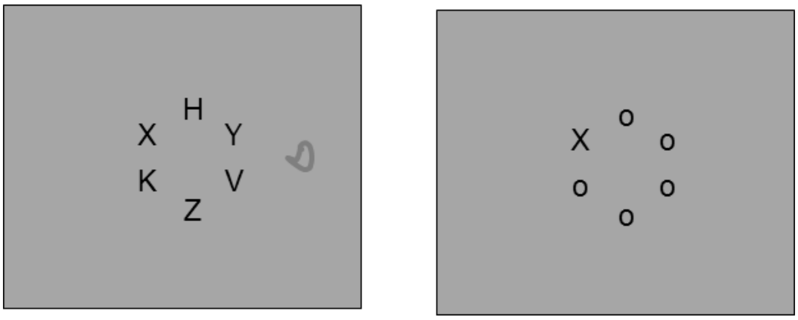
Load theory asserts that the extent to which irrelevant distractors will be processed depends on the level of perceptual load of the task. Perceptual load of a given task can be manipulated by increasing the number of different task stimuli and/or perceptual processing requirements, such as increasing the number of additional visual stimuli in a search display or by presenting participants with perceptually more complex processing requirements. Crucial to this model is the assumption that while perception processes have a limited capacity, any incoming stimuli that fall within this capacity are automatically and involuntarily processed until it runs out of capacity. It follows then that under conditions of low perceptual load (e.g. only target letter and distractor are presented) any spare capacity of the processing of task-relevant stimuli automatically "spills-over" to process irrelevant distractors. In tasks of high perceptual load however (e.g. identifying a target letter among five or six similar letters) all processing capacity is engaged by searching through the search array for the target letter, leaving no additional capacity to process irrelevant distractors (Lavie, 1995). The key factor is that the level of perceptual load at which task-irrelevant stimuli are no longer processed relates to an individual's perceptual capacity. In other words, an individual's perceptual resources will determine what constitutes high perceptual load for that individual.

Remington et al. (2009), using a hybrid between a visual search task (Treisman & Gelade, 1980) and a flanker task (Eriksen & Eriksen, 1974), assessed the extent to which visual distractors were processed under different levels of visual perceptual load in a group of adults with ASD and neurotypical adults (matched for chronological age and IQ). Participants were required to identify a relevant target letter (either X or N) briefly presented (100ms) among neutral letters in a central ring whilst attempting to ignore a distracting letter in the periphery, which could be either neutral (unrelated to the target letter; a T or an L) or incompatible (an X distractor when the target was N, or vice versa). When the perceptual load of the task was low (1 or 2 items in the search array), both groups were slower to search for a target in the presence of incompatible distractors compared to neutral distractors. This interference effect suggests that participants are processing distractors, (despite trying to ignore them). However, when perceptual load was higher (4 items in the search array) only the ASD group displayed an interference effect, suggesting that they continue to process distractors at a higher level of perceptual load than the comparison group. At even higher levels of perceptual load (6 search array items) there was no interference effect in either group. Remington et al. (2009) argued that this finding demonstrates a higher perceptual capacity in ASD as their capacity was not exhausted until there were 6 items in the search array, compared to 4 items in the search array for the neurotypical group. This study provided an indirect indication of the processing of task-irrelevant items by considering the reaction time costs within a focal task in the presence versus absence of the task-irrelevant items.

The increased perceptual capacity account of ASD may also explain why on some visual selective attention tasks individuals with ASD appear to demonstrate superior performance in (e.g., visual search and embedded figures), while on others they show a reduced resistance to distractors. Since according to load theory all stimuli in the visual field are processed automatically until perceptual capacity is reached, individuals with a higher perceptual capacity should process more information. This would lead to superior performance on tasks where all the information is task-relevant, as is seen for individuals with ASD in visual search tasks and embedded figures tasks (Hessels, Hooge, Snijders, & Kemner, 2014; O'Riordan, 2004; O'Riordan et al., 2001; Plaisted et al., 1998; Shah & Frith, 1983, 1993), particularly when perceptual load is high (e.g. when array sizes are large in visual search). When the information is task-irrelevant, then this would result in increased processing of distractor stimuli, as has been demonstrated with individuals with ASD using distractor tasks (Adams & Jarrold, 2012; Burack, 1994; Christ et al., 2007; Geurts, Luman, & Van Meel, 2008; Remington et al., 2009).

In Remington et al. (2009), the extent to which distractors were processed was measured via response interference effects at various levels of visual perceptual load. However, interference effects are only an indirect measure of distractor perception, as the to-be-ignored flanker (X or N), although presented at a different spatial location, is an exact copy of the target stimuli (also X or N). Hence, increased interference effects in ASD under high perceptual load might also be related to their inability to only focus on the central array of letters and ignore the peripheral distractor. In this sense, longer reaction times on incongruent trials may not necessarily reflect perception of those distractors, but instead reflect interference effects on response selection (Remington, Swettenham, et al., 2012). A subsequent study accounted for this effect by directly measuring detection of an additional visual shape which was both unrelated to the primary search task and was not required to be ignored by participants at different levels of perceptual load. Remington, Swettenham, et al. (2012) presented adults with ASD and controls with a dual-task paradigm, in which participants had to identify a target letter (X or N) in a ring of letters and then indicate absence or presence of a small visual shape presented on 50% of all trials in the periphery in one of six possible locations.

Figure 2.7 Stimuli used by Remington, Swettenham, et al. (2012)



Note: Left display (shape present, high perceptual load trial with target letter X)
Right display (shape absent, low perceptual load trial with target letter X)

Their results showed that detection sensitivity for the peripheral visual shape declined significantly as a function of visual perceptual load in controls, but remained unaffected in adults with ASD (Remington, Swettenham, et al., 2012). Importantly, detection remained high even under conditions of high visual perceptual load in participants with ASD, despite no cost in accuracy or reaction time on the central search task.

Recently, Swettenham et al. (2014) further tested the implications of the increased perceptual capacity account for perceptual awareness on an inattentional blindness task. Swettenham et al. (2014) presented children with ASD and age-and IQ-matched controls with either a subtle- (high perceptual load) or gross line discrimination task (low perceptual load). On a critical trial, an unexpected, additional visual stimulus (black square shape) was presented together with the central line discrimination cross in one of four possible locations in the periphery. Once participants had responded to the line discrimination they were asked whether they had noticed anything else. The results indicated that while high visual perceptual load reduced awareness of an unexpected visual stimulus in typically developing children, awareness rates remained high for children with ASD even when the perceptual of the central task was high. This finding suggests that in contrast to controls, ASD children had attentional resources left over indicating once again, an increased perceptual capacity. Importantly, the differential effect of high perceptual load between ASD and control groups was not due to differences in task performance, as both groups performed equally well on the low and high perceptual load line discrimination.

Further evidence for the differential effect of perceptual load on visual selective attention in ASD comes from functional magnetic resonance imaging (fMRI) studies. Ohta et al. (2012) used fMRI to measure brain responses evoked by irrelevant visual distractors at varying levels of perceptual load. In line with perceptual load theory and prior behavioural findings, increasing perceptual load reduced activation in visual cortices for both groups, yet this reduction at high perceptual load was significantly more pronounced for typically developing subjects than for subjects with a diagnosis of ASD. Examining these perceptual load effects at the neural level might also help to find a potential biomarker for an increased perceptual capacity in ASD. Schwarzkopf, Anderson, de Haas, White, and Rees (2014) have for example recently found larger extrastriate population receptive field maps (pRFs) in adults with ASD but not typically developing adults during performance of a visual task at varying levels of perceptual load. An enhanced capacity also seems to relate to the severity of autistic traits in the typically developing population. Bayliss and Kritikos (2011) found that those individuals with higher AQ scores in a large sample of neurotypical individuals reported greater interference effects by distractors at high levels of perceptual load. This (very) preliminary evidence suggests that an increased perceptual capacity may be part of the broader autism phenotype. Additional work using other complementary techniques would be desirable to further investigate these effects.

In the future, mapping of these specific brain-behaviour relationships may also contribute to broader initiatives in the field such as the Research Domain Criteria (RDoC) project from the US National Institute of Mental Health (NIMH). This framework emphasises dimensions both across and within psychiatric disorders and provides a very promising approach to investigate neurodevelopmental disorders independent of current DSM-5 and ICD-10 classification systems.

Perceptual load and cross-modal selective attention in ASD

Until now, the effects of perceptual load on perceptual awareness in ASD have only been demonstrated within the visual domain and it is currently not known whether this extends to contexts of cross-modal selective attention. Within the literature, the only studies that have investigated cross-modal selective attention in ASD have produced conflicting results and did not manipulate the perceptual load of the task.

Casey et al. (1993) for instance reported that autistic savants were less accurate than controls on a continuous performance test at detecting visual and auditory target stimuli presented simultaneously. However, methodological limitations of this study (small sample size, lower IQ scores in the ASD group among other) warrant caution in interpreting these results. Evidence from auditory-visual divided attention tasks is also mixed. While an early study reported impaired performance of individuals with ASD (Ciesielski et al., 1990), a subsequent study by the same group found similar behavioural performance between groups (Ciesielski et al., 1995). Interestingly, in the latter study, although individuals with ASD were able to perform the task as well as TD controls, they still showed atypical neural activation. This dissociation suggests that individuals with ASD did not need to deploy attention to the same extent as TD controls to be able to perform the task. It is difficult to tell whether these findings could be explained by an increased perceptual capacity in ASD. For example, in the divided attention condition, stimuli were presented in a serial order (2 flashes and 2 sounds presented in a random sequence), which suggests that performance on this task was dependent on rapid switching between target items rather than being able to process more perceptual information simultaneously. Perceptual load was also not directly manipulated in either of the above studies.

It therefore remains unclear whether the effects of perceptual load in ASD in the visual domain also translate to cross-modal contexts of attention. In everyday situations, attention is required to operate in a multisensory environment where incoming sensory information is rarely confined to a single sensory modality. If individuals with ASD are able to process more perceptual information regardless of the sensory modality within which this additional information is presented, then their experience of their sensory environment would be distinctively different to their peers. Anecdotally, this is often observed by clinicians and parents, with individuals with ASD able to perform in a well-controlled environment, yet experience difficulties and even distress if the environment features too many sensory stimuli.

In this respect, would individuals with ASD also demonstrate an increased perceptual capacity if a task features both visual and auditory stimuli? The research presented in this thesis will aim to answer this question by using different experimental paradigms that measure the effect of visual perceptual load on auditory awareness, and compare performance of children and adolescents with ASD with that of typically developing individuals. Before I am going to present the relevant research on ASD, I will present a study on the development of auditory awareness in the typically developing population.

Chapter 3 Development of awareness: Effects of age and perceptual load on inattentional deafness

Attention and awareness have traditionally been considered to be closely linked (Driver & Vuilleumier, 2001). This is supported by a range of phenomena that illustrate how salient stimuli (e.g. someone saying your name at a party) can capture attention (Moray, 1959), yet other quite conspicuous events (e.g. a person wearing a gorilla suit appearing unexpectedly) fail to get noticed if attention is directed somewhere else (Mack & Rock, 1998; Neisser, 1979). The precise nature with which attention and awareness interact however is the subject of a long-lasting and still on-going debate (see Koch & Tsuchiya, 2007; Lavie et al., 2014, for a review). Even less is known whether attending to one sensory modality (e.g. visual) influences awareness of a stimulus in another modality (e.g. audition), or indeed how development affects the interaction between these two processes.

The majority of developmental research on attention has typically used indirect reaction time (RT) measures to assess the magnitude of irrelevant distractor processing across different age groups. This body of research suggests that processes of selective attention and attentional control improve with age over childhood and into adulthood, and highlight how these changes in attention involve both significant improvements in the efficiency of attention with age (e.g. improved resistance to distractors), as well as the gradual development of attentional and information-processing capacities (see Plude & Enns, 1994; Ridderinkhof & van der Stelt, 2000, for a review). However, the question of how development affects the interplay between attention and awareness, and particularly how awareness is influenced in cross-modal contexts of attention, remains poorly understood.

One task that has been applied to investigate selective attention across development, and in particular the extent to which distracting information can interfere with a task response, is the garner interference task (Garner & Felfoldy, 1970). In this task, participants are asked to sort cards according to a single stimulus attribute (e.g. colour: red or orange) while ignoring its other dimension (e.g. form: square or circle). A drop in performance, i.e. longer RTs in response to a target dimension, is generally observed in a filtering condition where the irrelevant dimension varies randomly compared to a control condition where the irrelevant dimension remains constant (Garner & Felfoldy, 1970). In this condition, prolonged latencies are thought to reflect filtering costs associated with the processing of information in the irrelevant dimension. Shepp and Barrett (1991) for example asked 5- and 8-year-olds as well as adults to sort items according to shape, with colour constituting the irrelevant dimension. The results indicated that 5-year-olds (but not 8-year-olds and adults) were slower when colour varied independently of the shape of the object than when colour co-varied with the shape of the object. This was particularly pronounced for stimulus displays where the target and distractor dimension were conjoined in one stimulus and thus difficult to separate. The finding that younger children, but not older children or adults were processing the irrelevant aspects of the stimulus display therefore suggests that perceptual selection and gating of irrelevant information is less efficient in younger children (about 5 years of age), but improves gradually with age. Similar effects have been observed in an auditory version of the garner interference task, where children aged 3-6 years showed a greater degree of interference than adults when asked to selectively attend to a linguistic dimension (spoken word) while ignoring an auditory dimension of speech (speaker's gender) (Jerger, Pirozzolo, et al., 1993).

A number of studies have also shown that children are more susceptible to interference on Stroop tasks (Stroop, 1935) than adults (MacLeod, 1991). In the standard Stroop colour-word task (e.g. Stroop, 1935), participants are presented with a colour word printed in a conflicting hue (e.g. the word 'Blue' printed in red: Blue) and asked to name the colour of the ink whilst ignoring to read the word. Response latencies as measured by RTs in this condition (i.e. incongruent condition) are typically longer compared to control conditions in which, for example, the written text is congruent with the colour ink (e.g. the word 'Blue' printed in blue: Blue). In an early study that looked at inference effects across the life span (sample age range 7 – 80 years), Comalli Jr, Wapner, and Werner (1962) reported that the degree of interference from incongruent words (e.g. 'red' written in blue ink) on colour naming was greater in young children than adults. Whilst these interference effects decreased from childhood into adulthood, they became more pronounced in older ages, suggesting that perceptual control processes follow a linear developmental trajectory until they reach maturity in adulthood, after which they regress back to infantile levels in older ages. The finding of age-related improvements in attentional control on Stroop tasks has since been replicated with other visual stimuli such as non-target pictures (Day & Stone, 1980; Well, Lorch, & Anderson, 1980), printed words (Guttentag & Ornstein, 1990) and contextual shapes (Enns & Girgus, 1985). On auditory versions of the Stroop task, equivalent improvements in attentional control with age have been reported. Jerger, Martin, and Pirozzolo (1988) for example presented children aged 3- to 6-years with a speech Stroop-like task that required them to respond to a target speech dimension (e.g. talker gender) whilst ignoring the semantic content of the words being said by the talker. The semantic content could either be incongruent to the gender of the talker (e.g. hearing ‘daddy’ spoken in a female voice), congruent (e.g. hearing ‘daddy’ spoken in a male voice) or neutral (hearing ‘ice cream’ spoken in either voice). Children showed similar Stroop interference effects as adults, with slower response latencies on incongruent compared to congruent and neutral trials. The results also indicated that the magnitude of the interference effect (i.e. incongruent trials minus neutral trials) decreased significantly with age. Besides these reductions in interference on speech Stroop-like tasks (see Jerger, Stout, et al., 1993, for similar evidence), there is evidence that children become more efficient with age on cross-modal Stroop tasks. Hanauer and Brooks (2003) asked three age groups of children ranging from 4 to 11 years and adults to name the colour of visual targets (i.e. colour patches) whilst ignoring auditory distractors presented over headphones that could either be incongruent to the visual target (e.g. female voice saying ‘red’ if colour was green) or neutral (e.g. female voice saying a non-colour word). It was found that cross-modal interference effects on RTs were largest for the youngest children compared to older children and adults, and gradually diminished with age.

Further evidence that children are less proficient than adults to filter out irrelevant distractors was provided by response competition tasks (e.g. the Eriksen flanker task). Enns and Akhtar (1989) asked participants aged 4, 5, 7, and 20 years to perform a speeded response to a central target (square or plus) that was flanked by distractors on either side. The distractors were either identical to the target (compatible: e.g. square if target was square), neutral (object similar in perceptual complexity, but not associated with either target response) or were associated with the opposite target response (incompatible: e.g. plus if square was target). The results indicated that whilst all types of distracters led to significant RT costs, neutral distractors produced significantly greater RT costs in younger children than adults, suggesting again that perceptual interference of distractors was greatest in younger children and was reduced with age.

Despite the observation of poorer selective attention in children as reflected by larger interference effects from flanker stimuli, children and adults can demonstrate equivalent flanker effects when attentional demands are high (Huang-Pollock, Carr, & Nigg, 2002). The latter finding has been investigated within the framework of Lavie's Load theory of attention and cognitive control (Lavie, 1995; Lavie & Tsal, 1994). The theory proposes that successful focused attention (selection of task-relevant information over task-irrelevant information) depends on two mechanisms of selective attention. The first is a perceptual selection mechanism that details how the processing of flanker items is related to a 'spill-over' of untapped attentional resources into the processing of distracting information. Central to this mechanism is the idea of a limited processing capacity. Once this capacity is reached, as in high perceptual load tasks, no resources are available for any additional distractor processing. Low perceptual load tasks on the other hand do not consume all processing capacity and resources automatically 'spill over' into processing task-irrelevant information. The second mechanism is a more active mechanism of cognitive control that is needed to minimise interference from distractor stimuli when these are perceived (as in low perceptual load conditions). Efficient cognitive control is dependent on higher cognitive functions such as working memory to 'shield' task performance from distractor interference by maintaining current task priorities and goal-directed behaviour. Importantly, these control functions only become relevant in task situations where the distractor is perceived and interferes with a target response, and not when the distractor is already filtered out at an early perceptual stage as in high perceptual load displays. Contrary to the predicted effect of perceptual load on focussed attention, loading these control functions (e.g. by increasing working memory load) disrupts the ability to prioritise processing of task-relevant information and instead leads to increased distractor processing (Lavie, Hirst, de Fockert, & Viding, 2004). Thus, whereas high perceptual load should lead to less distraction, a high level of load on cognitive control functions should lead to more distraction (Lavie, 2000, 2005, 2010).

Huang-Pollock et al. (2002) examined interference effects across different age groups (children aged 7-8 years, 9-10 years and 11-12 years and adults) in a response competition task under varying levels of perceptual load. Participants made a speeded target letter response while a distractor letter (compatible, incompatible or neutral) appeared in the periphery. The perceptual load of the task was manipulated by increasing the search set size (adding one, three, or five non-target letters to the central letter display). Low perceptual load displays thus featured fewer attended objects, (i.e. fewer non-target letters in the central display) than did high perceptual load displays. It was found that at low levels of perceptual load, both children and adults showed large interference effects, which were eliminated for all age groups at the highest level of perceptual load. This suggests that at high perceptual load, children were able to ignore the distracting flanker, ruling out alternative explanations of a more general age-related deficit in inhibiting distractors. Interestingly, children experienced this reduction in interference at a smaller set size than adults. That is, smaller increases in perceptual load were sufficient in children to reduce distractor interference, suggesting that children’s more limited capacity was already exhausted at lower levels of perceptual load compared to adults. Maylor and Lavie (1998) also demonstrated age-related differences in perceptual load effects in older compared to younger subjects, with the former showing an elimination of distractor effects at earlier levels of perceptual load, suggesting that processing capacity declines with age. Taken together, these findings indicate that development involves both the maturation in attentional control mechanisms, and an increase in processing capacity that develops throughout childhood and into adulthood (McAvinue et al., 2012; Plude & Enns, 1994).

However, the aforementioned studies on distractor processing only provided an indirect measure of distractor perception (via RT performance). Consider for example the findings from response competition experiments reported earlier. There, longer target RTs in the presence of response-incongruent distractors (i.e. distractor identity was associated with the opposite target response) reflected the extent to which distractors were processed. This may imply that distractor stimuli were perceived, i.e. participants were aware of distractors. However, greater reaction time costs incurred on incompatible versus compatible trials could also reflect post-perceptual processes such as response selection. Finally, it is important to consider the nature of the irrelevant stimulus in studies of distractor processing compared to studies measuring awareness. In contrast to studies of distractor processing that measure the extent to which a distracting stimulus competes with a primary task response (via response interference effects), studies of awareness investigate the extent to which participants can report noticing an additional stimulus that is not interfering with a response and is expected to appear on only some of the trials (e.g. Macdonald & Lavie, 2008), or is not expected to appear (e.g. inattentional blindness) (Cartwright-Finch & Lavie, 2007; Remington, Cartwright-Finch, & Lavie, 2014; Swettenham et al., 2014).

In the visual domain, the inattentional blindness paradigm has been applied to investigate the effects of attention on awareness. Inattentional blindness refers to the phenomenon that participants often fail to notice an unexpected visual stimulus on a critical trial when their attention is engaged in the primary task (e.g. line discrimination), yet report awareness on a following control trial when they are told not to engage in the primary task (Mack & Rock, 1998; Neisser, 1979). The term awareness in this context refers to the conscious and perceptual awareness of an additional visual stimulus that is accessible for report by an individual (Lavie et al., 2014). Using an inattentional blindness paradigm, Remington et al. (2014) examined the role of perceptual load for awareness of a visual stimulus outside the focus of attention across different age groups. They presented children of varying age groups and adults with a line discrimination task (judging which line of a cross is longer) under varying levels of perceptual load (either a subtle (high load) or a gross (low load) line discrimination). On a critical trial, an unexpected visual stimulus (black shape) was presented in addition to the cross and participants were subsequently asked whether they had noticed anything else. The results indicated that younger children had reduced awareness for the additional stimulus (critical stimulus: CS) overall compared to older children and adults, and increasing the perceptual load of the task reduced awareness of the CS for children (7-14 years of age) but not adults. This suggested to the authors that awareness for stimuli outside of the focus of attention increases with age, and older children have an increased perceptual capacity compared to younger children.

As yet however, it is not known whether these developmental effects on awareness are also relevant in cross-modal contexts of selective attention. Will an increase in visual perceptual load also modulate auditory awareness across development, and will younger children’s awareness rates be more affected by increases in perceptual load? Opposing predictions of the results can be obtained from the findings of studies outlined in the literature review in chapter 2. In short, while some studies point towards perceptual load effects across modalities (Macdonald & Lavie, 2011; Parks et al., 2009; Raveh & Lavie, 2015), others have found that auditory processing is not dependent on the level of visual perceptual load (Matusz et al., 2015; Parks et al., 2011; Tellinghuisen & Nowak, 2003). For example, in the only study that also included children, Matusz et al. (2015) asked 6-year-olds, 11-year-olds and adults to search for a coloured shape according to a conjunction of features (a red square or a green circle) amongst other non-target shapes (red and green triangles, circles, and squares). The perceptual load of the task was manipulated by either presenting the target shape alone (low perceptual load), or together with three non-target shapes (high perceptual load) in one of six possible locations. Distractors were either compatible or incompatible with the target response and participants performed in three distractor conditions: (1) visual (visual flanker presented in the periphery), (2) auditory (voice recordings of a person saying “red” or “green”), or (3) audio-visual (visual flanker + voice recording). The results indicated that for visual distractors, increasing perceptual load reduced interference for all age groups, in line with previous findings by Huang-Pollock et al. (2002). Auditory distractors on the other hand were processed by all age groups regardless of the level of perceptual load. This would suggest that across development, processing of auditory distractors is not dependent on the level of visual perceptual load. However, in the study by Matusz et al. (2015) the auditory distractor was presented for a longer duration (500ms) than the visual search display (200ms), leaving open alternative explanations in terms of temporal overlap. Whilst the authors showed that in adults, unequal presentation times of the auditory stimulus was unlikely to be responsible for the results reported in the main study, they did not provide any evidence whether the same is true for the younger children (6- and 11-year-olds). The latter study also only provided an indirect measure of distractor perception (via RT performance), and therefore cannot support any direct conclusions about the extent to which task-irrelevant stimuli were perceived. Clearly, the limited amount of developmental research in this area of research necessitates further consideration.

With this in mind, the following study investigated how development affects the interaction between attention and awareness in cross-modal contexts of attention using perceptual load theory.

Experiment 1

An inattentional deafness task similar to that used by Macdonald and Lavie (2011), but adapted to suit younger participants was used. Participants from different age groups (5-6 years, 9-10 years, 14-15 years and adults) judged which line of a briefly presented cross was longer (horizontal vs. vertical) during six non-critical trials that only featured the visual cross stimulus. On a critical trial, an unexpected auditory stimulus was played concurrently with the visual stimulus and participants were asked whether they had noticed anything else. The extent to which attentional resources were still available on the critical trial to also perceive the unexpected auditory stimulus was manipulated by increasing the perceptual load of the visual line judgment task. This was achieved by increasing the processing requirements (i.e. adjusting the visual angle of one of the arms of the target cross) involved in the line judgment task. The low perceptual load condition thus featured a more gross line-length discrimination, whereas in the high perceptual load condition, a smaller line-length difference was used and therefore required a subtle line discrimination. The critical trial was followed by a control trial, which assessed whether participants noticed the auditory stimulus when their attention was not engaged on the visual task.

Prior to data collection, a pilot study comprising 20 adult participants and 10 young children (9-10 years of age), none of whom participated in the following experiment, was carried out to validate whether the changes in task parameters were effective. In contrast to the task used by Macdonald and Lavie (2011), the line length discrimination required in the current task was more obvious. In the low perceptual load condition, the shorter arm subtended 0.9° (vs. 1.4°) and the longer arm subtended 3.9° (vs. 3.8°). In the high perceptual load condition, the shorter arm subtended 2.4° (vs. 3.6°) and the longer arm subtended 3.9° (vs. 3.8°). The presentation time of the cross stimulus was also increased from 150ms to 170ms.

These changes were necessary to guarantee that the youngest children were able to perform the task at an adequate level and meet the strict inclusion criteria (see method section below). Based on previous findings that the capacity for awareness develops with age (Remington et al., 2014), it was hypothesised that younger children will show reduced awareness overall of an auditory stimulus compared to older children and adults. It was also hypothesised that across age groups, increasing visual perceptual load will reduce awareness of an auditory tone and that awareness reports in the younger age groups will be affected more by an increase in perceptual load than in the older age children and adults.

Method

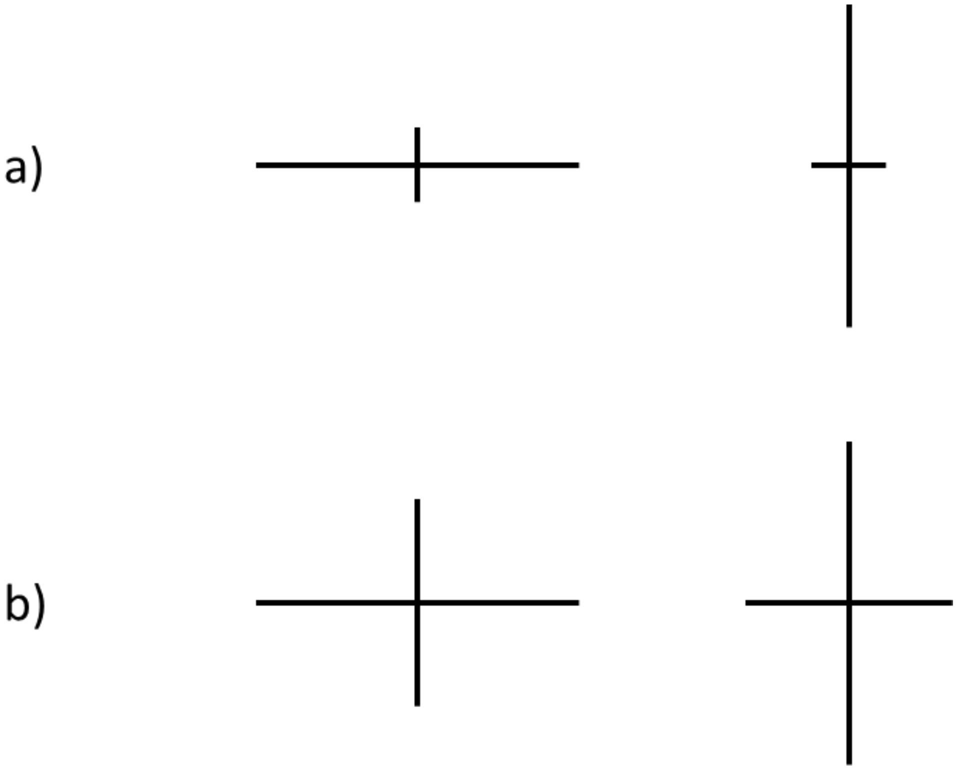
Participants

After applying a range of exclusion criteria (see below), a total of 157 participants, split into four age groups 5-6 years (*n* = 33, *M* = 6 y 1m, *SD* = 5m), 9-10 years (*n*= 44, *M* = 10y 3m, *SD* = 5m), 14-15 years (*n* = 40, *M* = 14 y 8m, *SD* = 4m), and adults (*n* = 40, *M* = 22y 7m, *SD* = 2.9 y) took part in the study. Informed consent was received prior of the experiment and all participants reported normal or corrected-to-normal vision. The design of this study is a 4x2 between subjects factorial design, with participants across the four age groups being randomly distributed across the two perceptual load conditions (high vs. low). Participants were excluded if they obtained a score of less than five correct on the six non-critical trials, were incorrect on the critical trial or were unable to hear the sound on the control trial. These exclusion criteria were necessary to ensure that all participants engaged with the primary task, were focused on the visual task during the critical trial, and were able to hear the critical stimulus (CS) on the control trial when their attention was not directed at the visual task. A total of 12 children (5-6 years) failed these exclusion criteria (eight scored less than five correct non-critical trials, three failed the critical trial and two failed to report awareness of the critical stimulus on the control trial). All 5-6 year-old children who scored less than five correct non-critical trials were in the high perceptual load condition. Three children (9-10 years) failed the critical trial and one adolescent (14-15years) failed the control trial. These participants were removed prior to analysis.

Stimuli

Microsoft Visual Basic (version 6) was used to create computer-based stimuli that were presented on an IBM Lenovo Thinkpad 14.1” personal laptop. Participants were seated directly in front of the computer screen such that viewing distance was 60cm. Fixation was indicated by a black circle (0.15°). Target displays consisted of a black cross (RGB: 0, 0, 0), presented in the centre of the screen, against a white background (RGB: 255, 255, 255). On each trial, either the horizontal (H) or the vertical (V) line of the cross was longer than the other one (presentation was randomised across the first 6 trials, and counterbalanced across participants on trial 7). Perceptual load of the primary visual task was manipulated by increasing the complexity of perceptual operations involved in the line discrimination task (Lavie, 2005, 2010). Apart from increasing the number of relevant items in a search task (e.g. by increasing the search set size), perceptual load can be manipulated by increasing the processing requirements of items in the relevant task (Lavie, 1995). For example, a more subtle line discrimination task should demand considerably more attentional resources than a gross line discrimination task. There have been a number of published studies that have manipulated the perceptual load of a single-element display (e.g. line discrimination) and demonstrated reduced distractor interference with increased perceptual load either behaviourally (Cartwright-Finch & Lavie, 2007; Macdonald & Lavie, 2011; Remington et al., 2014; Swettenham et al., 2014) or by reduced neural responses evoked by task-irrelevant information in high perceptual load single element displays (Carmel et al., 2011; Schwartz et al., 2005). In the current study, the visual angle of one of the arms of the target cross was therefore adjusted, so that perceptual identification was more demanding on attention. In the high perceptual load condition, a cross with a shorter arm subtending 2.4° and a longer arm subtending 3.9° appeared, whereas in the low load condition, a cross with a shorter arm subtending 0.9° and a longer arm subtending 3.9° appeared (see Figure 3.1). The auditory stimulus used was a 180-Hz pure tone of 69.4dB played through a pair of Sennheiser HD 25-1-II stereo headphones. The intensity level was measured prior to the experiment by a Bruel & Kjaer 4153 artificial ear together with an Ono Sokki CF-350Z spectrum analyser.

Figure 3.1 Illustration of stimuli used in (a) the low perceptual load condition and (b) high perceptual load condition

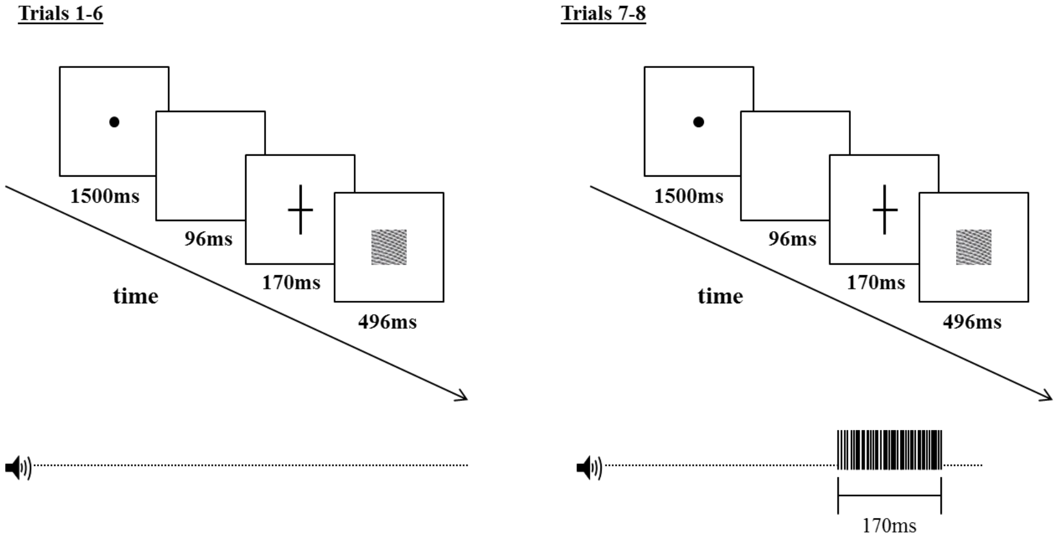


Note: In each perceptual load condition, presentation of the two crosses was randomised across trials

Procedure

Prior to starting the computer task, the experimenter made sure that each child was able to correctly discriminate which line of a cross presented on an A4 sheet of paper was the longer one. Participants were then told that the cross will only appear very briefly on the screen, and that they need to fixate on the middle of screen in order to tell the experimenter which line of the cross was longer. They were also told that they need to wear headphones as part of the experiment. Each trial began with the presentation of a fixation circle subtending 0.15° in the middle of the screen (1500ms); followed by a blank screen (96ms), a centrally located target cross (170ms), and a visual mask (496ms). A blank screen was then displayed and participants indicated which line of the cross was longer (see Figure 3.2 for experimental procedure). Responses to the cross task were either obtained by children's verbal responses referring to the lines as "the one going up and down" (V) vs. "the one going across" (H), pointing to visual aids placed next to the computer depicting each possible target cross scenario, or making appropriate hand gestures. The experimenter then entered their response on the computer. On the seventh and critical trial, the same procedure applied, but an auditory stimulus was played concurrently with presenting the cross. Responses to the cross task were recorded as in the previous trials, but participants were also asked whether they had noticed anything else. Participants responded verbally, giving details of the critical stimulus (i.e. describing having heard a 'beep' sound or imitating the beep sound) where possible. This is the standard way of assessing awareness on the critical trial in inattentional blindness/deafness paradigms (Memmert, 2006; Simons & Chabris, 1999; Swettenham et al., 2014). The critical trial was subsequently repeated in a control trial, which measured awareness of the critical stimulus in absence of attention to the visual task. Participants were told prior to the control trial to ignore the cross stimulus and instead report anything else they notice. Only those participants who successfully identified the critical auditory stimulus on the control trial were included in further analyses.

Figure 3.2 Procedure of experimental trials

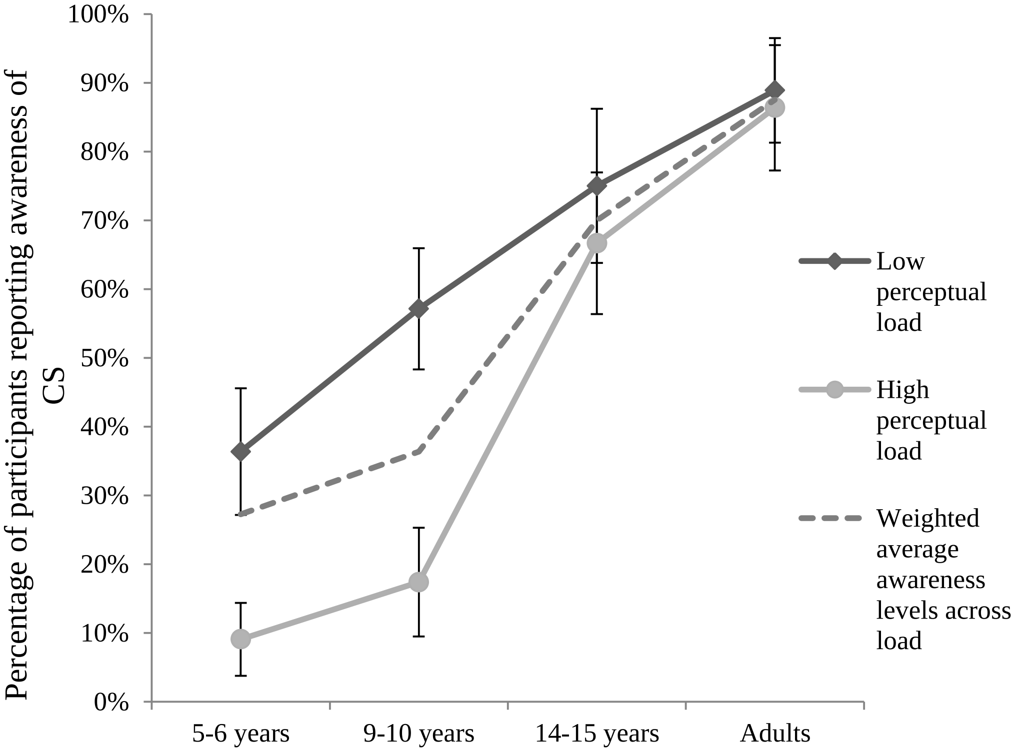


Results

Awareness of critical stimulus

Participants were considered to be aware of the critical stimulus (CS) if they reported hearing something on the critical trial and were able to accurately describe the auditory stimulus verbally or by imitating the beep sound. Awareness rates as a function of perceptual load and age group are shown in Figure 3.3. All statistical analyses used maximum likelihood ratio tests (model comparisons based on differences in -2 log likelihood).

Figure 3.3 Percentage of participants reporting awareness of the auditory stimulus (critical stimulus: CS) according to perceptual load and age group (error bars: 95% CI)



Effect of age and perceptual load on awareness rates

Controlling for the effect of perceptual load, the analysis revealed a significant increase in the percentage of children reporting awareness of the CS, $\chi 2$ (1) = 48.608, p < .001. Post-hoc comparisons (with Bonferroni-Holm corrected α-levels for multiple comparisons) indicated that the youngest children (5-6 years) failed to notice the presence of the CS significantly more often (9 of 33) than children aged 9-10years (16 of 44), $\chi 2$ (1) = 1.311, p = .252. In turn, children aged 14-15 years (28 of 40) showed significantly higher proportions of awareness reports than children aged 9-10 years, $\chi 2$ (1) = 9.707, p = .002. The difference in the proportion of awareness reports provided by 14-15 year old children compared to adults just missed significance, $\chi 2$ (1) = 3.749, p = .053.

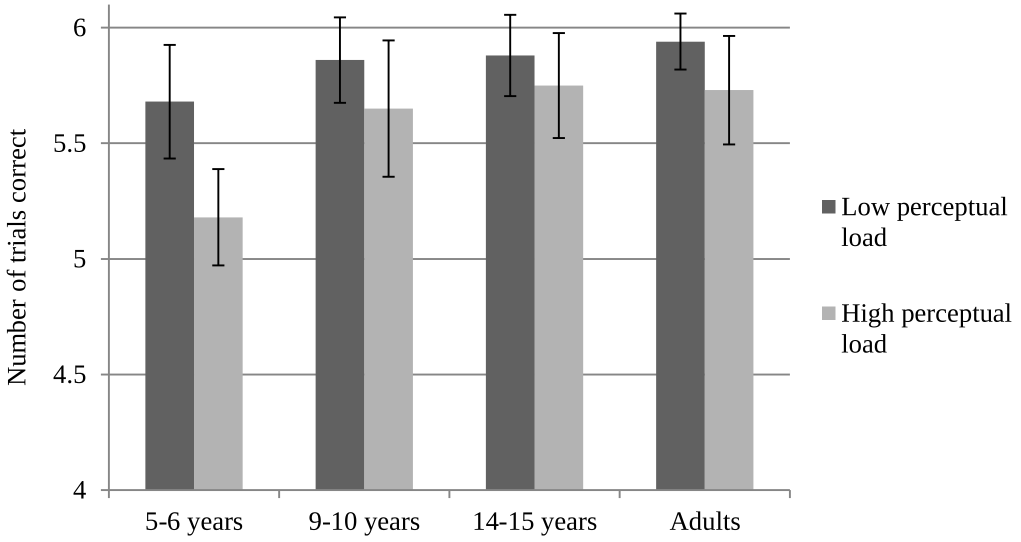
Furthermore, the significant increases in awareness reports with age were observed in both the low perceptual load condition ($\chi 2$ (1) = 13.915, p < .001) and high perceptual load condition ($\chi 2$ (1) = 39.839, p < .001). These results therefore indicate that awareness for an auditory stimulus outside the focus of attention increased from 9-10 year-olds onwards into adulthood.

Across all age groups, a significantly lower proportion of participants reported awareness of the CS in the high perceptual load condition (40 of 80 noticed the CS) compared to the low perceptual load condition (48 of 77 noticed the CS), χ^2 (1) = 10.097, p = .001. An interaction between the level of perceptual load and age group was also significant, $\chi 2$ (1) = 5.146, p = .023, suggesting that the effect of perceptual load is dependent on the age of participants. Individual comparisons indicated that increasing perceptual load from low to high significantly reduced awareness rates for 6-7 year old children (high load: 1/11, low load: 8/22, χ^2 (1) = 7.713, p = .005) and 9-10 year old children (high load: 4/23, low load: 12/21, χ^2 (1) = 7.747, p = .005). However, the level of perceptual load did not significantly modulate awareness in 14-15 year old children (high load: 16/24, low load: 12/16, χ^2 (1) = .322, p = .571) or adults (high load: 19/22, low load: 16/18, χ^2 (1) = .058, p = .809).

Cross task performance

Overall, participants across age groups made significantly more errors on the line discrimination task in the high (M = 5.64, SD = .51) compared to the low perceptual load condition (M = 5.83, SD = .38), $F(1, 149) = 13.606$, $p < .001$, $\eta_p^2 = 0.084$. Furthermore, there was a significant main effect of age group, $F(3, 149) = 5.975$, $p = .001$, $\eta_p^2 = 0.107$. Post-hoc comparisons (Bonferroni corrected α-levels for multiple comparisons) revealed that 6-7 year old children made significantly more errors than all other groups (all $p < .01$). There were no significant differences in error rates between 10-11 year old children, 14-15 year old children and adults. The interaction of perceptual load and group was not significant, $F(3, 149) = 1.146$, $p = .333$, $\eta_p^2 = 0.023$. This suggests that the youngest children, as with the older children and adults, were performing similarly across perceptual load conditions.

Figure 3.4 Task performance on line discrimination task according to perceptual load and age group (error bars: 95% CI)



Discussion

The findings indicated that with increasing age, participants failed less often to report presence of an additional, but unexpected auditory stimulus whilst being engaged in a visual line discrimination task and that an increase in perceptual load reduced awareness for children, but not adolescents and adults. Awareness rates were found to increase significantly from children (aged 9-10 years) to adolescents, and again to adults (albeit only approaching significance). This parallels findings in the visual domain, where similar age-related increases in awareness for a visual stimulus outside the focus of attention were found on an inattentional blindness task (Remington et al., 2014). The current findings therefore suggest that also awareness in cross-modal contexts of attention follows a developmental trajectory with linear increases in awareness observable throughout childhood and into adulthood. Note that this increase in awareness was observed both in low- and high perceptual load conditions. The finding that younger children (9-10 year olds) were less likely to notice the CS across these conditions supports the hypothesis that perceptual capacity is increased in older children compared to younger children, with these levels of perceptual load exhausting the smaller capacity of younger children to a greater extent.

There was no further significant increase in awareness from adolescents (14-15 year olds) to adults, potentially suggesting that the capacity for awareness develops with age until 14-15 years where it reaches a capacity level similar to adults. However, given that the task was adapted so that the youngest children were able to perform at an adequate level, it seems more likely that the current experimental set-up was not sensitive enough to detect any larger differences in awareness between these age groups. To further investigate these effects, a future study could present adolescents and adults with a more subtle line discrimination task (e.g. adopting the task parameters for the high perceptual load condition used by Macdonald & Lavie, 2011).

The results also showed that the effect of visual perceptual load on auditory awareness was dependent on age. In particular, increasing the perceptual load of the task reduced awareness for children (aged 6–10 years), but not adolescents or adults. This demonstrates a smaller capacity in children compared to adolescents and adults that is disproportionally taxed by an increase in perceptual load, thereby restricting processing of the auditory tone to reach conscious awareness. Note that reduced awareness in the high perceptual load condition is unlikely to be explained by a trade-off in line discrimination accuracy. There were no differences in task performance between perceptual load conditions for all age groups, including the youngest age groups. This is of course related to the strict exclusion criteria that were in place to ensure that participants engaged well with the visual task. Only those participants who performed correctly on at least 5 out of 6 line judgments, and were correct on the critical trial were included. It is worth noting that the youngest children (5-6-year olds) experienced the greatest difficulty performing the task at these levels, particularly in the high perceptual load condition (12 participants were excluded). However, we decided that it was necessary to impose these strict criteria in order to confidently include only those participants who engaged well with the task. This was necessary to ascertain that any differences in awareness between perceptual load conditions are not a result of difficulties performing the line discrimination task.

A failure to notice the auditory stimulus can also not be attributed to the low intensity of the auditory stimulus. On both the critical and control trial, the auditory stimulus was played at hearing levels well above threshold and was therefore easily perceivable. Importantly, only those participants who noticed the auditory stimulus on the control trial were included in the final sample. The proportion of participants not meeting this requirement was very low (2 out of 157). While it is not clear why these participants did not hear the auditory tone, the low proportion of participants not noticing the tone suggests that the tone was played well above normal hearing threshold. Together, these results indicate that it is unlikely that a lack of engagement with the central task or low audibility of the auditory tone is responsible for the results. Instead, the current findings suggest that any differences in noticing the presence of an additional auditory stimulus was dependent on whether sufficient attentional resources were available after processing of the visual input finished.

The current findings therefore support the idea that vision and hearing share an attentional capacity resource (Brand-D’Abrescia & Lavie, 2008; Broadbent, 1958; Macdonald & Lavie, 2011; Santangelo et al., 2007; Sinnett et al., 2006). Sinnett et al. (2006) for example showed that recognition memory for task-irrelevant words presented auditorily was reduced while monitoring either a rapid stream of pictures or sounds. Whilst this was the case for both within- (target and cue were presented in the same modality) and between modality conditions, participants performed significantly better when attending to the words in a control condition. These findings clearly show that word recognition depends on a capacity-limited resource common to vision and hearing. However, due to the long delay between presentation of the stimuli words and the recognition test raises the possibility that recognition failure may reflect, in some cases, rapid forgetting. In the visual domain, such ‘inattentional amnesia’ has been described by Wolfe (1999) and refers to the idea that a failure to detect a stimulus might be related to forgetting rather than not perceiving.

In the current study, could slower responding to the awareness question by younger children facilitated rapid forgetting and therefore resulted in lower awareness rates in younger children? There is evidence that younger children generally respond slower on a target task (as indexed by RTs) than older children and adults (Kail, 1991; Wickens, 1974). Kail (1991) for instance, in a meta-analysis of 70 studies, found that during childhood and adolescence, mean RTs increased linearly as a function of adult RTs in corresponding conditions. It is therefore possible that the younger children simply took longer to respond to the target task, thereby allowing a greater time window between presentation of the stimulus and the surprise question in which to forget the presence of the critical stimulus. Unfortunately, the absence of RT data in the current study does not allow us to evaluate this possibility. In the current study, I decided that it was important to keep the number of trials to a minimum in order to ensure that as many children as possible continued to engage with the task. To investigate the developmental effects of perceptual load on awareness in a cross-modal context of attention, it was essential to include the youngest age group (5-6 years old children) in the study and keep them engaged with the task in order to guarantee reliable performance on the critical trial. Given the small number of experimental trials (6 trials + 1 critical trial) and therefore larger variability in reaction times across trials, it is unlikely that in the current task design, reaction time would have been a reliable measure of task performance. Future research could attempt to increase the number of trials and also measure participants’ reaction times in order to help rule out the possibility that reduced awareness in the younger children was a result of rapid forgetting.

Taken together, the findings suggest a smaller perceptual capacity in children compared to adolescents and adults, reflected by the observation that awareness for an auditory stimulus increased with age and an increase in perceptual load reduced awareness in children but not adolescents and adults. This therefore demonstrates how development involves the maturation of perceptual capacity and its relevance for selective attention in cross-modal situations. In the following chapters, I am going to investigate the effects of visual perceptual load on auditory awareness in children and adolescents with Autism Spectrum Disorders.

Chapter 4 The effect of visual perceptual load on auditory awareness in Autism Spectrum Disorder

Perceptual and attentional atypicalities have often been reported in individuals with Autism Spectrum Disorder (ASD) and are now also included in the new DSM-5 criteria (American Psychiatric Association, 2013). The most prominent theories attempting to account for perceptual anomalies in ASD, such as Weak Central Coherence (Frith, 1989b; Happé & Frith, 2006) and Enhanced Perceptual Functioning (Mottron et al., 2006), have focussed on explaining enhanced processing of local, low-level information or scene-detail in stimuli. For example, in the visual domain, a preference for local processing could be reflected by performance on the Navon task (Plaisted et al., 1999), the embedded figures task (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983) and the block design task (Happé, 1996; Shah & Frith, 1993); and in the auditory domain by a higher incidence of perfect pitch (e.g. Heaton, 2003) and enhanced frequency discrimination skills, at least in a subgroup of those with ASD (Bonnel et al., 2010; Jones et al., 2009).

Recent work on visual selective attention has proposed that individuals with Autism Spectrum Disorder (ASD) are characterised by an increased perceptual capacity (Remington, Swettenham, et al., 2012; Remington et al., 2009; Swettenham et al., 2014). This proposal attempts to account for enhanced processing of low-level information and scene-detail, as well discrepant findings in visual selective attention in ASD. For example, whilst a number of studies suggest a deficit in selective attention as evidenced by higher distractibility to task irrelevant stimuli (Adams & Jarrold, 2012; Burack, 1994), others indicate that individuals with ASD are characterised by superior selective attention (e.g. Joseph et al., 2009; Plaisted et al., 1999; Shah & Frith, 1993).

The proposal that individuals with ASD are characterised by an increased perceptual capacity has been based on the framework of Lavie's Load theory of selective attention (Lavie, 1995). Load theory asserts that the extent to which irrelevant distractors will be processed depends on the level of perceptual load of the task. The perceptual load of a given task can be manipulated by increasing the number of different task-relevant stimuli (e.g. increasing the number of additional visual stimuli in a search display) or by increasing the perceptual processing requirements (e.g. presenting a more subtle line discrimination task) (Lavie, 1995; Lavie & Tsal, 1994). It is not just the number of units in a task-relevant display which constitutes perceptual load, but even for single item displays “perceptual load correlates with the amount of information required to process each unit in order to produce the required perceptual response” (Lavie & Tsal, 1994, p. 185). Crucial to this model is the assumption that while perceptual processing is limited in capacity, it proceeds automatically and involuntarily until it runs out of capacity (Lavie, 2005, 2010). It follows then that under conditions of low perceptual load (e.g. only a target letter and one non-target letter are presented) any spare capacity after the processing of task-relevant stimuli automatically “spills-over” to process irrelevant distractors. In tasks of high perceptual load however (e.g. identifying a target letter among six non-target letters), full processing capacity is engaged by searching through the search array for the target letter, leaving no additional capacity to process irrelevant distractors (Lavie, 1995). The key factor is that the level of perceptual load at which task-irrelevant stimuli are no longer processed relates to an individual’s perceptual capacity. In other words, an individual’s perceptual resources will determine what constitutes high perceptual load for that individual.

It is also important to note that the effects of perceptual load on attention can be distinguished from the effects of task difficulty. Perceptual load can be manipulated by increasing the number of task-relevant items or by increasing perceptual processing requirements, thereby placing higher attentional demands on available resources (i.e. increasing data “resource limits” (Lavie, 2005; Lavie, 2010). Task difficulty on the other hand can be increased by manipulations of extreme sensory degradation, altering sensory “data limits” (e.g. by manipulating contrast or size of a target) (Lavie and de Fockert, 2003). Lavie and de Fockert (2003) demonstrated that whereas an increase in perceptual load resulted in reduced distractor processing, task difficulty (as defined above) disrupts task performance while having no effect on distractor processing.

As outlined earlier, increasing the perceptual load in a task has been shown to reduce both distractor interference effects as well as awareness of task-irrelevant visual stimuli in neurotypical individuals (see Lavie, 2010 for a review). However, this reduction has been shown to only occur for individuals with Autism Spectrum Disorder (ASD) at higher levels of perceptual load, potentially reflecting a higher perceptual capacity in ASD (Remington, Swettenham, et al., 2012; Remington et al., 2009; Swettenham et al., 2014).

Experiment 2

Until now the effects of perceptual load on perceptual awareness in ASD have only been demonstrated within the visual domain and it is currently not known whether this extends to contexts of cross-modal selective attention. Within the literature, the only studies that have investigated cross-modal attention in ASD have produced conflicting results and did not manipulate the perceptual load of the task (Casey et al., 1993; Ciesielski et al., 1995). Would individuals with ASD also demonstrate an increased perceptual capacity if a task features both visual and auditory stimuli? The following experiment examined whether increasing perceptual load in the visual modality also influences awareness for an auditory stimulus in a group of children with ASD and a neurotypical comparison group. To measure these effects, children diagnosed with ASD and a matched control group on chronological age and non-verbal ability were presented with the same inattentional deafness paradigm used in the previous chapter. Based on the findings in the previous chapter that perceptual load modulates the incidence of inattentional deafness in typically developing children and the findings suggesting that perceptual capacity is increased in ASD, I reasoned that children with ASD would also show reduced inattentional deafness under high visual perceptual load compared to typically developing children.

Method

Participants

44 typically developing (TD) children, attending a local mainstream school, and 29 children with a diagnosis of Autism Spectrum Disorder (ASD), attending a school specifically for children with a diagnosis of ASD, took part in the study. The sample of TD children used in this experiment was selected from the previous experiment and was carefully matched with the ASD sample for chronological age and non-verbal ability using the Raven's Standard Progressive Matrices (Raven, Raven, & Court, 1998) (for descriptives see Table 4.1). Informed consent for all participants was received prior to the experiment. All participants with ASD had received a clinical diagnosis of ASD from a trained, independent clinician using the ADOS and following criteria listed in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (American Psychiatric Association, 1994). ASD diagnosis was also confirmed at the time of testing using the Social Communication Questionnaire (current version of the SCQ; Rutter, Bailey, & Lord, 2003); with all participants in the ASD group scoring above the recommended cut-off score of 15. None of the participants had any other neurological disorder. Note that the SCQ was not administered to typically developing participants. Given the time constraints in collecting data, as well as the limited value to further understand the primary research questions, it was decided that it was more important to collect SCQ data on the ASD group alone. This applies to all experiments presented in this thesis.

The experimental design of this study is a factorial design with two independent predictors ('Perceptual load': high vs. low and 'Group': ASD vs. TD), with all participants being randomly distributed across the two 'perceptual load' conditions. Participants were excluded if they obtained a score of less than five correct on the six non-critical trials, were incorrect on the critical trial or were unable to hear the tone on the control trial. These exclusion criteria were necessary to make sure that all participants were engaging with the primary task on the critical trial that featured the additional auditory stimulus. Three children with ASD scored less than five correct non-critical trials (all in the high perceptual load condition) and therefore were removed from the sample. The final sample was composed of 26 children with

ASD (14 in the low load condition and 12 in the high load condition) and 44 typically developing children (21 in the low load condition and 23 in the high load condition). An independent samples t-test indicated that there were no significant differences in non-verbal ability scores and chronological age between groups, between perceptual load conditions and between group/perceptual load conditions (maximum t-value = 1.84, minimum p-value = 0.07).

Table 4.1 Descriptive statistics for each group

Group	**Statistic**	**CA** (years : months)	**Raven's Score**	**Cross-judgment task**	**SCQ score**
ASD (n= 26)					
Low load (n= 14)	M	10:4	34.5	6.64	19.71
	SD	0:6	6.9	0.63	3.79
	Range	9:3 – 11:5	24 – 45		15 – 24
High load (n= 12)	M	10:6	36.7	6.58	18.92
	SD	0:6	5.1	0.52	2.84
	Range	9:6 – 11:9	24 – 46		15 – 26
TD (n= 44)					
Low load (n= 21)	M	10:3	38.5	6.86	
	SD	0:5	6.2	0.36	
	Range	9:4 – 11:2	27 – 46		
High load (n=23)	M	10:2	38.2	6.65	
	SD	0:3	6.4	0.57	
	Range	9:5 – 10:8	27 – 49		

Note:
CA = Chronological Age
SCQ = Social Communication Questionnaire

Stimuli and Procedure

The same line discrimination task used in the previous chapter was given to participants, with either the horizontal (H) or the vertical (V) line of the cross being longer than the other one (presentation was randomised across the first 6 trials, and counterbalanced across participants on trial 7). Perceptual load of the primary visual task was manipulated by increasing the complexity of perceptual operations involved in the line discrimination task (Lavie, 2005). This was achieved by adjusting the visual angle of one of the arms of the target cross, so that perceptual identification was more demanding on attention. In the high perceptual load condition, a cross with a shorter arm subtending 2.4° and a longer arm subtending 3.9° appeared, whereas in the low load condition, a cross with a shorter arm subtending 0.9° and a longer arm subtending 3.9° appeared (see Figure 3.1). Responses to the cross task were either obtained by children's verbal responses referring to the lines as "the one going up and down" (V) vs. "the one going across" (H), pointing to visual aids placed next to the computer depicting each possible target cross scenario, or making appropriate hand gestures. The experimenter then entered their response on the computer.

On a critical trial, the same procedure applied, but an auditory stimulus was played concurrently with presenting the cross (for procedure see Figure 3.2). Responses to the cross task were recorded as in the previous trials, yet participants were also asked whether they had noticed anything else. This is the standard way of assessing awareness on the critical trial in inattentional blindness/deafness paradigms (Memmert, 2006; Simons & Chabris, 1999). Participants responded verbally, giving details of the critical stimulus (i.e. imitating the beep sound) where possible. The critical trial was subsequently repeated in a control trial, which measured awareness of the critical stimulus in absence of attention to the visual task. Participants were told prior to the control trial to ignore the cross stimulus and instead attend to any other stimulus they might notice. Only those participants who successfully identified the critical stimulus on the control trial were included in further analyses. Data from four children (2 TD and 2 ASD children) was excluded prior to analysis due to an inability to notice the critical stimulus on the control trial (no change in final sample size reported earlier).

Results

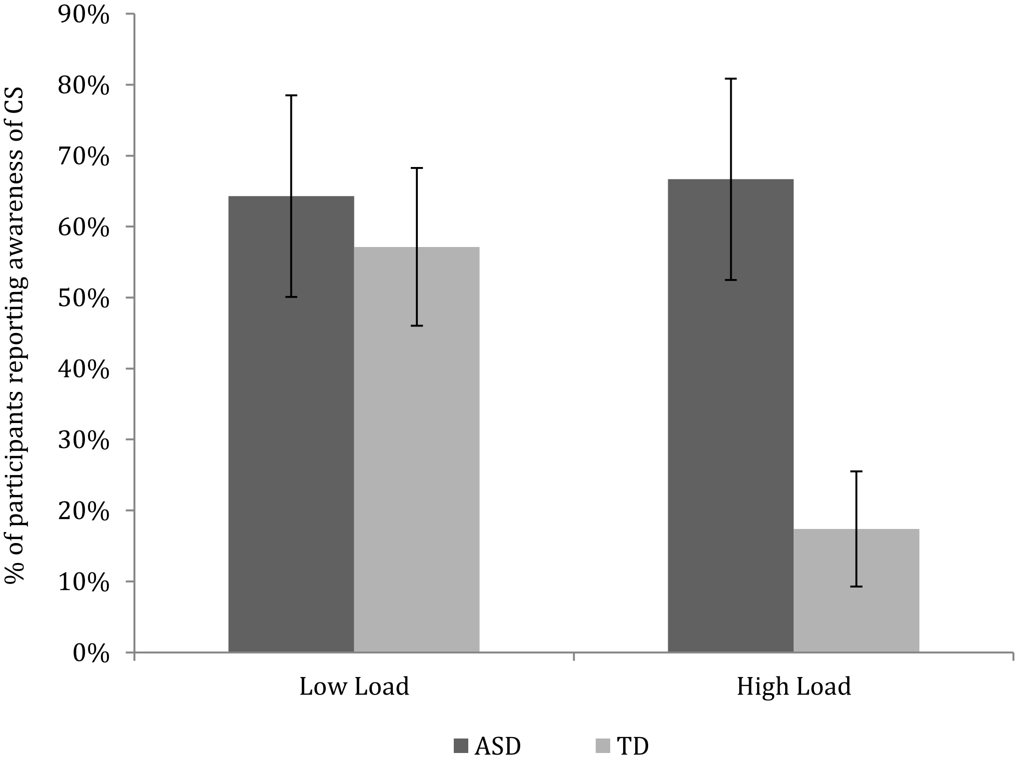
Cross task performance

Task performance was analysed by comparing the number of correct responses on the line discrimination task according to diagnostic group (ASD vs. TD) and perceptual load (high vs. low). A 2x2 between-participants ANOVA indicated that there was no significant difference in correct responses according to perceptual load (high load: *M* = 6.63; low load: *M* = 6.77), *F*(1,66) = 1.048, p = .310, η_p^2 = .02, suggesting that participants from both groups performed similarly across perceptual load conditions. To some extent, this result is not surprising, given the rather strict exclusion criteria that were in place to ensure all participants were engaged to a high degree with the primary task. Indeed, there was also no main effect of group (ASD: *M* = 6.62; TD: *M* = 6.75), *F*(1,66) = 1.201, p = .277, η_p^2 = .02 and no significant interaction between diagnostic group and perceptual load, *F*(1,62) = 0.317, p = .575, η_p^2 = .005, suggesting that both groups engaged well with the task.

Awareness of critical stimulus

Participants were considered to be aware of the critical stimulus (CS) if they reported hearing something on the critical trial, and were able to accurately describe the auditory stimulus verbally or by imitating the beep sound. Awareness rates as a function of perceptual load and group are shown in Figure 4.1.

Figure 4.1 Percentage of participants reporting awareness of the auditory stimulus (critical stimulus: CS) according to perceptual load and diagnostic group (error bars: standard error)



Due to the binary nature of the dependent variable, a hierarchical logistic regression analysis was carried out to predict awareness of the auditory stimulus (0 =“No”, 1 =”Yes”) according to perceptual load, diagnostic group, and their interaction. In a first step, an intercept-only model was compared against a model with perceptual load and diagnostic group as predictors. The latter model was subsequently compared to a full model including the interaction between perceptual load and diagnostic group. All statistical analyses used maximum likelihood ratio tests (model comparisons based on differences in -2 log likelihood) and the statistical cut-off criterion for all predictors was set at .05.

The first regression model predicting awareness of the critical stimulus (CS: unexpected auditory stimulus) from perceptual load and diagnostic group performed significantly better overall than the intercept-only model, χ^2 (2) = 10.054, p = .007. The Hosmer and Lemeshow test also indicated a good fit of the model to the data, χ^2 (2) = 3.322, p = .190. When controlling for the effect of group, there was a significant effect of perceptual load on awareness, χ^2 (1) = 4.467, p = .035, with participants in the high perceptual load condition being 0.342 times less likely to notice the stimulus than participants in the low perceptual load condition.

Table 4.2 Logistic regression analysis predicting awareness of the critical stimulus from perceptual load condition and diagnostic group

Variable	**B**	**SE B**	**df**	**Maximum Likelihood Estimation (MLE)**	**p**	**Odds ratio (OR)**	**95% CI of OR**
Perceptual load	-1.074	.518	1	4.467	.035*	.342	.124 - .943
Group	1.212	.537	1	5.357	.021*	3.361	1.173-9.632
Load X Group	2.251	.823	1	7.479	.006**	9.5	1.892-47.689

Note:
* p < .05
** p < .01

Diagnostic group also significantly predicted awareness of the CS, χ^2 (1) = 5.357, p = .021 with participants in the ASD group being 3.4 times more likely to notice the critical stimulus (for maximum likelihood ratio tests, odds ratio and CI of odds ratio see Table 4.2). The interaction between perceptual load and diagnostic group was tested by comparing a full model that included all predictors (perceptual load, group, and their interaction), against a reduced model with only load and group as predictors. The likelihood ratio test revealed a significant interaction between perceptual load and group, χ^2 (1) = 7.479, p = .006, suggesting a different effect of perceptual load on detection between groups. In particular, whereas in the low perceptual load condition detection rates did not differ between groups (TD: 57% vs. ASD: 64%), χ^2 (1) = .179, p = .672, detection rates were significantly reduced for the TD group compared to the ASD group in the high perceptual load condition (TD: 17% vs. ASD: 66%), χ^2 (1) = 8.498, p = .004. An additional logistic regression analysis also confirmed that neither non-verbal ability scores (raw score on the Raven's Progressive Matrices) nor scores on the SCQ was a significant predictor (both p > .05) of awareness rates of the CS in the ASD group.

Discussion

The findings demonstrate greater awareness for an unexpected auditory stimulus (critical stimulus: CS) overall and a reduced effect of visual perceptual load on CS awareness in children with ASD compared to typically developing (TD) children. Importantly, the increased rates of CS awareness in children with ASD, when visual perceptual load was high, are not likely to be explained by deterioration in task performance on the line discrimination task. These findings suggest an increased perceptual capacity in children with ASD that operates across sensory modalities.

According to Load theory, whether or not a stimulus reaches awareness depends on whether sufficient capacity is available to process additional information. Whereas high perceptual load conditions should result in lower awareness rates as all processing capacity is already exhausted by performing a primary task, low perceptual load leads to greater awareness as there is enough capacity available to also attend to any other additional stimulus (Lavie, 2005). It follows then that if the relevant task fails to exhaust capacity, then any excess capacity will automatically and involuntarily be allocated to the processing of any other stimulus regardless of whether that stimulus is task-unrelated. As awareness rates remained unaffected by the increase in perceptual load of the visual task in children with ASD, yet dropped significantly in TD children, the findings suggest that children with ASD had processing resources left-over to attend to the auditory stimulus after processing of the visual task finished. The findings from this experiment therefore provide further support for the hypothesis that individuals with ASD have an increased perceptual capacity.

Both groups showed equally high performance rates in the high as well as the low perceptual load conditions of the line discrimination task. Of course this was not surprising given that any participant who did not meet the criteria of 5 out of 6 correct discriminations on non-critical trials and a correct discrimination on the critical trial (when the CS was presented) was excluded. It is worth noting though that only three participants failed to reach these inclusion criteria. All three were children with ASD in the high perceptual load condition. It is not possible to tell exactly why these three participants did not perform well on the line discrimination task, this may have been due to a lack of motivation, a misunderstanding of instructions or a genuine difficulty in making discriminations. However, for the purpose of this study it was important only to include participants who were successfully performing the central task when the CS appeared. Any differences in CS awareness are therefore unlikely to be due to a lack of engagement with the central task. The participants' performance on the central task was only measured in terms of accuracy on the line discrimination task and not in terms of reaction time. In the current study we decided that it was important to keep the number of trials to a minimum in order to ensure that as many children as possible continued to engage with the task. Given the small number of trials and therefore larger variability in reaction times across trials, it is unlikely that in the current task design, reaction time would have been a reliable measure of task performance. Future research could attempt to increase the number of trials and also measure participants' reaction times in order to obtain a more nuanced measure of task performance. Such reaction time data could help rule out the possibility that increased detection rates occurred because the ASD participants had more time to divert attentional resources from the primary task to the unexpected auditory stimulus. Whilst this explanation cannot be completely dismissed with the current data, it seems unlikely given the experimental set-up. The auditory stimulus was a single, unexpected event and as a result, participants were neither expecting the additional auditory stimulus nor the surprise question following the critical trial. As the auditory stimulus was unexpected, it seems unlikely that task strategies influenced detection rates such that participants prepared to divert attention to the unattended modality prior to the critical trial.

The results also indicated that overall cognitive abilities (non-verbal ability scores) and ASD symptomatology (SCQ scores) were not able to account for the increased awareness rates of the CS in the ASD group, suggesting that the results were not simply driven by a subgroup of more able children with ASD (i.e. those with higher non-verbal ability scores and lower SCQ scores). However, the sample in this study, as well as those from previous studies (Remington, Swettenham, et al., 2012; Remington et al., 2009; Swettenham et al., 2014) only included participants with ASD with IQs within the typical range. To date there have been no studies examining perceptual capacity in children with ASD who also have learning difficulties. Could the difference in awareness rates between the ASD and TD group be due to under reporting by the TD group? For example, there is evidence that individuals with autism are less concerned about social pressures and more ready to report veridical experience (e.g. Bowler & Worley, 1994). This seems unlikely as a main explanation for the findings given that the difference between the groups in reporting rates occurs in one load condition (high load) but not in another (low load) despite the auditory stimulus being the same in both.

Reduced awareness rates in TD children on the other hand cannot be attributed to the low intensity of the auditory stimulus. On both the critical and control trial, the auditory stimulus was played at hearing levels well above threshold and was therefore easily perceivable, and all participants noticed the auditory stimulus and were able to describe it on the control trial when their attention was not focused on the primary visual task. The observed group effect is also unlikely to be caused by any differences in cognitive abilities as all participants were carefully matched for performance on the Raven's Progressive Matrices.

The finding of reduced inattentional deafness under load in children with ASD extends existing work on the effect of perceptual load on selective attention in ASD. In particular, whereas previous demonstrations of an increased perceptual capacity in ASD have only been within the visual domain (Remington, Swettenham, et al., 2012; Remington et al., 2009; Swettenham et al., 2014), the current findings suggest that this increased capacity operates across sensory modalities. However, the one-trial nature of the inattentional deafness paradigm means that one should be cautious to not overstate the conclusions of this single study.

In the following chapter, I am going to examine whether a stimulus that conveys biological and socially relevant information (e.g. a person greeting another person) would produce similar results. In the visual domain, there is evidence that social stimuli (e.g. faces) do not capture attention to the same extent in ASD compared to TD children. Remington, Campbell, and Swettenham (2012) for instance demonstrated that unlike TD adults who processed distracting faces regardless of the perceptual load of a task, adults with ASD only processed distracting faces at low levels of perceptual load, but not at high levels of perceptual load. These findings suggest that in the typical population, social stimuli have a "special status" and are processed in an automatic and mandatory fashion regardless of the perceptual load of a relevant task. Whether similar differences in attention to social auditory information can be observed will be investigated in the following chapter.

Chapter 5 The effect of visual perceptual load on auditory awareness of a social vs. non-social stimulus in ASD

Whereas the research presented so far has dealt with the cross-modal effects of attention on awareness of a neutral, socially-meaningless auditory stimulus (e.g. a simple sinewave tone), the purpose of the current chapter was to examine these cross-modal effects for social attention, in particular, the effects of visual perceptual load on awareness of a speech sound.

There is some evidence that in typically developing individuals, processing of distracting visual social stimuli (i.e. faces) is unaffected by the perceptual load of a relevant task. Lavie, Ro, and Russell (2003) found that interference from famous distractor faces was observed at all levels of perceptual load, including high perceptual load, suggesting that face stimuli cannot be ignored and are processed automatically. By contrast, increasing perceptual load in a task that featured irrelevant neutral, non-face stimuli (categorising the names of fruits and musical instruments while ignoring their photographs) eliminated interference effects from distractors. Continued interference in typical individuals under high perceptual load levels for irrelevant face stimuli, but not non-face distractors indicated that processing of face stimuli does not depend on general capacity limits. Instead, Lavie and colleagues proposed that face processing may have a separate, face-specific capacity (Lavie et al., 2003).

Applying perceptual load theory to investigate these effects in individuals with ASD, Remington, Campbell, et al. (2012) found that adults with ASD do not show the same prioritisation of attention towards faces. Participants performed a speeded classification task indicating whether a central target name, presented among other non-words, was female or male (e.g. Katie or John) whilst ignoring either congruent (same gender as target name) or incongruent (opposite gender as target name) distractor faces shown simultaneously in the periphery. The perceptual load of the task was manipulated by increasing the number of non-words adjacent to the target name. In individuals with ASD, processing of distractor faces was only evident at low-, but not at high levels of perceptual load, whereas TD individuals demonstrated a high level of distraction irrespective of the perceptual load of the task. This indicated to the authors that faces do not capture attention of adults with ASD to the same extent as in typical adults, where faces seem to have a “special status” for attention and are processed regardless of task relevance or perceptual load of the task.

With this in mind, the aims of the current study were two-fold: First, would an unexpected, socially salient auditory signal (e.g. a person greeting another person) also capture attention in TD individuals regardless of the visual perceptual load of an ongoing task? In other words, as with faces, do speech sounds have a “special status” for attention in the typically developing population? And second, how does visual perceptual load affect attentional capture of a speech sound in individuals with ASD?

Speech sounds are ostensibly the most important social signal in our auditory environment. Speech is not only fundamental for everyday social interactions, but also forms the basis for human communication by allowing us to share ideas, thoughts and emotions with the people around us. Whilst the exchange of social information can proceed directly via the content of speech, listeners are also able to gather important social cues through certain properties of the human voice (Ellis, 1989). For example, emotional prosody, a set of acoustic parameters of speech (e.g. mean amplitude, mean segment and pause duration) that is directly influenced by affect, allows the listener to infer the speaker’s affective state (Scherer, 1995). The voice also contains important information on an individual’s identity. By listening to a speaker’s voice, listeners are able to accurately determine the gender of a speaker (Lass, Hughes, Bowyer, Waters, & Bourne, 1976; Mullennix, Johnson, Topcu‐Durgun, & Farnsworth, 1995) and her/his approximate age (Hartman & Danhauer, 1976; Linville, 1996). The ability to attend to, process, and extract this multitude of information transmitted via speech or the voice is therefore fundamental for social interactions.

However, in individuals with ASD, impairments in processing social and emotional information, as well as atypical orienting and attention to social stimuli, including speech stimuli have been well documented (Baron-Cohen, Lombardo, Tager-Flusberg, & Cohen, 2013; Dawson, Bernier, & Ring, 2012). For example, one of the striking characteristic of children with ASD is their poor orienting to the human voice (Klin, 1991). Whereas typically developing children show an attentional bias towards speech sounds from a very early age (Alegria & Noirot, 1978; Jusczyk & Bertoncini, 1988), children with ASD often do not exhibit such a preference (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Dawson et al., 2004; Kuhl, Coffey-Corina, Padden, & Dawson, 2005). It remains unclear why individuals with ASD demonstrate this atypical orientation to socially relevant auditory information, and in particular to speech. A deficit in orienting could be a result of a more fundamental perceptual impairment in acoustic encoding of complex stimuli, as advocated by Mottron et al. (2006). Alternatively, reduced attention to social stimuli might underlie this deficit in orienting, such that individuals with ASD assign fewer attentional resources to social stimuli than TD individuals (Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Swettenham et al., 1998).

This chapter examines the predictions of perceptual load theory for attention to social stimuli within a cross-modal context of selective attention in ASD. Before I introduce the experiment, I will first outline the relevant literature on speech processing and the implications for social attention in ASD.

Processing of speech sounds in typically developing individuals

The development of speech sound processing abilities

Long before speech perception abilities develop, infants already seem to be drawn to the social properties of the human voice (Vouloumanos & Werker, 2007a). Indeed, one of the earliest observations in infants is their preferential orienting and processing of the human voice (Grossmann, Oberecker, Koch, & Friederici, 2010). Experiments measuring sucking preference or heart rates in newborn infants during presentation of different voices have demonstrated a preference of infants, and even fetuses, of their mother's voice to the voice of another newborn's mother (DeCasper & Fifer, 1980; Kisilevsky et al., 2003) and their father’s compared to another person (Ockleford, Vince, Layton, & Reader, 1988). By the age of three months, infants also seem to prefer human voices to similar non-social auditory stimuli (Vouloumanos, Hauser, Werker, & Martin, 2010). A range of studies also suggest that infants have an attentional and perceptual bias for speech sounds relative to non-speech sounds. For example, Glenn, Cunningham, and Joyce (1981) found that 9-month-olds chose more frequently to listen to a female person singing compared to instrumental music matched in melody. Other studies have shown that neonates have a preference for speech over filtered speech (Spence & DeCasper, 1987) and prefer speech spoken in their own language to a language from a different rhythmic class (Mehler, Jusczyk, Lambertz, Halsted, Bertoncini, & Amiel-Tison, 1988; Moon, Cooper, & Fifer, 1993).

However, whether this reflects an innate bias to listen to speech or a preference for speech patterns in rhythm and intonation (as a result of prenatal experiences) remains an issue of debate. In a set of studies that compared speech to carefully matched sine-wave analogues of speech in terms of duration, timing and fundamental frequency, Vouloumanos and Werker found that 2- to 7- month-olds listened longer to spoken words than to the complex non-speech analogues (Vouloumanos & Werker, 2004) and adjusted their high amplitude sucking in response to speech sounds (Vouloumanos & Werker, 2007a), indicating a preference for speech stimuli. In a response to Vouloumanos and Werker (2007a), Rosen and Iverson (2007) however pointed out that in their study, the non-speech analogues stimuli differed from the speech stimuli in voice pitch and therefore any bias towards speech stimuli could simply reflect a preference of infants for a strong voice melody that underlies prenatal learning experiences (for counter-arguments see Vouloumanos & Werker, 2007b). This account of the findings also fits with the general auditory theory, which suggests that preferential treatment of speech sounds is the result of perceptual learning (see Dumoulin & Wandell, 2008 for a review). Perceptual learning relates to the idea that increased exposure to certain environmental stimuli improves the ability of perceptual systems to respond to these signals and possibly involves increased attentional weighting to these stimuli (Goldstone, 1998). While this debate suggests that newborns may not possess an innate bias to listen to speech, there is certainly something special about the way infants attend to speech to guide their social interactions.

Neural selectivity for speech sounds

Studies from neuropsychology, neuroimaging and neurophysiology have also addressed the issue of whether speech is processed differently and/or activates specific brain regions compared to non-speech stimuli. In this respect, much of the research has investigated whether processing of speech sounds is domain-specific or domain-general, that is, whether specific modules for speech processing are in place (Liberman & Mattingly, 1985) or whether these modules also process non-speech stimuli (Tallal, 2003). Preliminary evidence for a speech-specific processing system was put forward by studies on patients with cerebral lesions. Lesions in the region of the left posterior superior temporal gyrus can produce a syndrome referred to as 'Wernicke's aphasia', characterised by severe deficits in speech comprehension yet intact fluent speech (Wernicke, 1874). Another syndrome known as 'pure word deafness', reported to occur after lesions to the auditory cortex bilaterally (Coslett, Brashear, & Heilman, 1984; Shoumaker, Ajax, & Schenkenberg, 1977), is characterised by a double dissociation of a selective deficit to comprehend speech with concurrent intact hearing, speech production and reading ability. In these two syndromes, perception of non-speech sounds is generally preserved, suggesting that the observed deficits are restricted to human speech. This indicates the existence of domain-specific perceptual brain mechanisms that are finely tuned to processing speech.

Domain-specific accounts of speech processing also received support from neuroimaging studies. Regions in the left superior temporal gyrus/sulcus (STG/STS) have been shown to exhibit significantly greater activation in response to speech sounds compared to other auditory stimuli such as tones (Binder et al., 2000), environmental sounds (Humphries, Willard, Buchsbaum, & Hickok, 2001), amplitude-modulated noise (Zatorre, Evans, Meyer, & Gjedde, 1992) and spectrally rotated speech (Scott, Blank, Rosen, & Wise, 2000). When comparing auditory speech to tones and complex non-speech sounds, Vouloumanos, Kiehl, Werker, and Liddle (2001) only found increased activation for speech stimuli in the middle temporal gyri, left superior temporal gyrus (STG) and right inferior frontal gyrus and not for any other sound (Vouloumanos et al., 2001). There is mounting evidence that also other specific brain areas are involved in the analysis of speech, particularly the anterior parts of the superior temporal cortex (Binder et al., 2000; Liebenthal, Binder, Spitzer, Possing, & Medler, 2005; Narain et al., 2003; Scott et al., 2000).

These specific activations also seem to extent to human voice stimuli apart from speech (e.g. laughs, coughs). A number of functional magnetic resonance imaging (fMRI) studies suggest that voice-selective brain regions are found bilaterally along the upper bank of the STS, (Fecteau, Armony, Joanette, & Belin, 2004, 2005). Referred to as ‘temporal voice areas’ (TVA), these regions showed greater activation when participants’ listened passively to human voice-specific sounds (e.g. speech, laughs, coughs) compared to non-human (e.g. animal cries) and mechanical sounds (Belin, Zatorre, Lafaille, Ahad, & Pike, 2000; Zatorre, Belin, & Penhune, 2002). The STS also seems to be involved in processing affective information (anger, sadness, fear, happiness) conveyed in a speaker’s voice (Ethofer, Van De Ville, Scherer, & Vuilleumier, 2009; Grandjean et al., 2005) and identity information during speaker recognition (Kriegstein & Giraud, 2004).

However, a fundamental problem of comparing speech and non-speech sounds is that any differences in brain activations could be the result of acoustic features of the stimuli. For example, the left posterior STG/STS may not be involved in speech perception *per se*, but gets activated in response to complex acoustic features that are also characteristic of speech sounds. Are these activations to speech sounds based on properties specific to speech sounds, or simply reflect activation in response to more complex stimuli? In line with this account, some studies have found a significant overlap in the brain regions, particularly the left STG/STS, in processing the rapid temporal characteristics of both speech and non-speech signals (Joanisse & Gati, 2003; Zatorre et al., 2002). Similar overlaps of activation for speech and non-speech signals were also observed for melody and pitch processing (Price, Thierry, & Griffiths, 2005) and complex auditory stimuli (e.g., a dog barking) (Dick et al., 2007; Lewis, Wightman, Brefczynski, Phinney, Binder, & DeYoe, 2004).

Whilst this debate suggests that these areas are not necessarily speech-specific (e.g. areas activate only in response to speech input), stronger activation of speech or voice-selective areas in response to human sounds as opposed to other complex sounds indicates preferential activation to this input. There is evidence that preferential processing of human sounds has been present for a long evolutionary period. Macaque monkeys activate a similar voice-selective region in the superior temporal plane in response to conspecific vocalizations (Petkov, Kayser, Steudel, Whittingstall, Augath, & Logothetis, 2008), and possess voice-selective neurons in that region (Perrodin, Kayser, Logothetis, & Petkov, 2011). This suggests that voice-specific mechanisms in humans did not recently emerge and that preferential processing of species-specific vocalization is a long evolutionary process.

Is speech processing an automatic and mandatory process?

Linked to the idea of specialised brain mechanisms for speech processing is the concept that speech processing is a mandatory and automatic process. Fodor (1983) proposed that information from the environment is processed by specialised, independently functioning modules or input systems. These modules are thought to be domain specific in the sense that they can only process certain types of information (e.g. speech) and ignore other, potentially competing input. Important in this respect is the notion that for each module, processing of relevant information proceeds automatically, i.e. a module cannot refrain from processing relevant target material. Liberman and Mattingly (1985), by adopting Fodor's (1983) idea of modularity, proposed that speech perception underlies such a specialised module that processes speech input in an automatic fashion. When listening to sine wave speech (synthesized stimulus based on frequency-amplitude modulations of the original speech recording), most people initially only hear 'funny noise' and not speech (Remez, Rubin, Pisoni, & Carrell, 1981). Yet, when primed to hear some form of speech, most people will be able to identify what was said on repeated presentation. This suggests the existence of a special 'speech mode' of processing that operates in an automatic and mandatory fashion, that is, when exposed to speech-like stimuli, we cannot choose but to process them.

Speech sound processing in ASD

Impaired or atypical attention to social stimuli has been highlighted as a possible explanation for the core impairments in social communication seen in individuals with ASD (Dawson et al., 2012). Indeed, Kanner already noted in his initial report on autism a relative indifference to the human voice:

"He did not register any change of expression when spoken to [...] he did not respond to being called or to any other words addressed to him" (Kanner, 1943)

The following literature review will outline the behavioural and neurophysiological evidence on how individuals with ASD attend to speech sounds in their environment.

Orienting to speech in ASD

As mentioned earlier, one of the striking characteristic of children with ASD is their poor orienting to the human voice (Klin, 1991), and particularly to spoken language. An important contribution in understanding atypical attention to speech in infants with autism was made by analysing retrospectively home videotapes and parental descriptions of children's behaviour within the first two years of life prior to diagnosis (Werner & Dawson, 2005; Wimpory, Hobson, Williams, & Nash, 2000). These studies have shown atypical orientation in infants with ASD to their own name at –10 months (Werner, Dawson, Osterling, & Dinno, 2000), 9–12 months (Baranek, 1999) and 1 year of age (Osterling, Dawson, & Munson, 2002; Osterling & Dawson, 1994) relative to both age-matched typically developing (TD) controls and infants with mental retardation (Osterling et al., 2002). Similar findings were also reported in older children. Dawson et al. (1998) compared the ability of 5-year-old children with ASD, children with Down syndrome, and mental-age (MA) matched TD children to orient to a range of social (e.g. name called, hands clapping) and non-social stimuli (e.g. rattle, musical jack-in-the-box). In relation to both other groups, children with ASD more frequently failed to orient to both social and non-social stimuli, and showed a particularly severe deficit in orienting to social stimuli. In addition, those children with ASD who did orient to social stimuli took longer to do so than individuals in both comparison groups. In a follow-up study, Dawson et al. (2004) replicated these findings in a larger sample of 4-year-old children with ASD, developmentally delayed children and MA matched TD toddlers.

Consistent with these findings, research by (Klin, 1991, 1992) has demonstrated that when given the choice to elicit either motherese (i.e. child-directed speech) or a mixture of environmental noises (i.e. multi-talker-babble) during spontaneous play with an audio toy, children with ASD either demonstrated no preference for either sound or were more interested in environmental noise. Similar evidence has been reported by Kuhl et al. (2005), who examined the preference of preschool children with ASD and chronologically- and mentally-matched TD children for either motherese speech or non-speech analogues that were matched acoustically to the motherese speech samples. Their findings indicated that most children with ASD preferred a non-speech analogue to child-directed speech. However, when the ASD group could be divided into two groups (a group that preferred non-speech analogues and a group that preferred speech stimuli), those children with ASD that did orient to speech sounds had a more typical ERP pattern. Kuhl et al. (2005) also demonstrated that a listening preference for non-speech stimuli was strongly associated with autism severity as reflected by higher scores on the social-communicative sub-test of the ADOS. A similar pattern of findings was reported in toddlers with ASD by Paul, Chawarska, Fowler, Cicchetti, and Volkmar (2007), who found that those toddlers with ASD who oriented longer to motherese speech displayed better receptive language skills even one year post-study. Together, these studies suggest that an early basic impairment in the preferential processing of speech sounds could contribute to the deficits in social communication and language abilities that are characteristic of individuals with ASD.

Neuroimaging and electrophysiological studies

Functional imaging research also points to atypical neural activation in response to vocal sounds in individuals with ASD compared to typically developing (TD) individuals. Gervais et al. (2004), for example, found decreased activation in speech- and voice-selective areas such as the superior temporal sulcus (STS) in response to vocal stimuli (speech and vocal stimuli) in individuals with ASD relative to TD controls. No group differences were observed for non-vocal environmental stimuli. In a recent study, Abrams et al. (2013) examined functional connectivity of voice-selective regions in ASD using resting-state functional MRI. The results indicated that children with ASD had reduced intrinsic connectivity between voice-selective brain regions (i.e. posterior STS) and cortical structures involved in emotion and speech processing such as the ventral tegmental area (VTA), nucleus accumbens (NAc), amygdala, and orbitofrontal cortex (OFC). The authors also demonstrated that reduced brain connectivity was a significant predictor for communication subtest scores on the Autism Diagnostic Observation Schedule (ADOS). These findings indicated that weak connectivity may be linked to reward circuits in experiencing speech, thereby impacting the development of language and social communication in individuals with ASD. Other areas that have been found to be less activated in high functioning adults with ASD compared to controls are the left middle temporal gyrus, left medial prefrontal cortex and left precuneus, particularly during presentation of long connected speech stimuli that featured complex prosodic components (e.g. intonation, rhythm and affect) (Hesling, Dilharreguy, Peppé, Amirault, Bouvard, & Allard, 2010). Studies using positron emission tomography (PET) have supported these findings and have shown reduced activity of left frontal-temporal language regions for complex speech-like sounds in children with ASD relative to mental-age matched controls (Boddaert et al., 2014).

In addition, electrophysiological studies have investigated how individuals with ASD attend to speech stimuli. ERP markers for attentional effects can be found at the P300 latency, with the earlier subcomponent P3a, largest at frontocentral sites, being elicited by rare stimuli in passive oddball paradigms. In an active oddball task, a small percentage of infrequent stimuli (deviant) are presented amongst frequent stimuli (standards) and subjects are asked to respond to the deviant stimulus. In the passive version of this task, participants do not respond to the deviant stimuli and ERPs are recorded in response to involuntary orienting to the deviant stimulus. The P3a measured in passive oddball tasks is therefore thought to reflect a response to novelty and attention switching to perceptually salient stimuli (O’Connor, 2012).

When asked to listen passively to either speech or non-speech stimuli, a number of studies have observed smaller or absent P3a amplitudes in children with ASD compared to TD children, indicative of a deficit in switching attention to speech stimuli. Ceponiene et al. (2003), for example, demonstrated that whilst auditory sensory processing of vowels as measured by the mismatch negativity (MMN) was intact in children with ASD, attentional orienting to vocal-speech sounds (i.e. vowel changes) as indexed by P3a was absent in the ASD group compared to the TD group. Importantly, simple and complex tones elicited a more normal P3a response in the ASD group. This suggested to the authors that atypical orienting to speech in ASD cannot be accounted for by a low-level deficit in sensory processing. Impaired attention-switching in ASD therefore seems to be speech-specific. Similar findings of reduced P3a amplitude in response to speech sounds have since been reported in children with autism (Lepistö, Kujala, Vanhala, Alku, Huotilainen, & Näätänen, 2005), in children with Asperger's Syndrome (AS) (Lepistö, Silokallio, Nieminen-von Wendt, Alku, Näätänen, & Kujala, 2006) and adults with AS (Lepistö, Nieminen-von Wendt, von Wendt, Näätänen, & Kujala, 2007).

Whitehouse and Bishop (2008) however questioned whether individuals with ASD are impaired in switching attention to speech stimuli. They recorded ERPs of high functioning children with ASD and TD children during either a passive (no task) or active (respond to deviants stimuli) oddball task. The findings indicated that when not attending to sounds, children with ASD had smaller P3a amplitudes for novel tones (presented amongst standard speech sounds), but not to novel speech sounds (presented amongst standard tones). In the active condition, children with ASD did not differ from controls on any ERP measures. This suggests that in contrast to previous research (e.g. Ceponiene et al., 2003) children with ASD were orienting to speech sounds. Whitehouse and Bishop proposed that the difference in findings can be explained by the choice of oddball standards. In previous studies, the infrequent speech sounds were embedded within other speech-standards (Ceponiene et al., 2003), yet in their study, the deviant stimuli were presented amongst non-speech standards. The nature of the repetitive standard stimuli thus seems to modulate responsiveness to speech sounds in ASD. These findings indicate that "top-down" factors influence basic sensory processing in the sense that individuals with ASD might be actively inhibiting processing of speech sounds. However, it has to be noted that in their study, only those participants with an accuracy of at least 80% on the attentive task were included. It is therefore likely that these findings relate to a subgroup of more able children with ASD.

Other variations of the oddball task require participants to detect a target stimulus (deviant) among frequent (standards) and infrequent non-target (novel) stimuli. In these conditions, a later sub-component of the P300, the P3b is elicited when subjects attend to infrequent target stimuli (i.e. deviant targets). The P3b is thought to correlate with memory updating and allocation of attention during stimulus categorisation (Kok, 2001; Landry & Bryson, 2004). Courchesne et al. (1984, 1985) found that in response to infrequent speech-targets presented amongst other speech standards, individuals with ASD recorded reduced P3b amplitudes compared to age-matched controls. Smaller P3b amplitudes were also observed in children with ASD for rare phoneme stimuli ('*da'*) embedded within click stimuli (Dawson, Finley, Phillips, Galpert, & Lewy, 1988). Kemner, Verbaten, Cuperus, Camfferman, and van Engeland (1995) also demonstrated that during an active oddball task that required participants to detect a deviant stimulus (i.e. phoneme 'ay') amongst standards (i.e. phoneme 'oy') and a novel stimulus (complex sound '*bbrrzzz*'), children with ASD had smaller P3b amplitude relative to children with dyslexia, children with ADHD and TD children. The ASD group however was as accurate as all other groups on detecting the deviant stimulus. This suggests that although behavioural performance was similar across groups, i.e. individuals with ASD were attending as well as other groups to the deviant stimulus, marked differences in neural activity can still occur.

Attention to speech – is speech special in ASD?

In contrast to typically developing children who are engaged by (Alegria & Noirot, 1978) and highly sensitive (Eimas, Siqueland, Jusczyk, & Vigorito, 1971) to the human voice, children with ASD are often observed to not automatically orient to the human voice (Dawson et al., 2004) and are relatively indifferent to vocal stimuli (Kuhl et al., 2005). As suggested above, this lack of interest in social stimuli might stem from individuals with ASD assigning less of their attention to social stimuli than TD individuals (Klin et al., 2002; Swettenham et al., 1998). Electrophysiological studies also suggest that whilst basic sensory processing of speech stimuli is relatively intact in ASD (Ceponiene et al., 2003), a lack of attention to speech sounds is reflected in reduced P3a and P3b amplitudes. Reduced activity (Gervais et al., 2004) and connectivity (Abrams et al., 2013) in speech-specific regions such as the STS also indicates distinct differences in cortical speech processing in individuals with ASD. In this chapter, I will further investigate these altered patterns in attention to speech sounds within the framework of perceptual load theory.

Experiment 3: Effect of visual perceptual load on awareness of a socially meaningful stimulus in ASD

The evidence presented above indicates that individuals with ASD show a distinct behavioural and neurophysiological profile in response to speech sounds. Important for this thesis is the observation that in individuals with ASD, speech sounds do not seem to be prioritised over processing of other auditory stimuli, i.e. they do not capture attention to the same extent as in TD individuals.

This may suggest that typically developing individuals possess a dedicated capacity for social stimuli, which however is absent in individuals with ASD. In other words, in TD individuals, there are extra processing resources for social stimuli regardless of the level of perceptual load, which may not be the case however in individuals with ASD. The current experiment set out to investigate the extent of reported awareness for an unexpected auditory social stimulus in TD individuals and individuals with ASD within the capacity-based framework of perceptual load theory. It was hypothesised that increasing the perceptual load of a visual task would not affect awareness of an unexpected speech sound in TD individuals, i.e. awareness rates will remain high across perceptual load conditions, yet increasing perceptual load would reduce awareness rates of a speech sound in individuals with ASD.

Participants performed either a subtle (high perceptual load), or more gross (low perceptual load) line discrimination task. Following a set of trials that did not feature the unexpected stimulus (referred to as non-critical trials), participants performed the critical trial. On this trial, participants indicated as before which line of the cross was longer, yet at the same time, a speech sound (a male person saying ‘hi’) was played via headphones. Immediately following this trial, participants were asked whether they noticed anything else.

Following on from the findings in experiment 2, the current experimental design was adapted to control for some of the methodological limitations outlined earlier. For example, the retrospective measure of awareness with a surprise question about an unexpected stimulus raises the possibility that the failure to report presence of the auditory stimulus may reflect, in some cases, rapid forgetting. In the visual domain, such ‘inattentional amnesia’ has been described by Wolfe (1999) and refers to the idea that a failure to detect the presence of the unexpected stimulus might be related to a weak memory trace of the unexpected stimulus rather than inattention. Another possibility is that the findings in the previous experiment reflect a change in the response criterion such that participants may be more reluctant to admit noticing an unexpected stimulus for which there is only a weak memory trace in conditions of high perceptual load. In order to control for these effects in the current experiment, the surprise question was presented after a short and fixed amount of time following the critical trial.

In the previous experiment, participant’s performance on the central task was only measured in terms of accuracy on the line discrimination task. The number of trials was now increased to allow measurement of each participant’s reaction time in order to obtain a more nuanced measure of task performance. In addition, measuring RT data for both groups on critical trials will allow us to evaluate whether increased awareness rates in the ASD group in the previous experiment might have been a consequence of them diverting attentional resources from the visual to the auditory modality. A shift in attention of participants away from the visual task to the auditory modality would be reflected in a significant difference between RT on the critical trial compared to average RTs on non-critical trials. To measure this effect, an RT difference score was created (RToverall – RTcritical), where a positive score reflects a slowing of response on the critical trial, whereas a negative score reflects a faster response on the critical trial relative to average response times on non-critical trials.

Lastly, to control for the possibility that increased detection rates of the CS on the critical trial were due to lower perception thresholds in some individuals, participants also performed an auditory threshold task (2-up, 1-down procedure). This also allowed us to test whether the two groups (ASD vs. TD) differed in perceptual thresholds and to confirm that the intensity level of the auditory stimulus was well above the threshold for each participant (and similarly so for both groups). In order to not prime participants of the occurrence of the auditory stimulus in the inattentional deafness task, the threshold task was always administered after participants performed the inattentional deafness task.

Method

Participants

A new sample of 30 typically developing (TD) adolescents and 31 adolescents with a diagnosis of Autism Spectrum Disorder (ASD), naïve to the aim of the experiment, took part in this study. All participants were diagnosed and recruited in the same manner as in the previous experiment. Participants were randomly allocated across the two ‘perceptual load’ conditions (high vs. low). Similar task-specific exclusion criteria as in the previous experiment were in place. Participants were excluded if they obtained a score of less than 9 correct on the 11 non-critical trials, were incorrect on the critical trial or were unable to hear the tone on the control trial. These exclusion criteria were necessary to make sure that all participants were engaging with the primary task on the critical trial that featured the additional auditory stimulus. This resulted in six participants (four ASD, two TD) being excluded from further analysis. Two participants made an incorrect judgment on the critical trial (one ASD and one TD participant in the low perceptual load condition). Three ASD and one TD participants did not hear the critical stimulus (CS) on the control trial. No participant scored less than 9 out of 11 correct on the line discrimination task. The remaining 28 TD and 27 ASD participants were matched for non-verbal ability (using the Raven’s Standard Progressive Matrices, Raven et al., 1998) and chronological age (see Table 5.1 for descriptives). Independent samples t-tests indicated that there were no significant differences between groups on any of these measures (maximum t-value = 1.946, minimum p-value = 0.06).

Table 5.1 Descriptive statistics for each group

Group	Statistic	CA (years : months)	Raven's Score	SCQ score
ASD (n= 27)				
Low load (n= 13)	M	14:4	41.9	27.1
	SD	0:9	6.8	6.6
	Range	12:8 – 15:6	31 – 52	17 – 35
High load (n= 14)	M	13:6	42.5	25.3
	SD	1:3	5.2	4.7
	Range	11:1 – 15:2	34 – 52	18 – 33
TD (n= 28)				
Low load (n= 14)	M	14:9	44.9	
	SD	0:6	5.2	
	Range	14:1 – 15:5	36 – 52	
High load (n=14)	M	14:3	43.7	
	SD	1:3	4.9	
	Range	11:6 – 15:5	35 – 52	

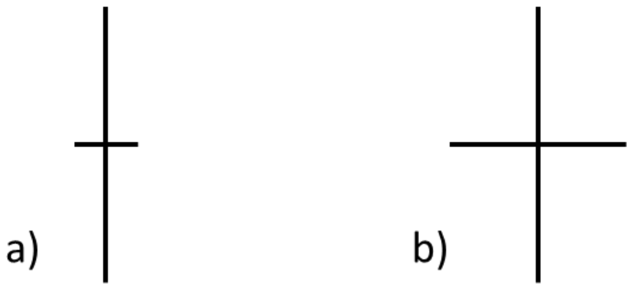
Note:
CA = Chronological Age
SCQ = Social Communication Questionnaire

Stimuli and Procedure

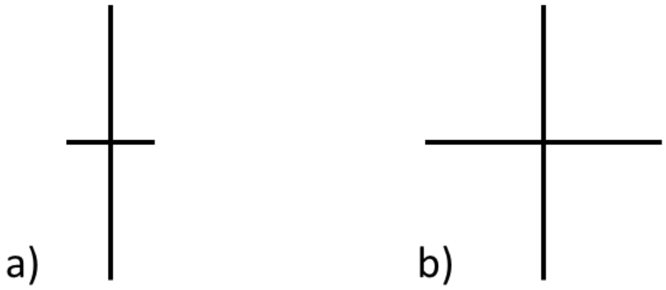
Microsoft Visual Basic (version 6) was used to create computer-based stimuli that were presented on an IBM Lenovo Thinkpad 14.1" personal laptop. The task involved a black circle (0.15°), presented at fixation, followed by a black cross (RGB: 0, 0, 0) against a white background (RGB: 255, 255, 255). Viewing distance was 60cm. On each trial, participants indicated via appropriate button presses on the keyboard which line of a centrally presented cross was longer than the other one (horizontal or vertical, presentation was randomised across all experimental trials and counterbalanced on the critical trial). Perceptual load of the visual task was manipulated by increasing the visual angle of one of the arms of the target cross. In the low perceptual load condition, the short arm extended 1.25° and the long arm 3.9°, whereas in the high perceptual load condition the short arm extended 3.35° and the long arm 3.9°.

Figure 5.1 Comparison of stimuli used in the current and previous two chapters according to (a) low perceptual load condition and (b) high perceptual load condition

Stimuli used in experiment 1 & 2



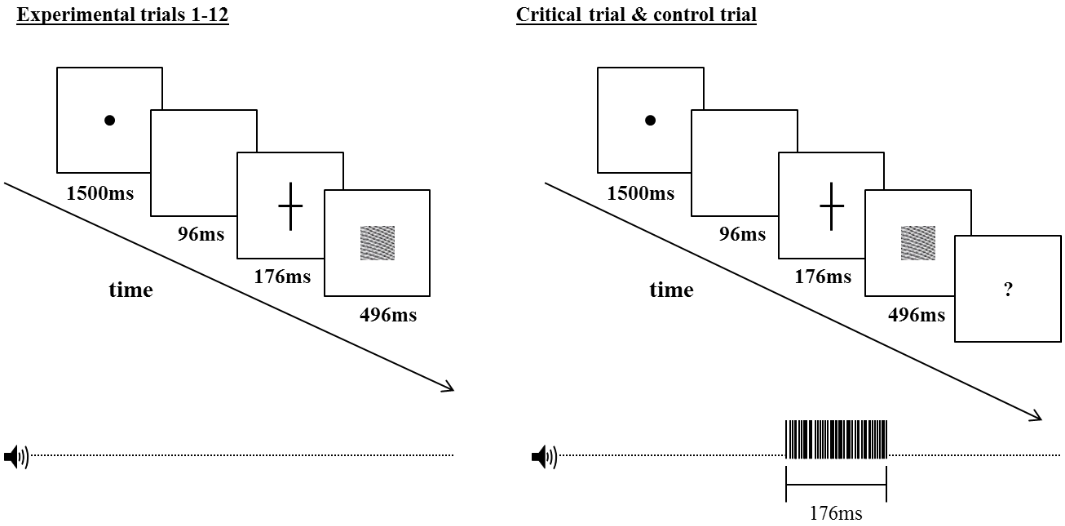
Stimuli used in current experiment



It is important to point out that the cross task stimuli in this experiment were slightly adjusted compared to the stimuli used in the previous chapters (see Figure 5.1 for an illustration). In particular, whilst the visual angle of the longer arm of the cross was kept the same (3.9°), the shorter arm of the cross in both the low- and high perceptual load condition was increased. These changes were made based on a pilot study with TD adolescents that indicated that adolescent participants performed at ceiling on a cross task using the same task parameters as in the previous experiments.

Participants were told that they should be as fast, but also as accurate as they can on the line discrimination task. Participants performed a total of 19 trials, of which 6 were practice trials that were not included in any further analysis. Reaction time (RT) and accuracy data were recorded on 13 trials, of which the 13th trial was the critical trial. On the critical trial, an auditory stimulus was played concurrently with presenting the cross. Responses to the cross task were recorded as in the previous trial, yet immediately after participants made the cross task response, a question mark appeared on the screen that prompted participants to indicate whether they noticed anything else. The critical trial was subsequently repeated in a control trial, which measured awareness of the critical stimulus in absence of attention to the visual task. Participants were told prior to the control trial to ignore the cross stimulus and instead attend to any other stimulus they might notice. Only those participants who successfully identified the critical stimulus on the control trial were included in further analyses.

Figure 5.2 Procedure of experimental trials



The auditory stimulus used in this experiment was a recording of a male person saying “Hi” (85-150Hz). The duration of the stimulus was set at 176ms to match the presentation time of the visual cross stimulus and played at an intensity level of 33db through a pair of Sennheiser HD 25-1-II stereo headphones. The intensity level of the stimulus was determined by piloting with adult volunteers and measured prior to the experiment by a Bruel & Kjaer 4153 artificial ear together with an Ono Sokki CF-350Z spectrum analyser.

After completing the line discrimination task, the absolute perceptual threshold for the auditory stimulus was established for each participant using a two alternative forced-choice (2AFC) adaptive threshold procedure. Each trial consisted of two pictures appearing on the screen (one left and one right) after each other, with the target sound (speech sound) being randomly presented together with either the first or the second picture. Participants indicated when they heard the target sound (first or second) and the experimenter entered their response via the keyboard. If participants produced two consecutive correct answers, the intensity of the auditory stimulus was reduced by 1db. As soon as they provided an incorrect answer, the intensity of the auditory stimulus was increased by 1db. Individual absolute thresholds were based on an average of five reversals (point at which direction is changed, i.e. either when producing a correct answer followed by an incorrect answer or when producing 2 correct after an incorrect answer).

Results

Line discrimination performance

Reaction times (RT) on the line discrimination task above 2500ms were discarded and average correct RT and accuracy rates were calculated (see **Table 5.2** for summary statistics). Before presenting the statistical results, it is noteworthy that the ASD group in the high perceptual load condition reported much greater variability in mean RT scores compared to the TD group (SD=225ms vs. SD=123ms respectively), yet both groups showed similar RT variability in the low load condition (SD=109ms vs. SD=123ms respectively). A consequence is that equal error variance between groups cannot be assumed, which necessitated log-transforming the dependent variable (RT). All analyses on RT data (i.e. total RT data and RT on critical trial) will be based on the log transformed values to satisfy the assumption of equality.

Table 5.2 Summary of task performance and threshold measures according to diagnostic group and perceptual load condition

Group	Statistic	**RT** (in ms)	**RT** (on crit. trial; in ms)	**RT difference score** (in ms)	**Acc.** (out of 12)	**Threshold** (db SPL)
ASD (n= 27)						
Low load (n= 13)	M	573.8	522.2	29.8	11.4	23.6
	SD	109.2	124.9	97.5	.8	6.1
High load (n= 14)	M	933.4	868.6	46.4	10.8	21.36
	SD	225.7	281.4	123.6	1.1	8.0
TD (n= 28)						
Low load (n= 14)	M	514.4	559.1	-15.6	11	25.5
	SD	173.7	223.8	154.1	.9	4.6
High load (n=14)	M	815.6	802.9	21.2	10.6	21.9
	SD	123.2	148.8	124.6	.9	6.3

Note:
RT = Reaction Time
RT difference score = RToverall – RTcrit
Acc. = Accuracy on line discrimination task
Threshold = Threshold level for CS

A 2x2 between-subjects ANOVA was used to analyse RTs according to diagnostic group (ASD vs. TD), perceptual load (high vs. low), and an interaction term of group and load. The results indicated that participants across groups responded significantly slower in the high- compared to the low perceptual load condition, $F(1,51) = 61.787$, $p < .001$, $\eta_p^2 = .548$. There was no significant effect of group on RT, $F(1,51) = 2.805$, $p = .100$, $\eta_p^2 = .052$, and the interaction between group and load was also not significant, $F(1,51) = .047$, $p = .829$, $\eta_p^2 = .001$. This suggests that the manipulation of perceptual load was effective as significantly slower RT scores (index of higher processing demands) were observed in the high perceptual load compared to the low perceptual load condition. In addition, the absence of any group or interaction effects indicates that both groups performed similarly on the task and across perceptual load conditions.

Reaction time on the critical trial was subsequently compared to the overall RT performance on non-critical trials by creating a RT difference score (RToverall – RTcritical; see **Table 5.2**). A positive score reflects a faster response on the critical trial, whereas a negative score reflects a slowing of response on the critical trial relative to average response times on non-critical trials. Prior to analysis, one outlier was removed (RT difference score of two standard deviations away from the mean). This participant was in the TD group and performed in the low perceptual load condition. Using ANOVA, the results indicated that there was no significant main effect of group or condition, nor a significant interaction effect of group and condition (maximum F-value = 2.465, smallest p-value = .123).

Analysis of accuracy data (number of correct responses on the line discrimination task) was also carried out using ANOVA. Participants made significantly more errors in the high perceptual load condition than the low perceptual load condition, $F(1,51) = 4.525$, $p = .038$, $\eta_p^2 = .081$. There was no main effect of group, $F(1,51) = 1.537$, $p = .221$, $\eta_p^2 = .029$, and no interaction effect, $F(1,51) = .124$, $p = .726$, $\eta_p^2 = .002$. Again, this suggests that whilst task performance was affected by increasing perceptual load, task performance and therefore task engagement was similar between groups.

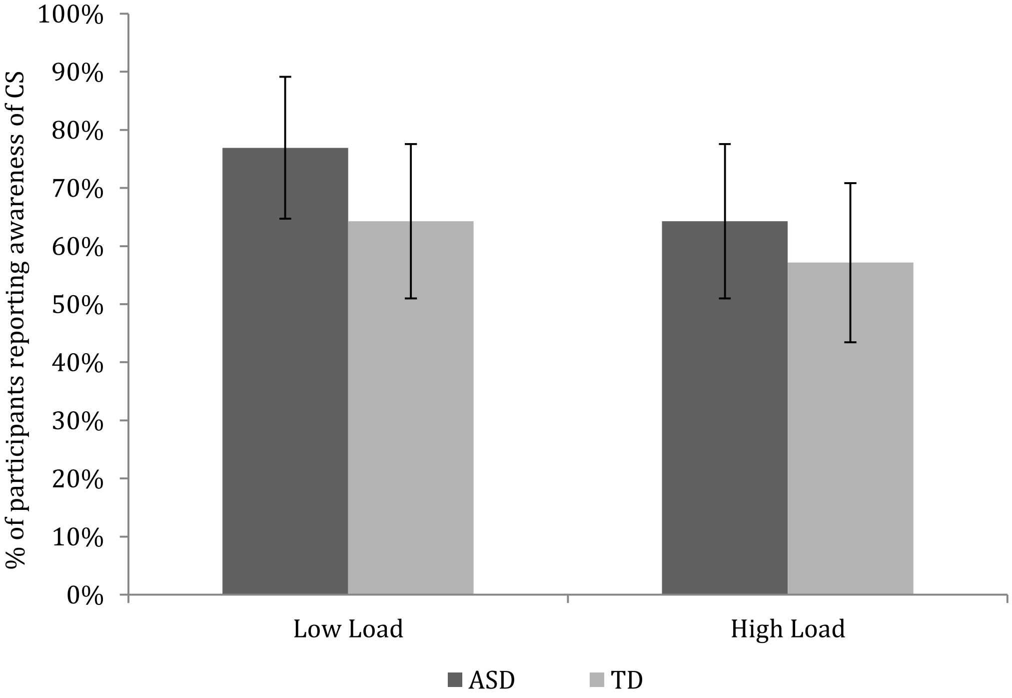
Threshold analysis

Overall, the perceptual threshold for the auditory stimulus (critical stimulus: CS) across all participants ($M = 23.1$db, $SD = 6.39$db) was well below the intensity level of the CS on the critical trial (CS was played at an intensity level of 33db). This provides some preliminary evidence that a failure to notice the CS on the critical trial does not relate to an inability to hear the CS. Statistical analyses confirmed this observation, as the absolute threshold for the CS was significantly lower than the intensity of the CS used in the inattentional deafness task, $t(54) = 11.496$, $p < .001$, [95% CI: 8.2 – 11.64]. Importantly though, there were no significant group differences in perceptual threshold, $F(1,51) = .513$, $p = .477$, $\eta_p^2 = .01$, no differences between thresholds for each perceptual load condition, $F(1,51) = 2.888$, $p = .095$, $\eta_p^2 = .054$, and no interaction effect, $F(1,51) = .147$, $p = .703$, $\eta_p^2 = .003$. Perceptual sensitivity of the CS was thus similar across groups.

Awareness of CS

Participants were considered to be aware of the critical stimulus (CS) if they reported hearing something on the critical trial, and were able to accurately describe the auditory stimulus verbally or by imitating the speech sound. Awareness rates as a function of perceptual load and group are shown in Figure 5.3.

Figure 5.3 Percentage of participants reporting awareness of the auditory stimulus (critical stimulus: CS) according to perceptual load and diagnostic group (error bars: standard error)



As in the previous chapter, a hierarchical logistic regression analysis was carried out to predict awareness of the auditory stimulus (0 ="No", 1 ="Yes") according to perceptual load, diagnostic group, and their interaction. In a first step, an intercept-only model was compared against a model with perceptual load and diagnostic group as predictors. The latter model was subsequently compared to a full model including the interaction between perceptual load and diagnostic group. All statistical analyses used maximum likelihood ratio tests (model comparisons based on differences in -2 log likelihood) and the statistical cut-off criterion for all predictors was set at .05 (see Table 5.3 for a summary). The results indicated that diagnostic group, χ^2 (1) = .596, p = .440, and perceptual load did not significantly modulated awareness, χ^2 (1) = .596, p = .440. This suggests that awareness was not modulated by either increasing perceptual load or by group membership. The interaction between perceptual load and group was also not significant, χ^2 (1) = .074, p = .785.

Table 5.3 Logistic regression analysis predicting awareness of the CS from perceptual load, diagnostic group, and their interaction

Variable	**B**	**SE B**	**df**	**MLE**	**p**	**OR**	**95% CI of OR**
Perceptual load	-.221	.29	1	.596	.440	.801	.456 – 1.409
Group	221	.29	1	.596	.440	1.248	.710 – 2.194
Load X Group	-0.79	.29	1	.074	.785	.924	.523 – 1.632

Note:
MLE = Maximum Likelihood Estimation
OR = Odds Ratio

An additional logistic regression analysis also confirmed that neither non-verbal ability scores (raw score on the Raven's Progressive Matrices) nor scores on the SCQ was a significant predictor (both p > .05) of awareness rates of the CS in the ASD group.

Discussion

The results showed that for both groups, awareness of an unexpected, socially meaningful auditory stimulus was not affected by the level of perceptual load in a visual task. That is, both the ASD and TD group continued to report presence of an unexpected speech sound despite an increase in the level of perceptual load in the visual task. Note that for TD individuals, the pattern of awareness for a social stimulus observed here is markedly different from the results observed in experiment 2, where an increase in visual perceptual load significantly reduced awareness of a neutral sound in TD individuals. The findings here thus provide preliminary evidence that in the typical population, unexpected socially meaningful auditory information is processed regardless of the level of visual perceptual load. Interestingly, individuals with ASD demonstrated similar levels of awareness of a speech sound across perceptual load conditions. The implications of these results will be discussed in the overall chapter discussion.

Experiment 4: Effect of visual perceptual load on awareness of a neutral stimulus in ASD

In order to confidently determine whether speech sounds capture attention differently than neutral sounds at different levels of perceptual load, the results from the previous experiment must be compared to data on a task that carefully matches the speech sound to a neutral sound. The data in experiment 2 (inattentional deafness in children with ASD and TD children) is not sufficient for this purpose, given the subtle differences in methodology, the acoustic properties of the critical auditory stimulus compared to the speech stimulus (experiment 3), and differences in participant characteristics (i.e. large differences in chronological age between the two samples). Instead, a control task identical in task design to the previous experiment was employed to measure awareness of a socially meaningless auditory stimulus (beep tone) that was matched with the social stimulus used in the previous experiment on a number of acoustic properties including pitch, frequency range and intensity (see method section below). Participants performed the same line discrimination task as before, which this time however featured a neutral sound rather than a speech sound on the critical trial.

Method

Participants

32 typically developing (TD) adolescents and 32 adolescents with a diagnosis of Autism Spectrum Disorder (ASD), who were naïve to the aim of the experiment, took part. All participants were diagnosed and recruited in the same manner as in the

previous experiment. Participants were randomly allocated across the two 'perceptual load' conditions (high vs. low). The same task-specific exclusion criteria as in the previous experiment were in place, which resulted in four participants (two ASD, two TD) being excluded from further analysis. One participant made an incorrect judgment on the critical trial (one ASD in the high perceptual load condition). One ASD and two TD participants did not hear the critical stimulus (CS) on the control trial. No participant scored less than 9 out of 12 correct on the line discrimination task. The remaining 30 TD and 28 ASD participants were matched for non-verbal ability (using the Raven's Standard Progressive Matrices, Raven et al., 1998) and chronological age (see Table 5.4 for descriptives). Independent samples t-tests indicated that there were no significant differences between groups on any of these measures (maximum t-value = 1.351, minimum p-value = 0.182).

Table 5.4 Descriptive statistics for each group

Group	**Statistic**	**CA** (years : months)	**Raven's Score**	**SCQ score**
ASD (n= 28)				
Low load (n= 14)	M	15:0	44.6	26.8
	SD	1:3	5.3	6.5
	Range	12:4 – 17:5	37 – 54	17 – 35
High load (n= 14)	M	14:11	45.6	24.1
	SD	0:5	5.8	4.3
	Range	14:4 – 15:7	34 – 52	18 – 33
TD (n= 30)				
Low load (n= 15)	M	15:1	45.7	
	SD	0:6	6.4	
	Range	14:3 – 15:10	35 – 57	
High load (n=15)	M	15:1	45.1	
	SD	0:5	6.3	
	Range	14:3 – 15:7	36 – 56	

Note:
CA = Chronological Age
SCQ = Social Communication Questionnaire

Stimuli and Procedure

Participants were presented with the same line discrimination task used in the previous experiment. On each trial, participants indicated via appropriate button presses on the keyboard which line of a centrally presented cross was longer than the other one (horizontal or vertical). Perceptual load of the visual task was manipulated by increasing the visual angle of one of the arms of the target cross.

However, instead of presenting a speech sound on the critical trial, the auditory stimulus was a socially meaningless/neutral tone (beep). Specifically, the sound employed here was a saw-tooth wave that was matched with the social stimulus in the previous experiment on pitch (85-150Hz), duration (176ms) and intensity (33db) and presented with the same Sennheiser HD 25-1-II stereo headphones. As in the previous experiment, after completing the line discrimination task, the perceptual threshold for the auditory stimulus was established for each participant using a two alternative forced-choice (2AFC) adaptive threshold procedure.

Results

Task performance

Reaction times (RT) on the line discrimination task above 2500ms were discarded and average correct RT and accuracy rates were calculated (see Table 5.5 for summary statistics).

Table 5.5 Summary of task performance and threshold measures according to diagnostic group and perceptual load condition

Group	**Statistic**	**RT** (in ms)	**RT** (on crit. trial; in ms)	**RT diff. score** (in ms)	**Acc.** (out of 12)	**Threshold** (db SPL)
ASD (n= 28)						
Low load (n= 14)	M	586.9	577.4	9.6	11.3	26.8
	SD	214.9	202.4	84.3	.9	2.1
High load (n= 14)	M	818.4	790.2	28.1	10.9	26.6
	SD	208.5	167.7	99.4	.9	2.5
TD (n= 30)						
Low load (n= 15)	M	534.3	522.8	11.5	11.3	25.3
	SD	127.5	121.4	47.8	.6	2.6
High load (n=15)	M	750.1	721.1	29	10.7	26.3
	SD	203.8	200	158.1	.9	2.8

Note:
RT = Reaction Time
RT difference score = RToverall – RTcrit
Acc. = Accuracy on line discrimination task
Threshold = Threshold level for CS

A 2x2 between-subjects ANOVA was used to analyse RTs according to diagnostic group (ASD vs. TD), perceptual load (high vs. low), and an interaction term of group and load. The results indicated that participants across groups responded significantly more slowly in the high- compared to the low perceptual load condition, $F(1,54) = 19.799$, $p < .001$, $\eta_p^2 = .263$. There was no significant effect of group on RT, $F(1,54) = 1.448$, $p = .234$, $\eta_p^2 = .026$, and the interaction between group and load was also not significant, $F(1,54) = .024$, $p = .877$, $\eta_p^2 = .001$. This suggests that as in the previous experiment, the manipulation of perceptual load was effective as significantly slower RT scores (index of higher processing demands) were observed in the high perceptual load compared to the low perceptual load condition. The absence of any group or interaction effects indicates that both groups performed similarly on the task and across perceptual load conditions.

Reaction time on the critical trial was subsequently compared to the overall RT performance on non-critical trials by creating a RT difference score (RToverall – RTcrit). A positive score reflects a faster response on the critical trial, whereas a negative score reflects a slowing of response on the critical trial relative to average response times on non-critical trials. Prior to analysis, one outlier was removed (RT difference score of two standard deviations away from the mean). This participant was in the TD group and performed in the low perceptual load condition. The results indicated that there was no significant main effect of group or condition, nor a significant interaction effect of group and condition (maximum F-value = .424, smallest p-value = .518). Analysis of accuracy data (number of correct responses on the line discrimination task) was also carried out. Participants made significantly more errors in the high perceptual load condition than the low perceptual load condition, $F(1,54) = 4.733$, $p = .034$, $\eta_p^2 = .081$. There was no main effect of group, $F(1,54) = 1.480$, $p = .229$, $\eta_p^2 = .027$, and no interaction effect, $F(1,54) = .596$, $p = .444$, $\eta_p^2 = .011$. Again, this suggests that whilst task performance was affected by increasing perceptual load, task performance and therefore task engagement was similar between groups.

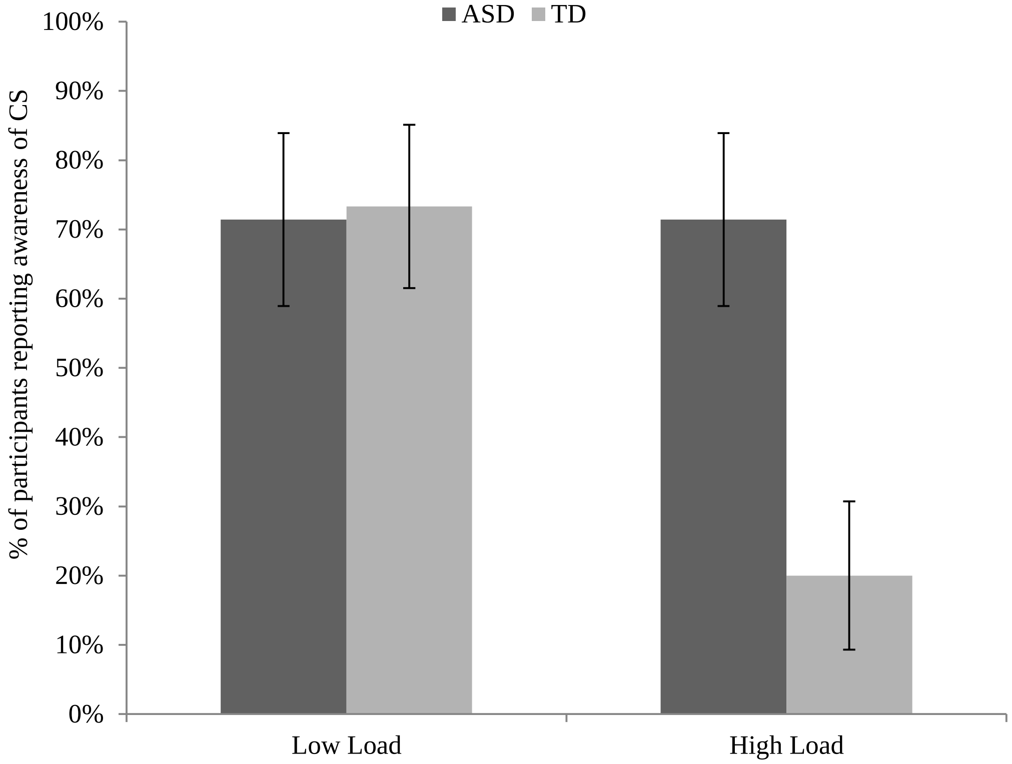
Threshold analysis

Overall, the perceptual threshold for the auditory stimulus (critical stimulus: CS) across all participants (*M* = 26.2db, *SD* = 2.49db) was significantly lower than the intensity level of the CS on the critical trial (CS was played at an intensity level of 15db), $t(57) = 20.704$, $p < .001$, [95% CI of the difference: 6.12 – 7.43]. This again suggests that a failure to notice the CS on the critical trial does not relate to an inability to hear the CS. Importantly though, there were no significant group differences in perceptual threshold, $F(1,54) = 1.796$, $p = .186$, $\eta_p^2 = .032$, no differences between perceptual load conditions, $F(1,54) = .301$, $p = .586$, $\eta_p^2 = .006$, and no interaction effect, $F(1,54) = .766$, $p = .385$, $\eta_p^2 = .014$. Perceptual sensitivity of the CS was thus similar across groups.

Awareness of CS

Participants were considered to be aware of the critical stimulus (CS) if they reported hearing something on the critical trial, and were able to accurately describe the auditory stimulus verbally (e.g. “it was a beep sound”). Awareness rates as a function of perceptual load and group are shown in Figure 5.4.

Figure 5.4 Percentage of participants reporting awareness of the auditory stimulus (critical stimulus: CS) according to perceptual load and diagnostic group (error bars: standard error)



A hierarchical logistic regression analysis was carried out to predict awareness of the auditory stimulus (0 =“No”, 1 =”Yes”) according to perceptual load, diagnostic group, and their interaction. In a first step, an intercept-only model was compared against a model with perceptual load and diagnostic group as predictors. The latter model was subsequently compared to a full model including the interaction between perceptual load and diagnostic group. All statistical analyses used maximum likelihood ratio tests (model comparisons based on differences in -2 log likelihood) and the statistical cut-off criterion for all predictors was set at .05. The first regression model predicting awareness of the CS from perceptual load and diagnostic group performed significantly better overall than the intercept-only model, χ^2 (2) = 8.667, p = .013. The Hosmer and Lemeshow test also indicated a good fit of the model to the data, χ^2 (2) = 4.157, p = .125. When controlling for the effect of group, there was a significant effect of perceptual load on awareness, χ^2 (1) = 4.954, p = .026, with participants in the high perceptual load condition being 0.5 times less likely to notice the stimulus than participants in the low perceptual load condition.

Table 5.6 Logistic regression analysis predicting awareness of the CS from perceptual load, diagnostic group, and their interaction

Variable	**B**	**SE B**	**df**	**MLE**	**p**	**OR**	**95% CI of OR**
Perceptual load	-.632	.29	1	4.954	.026*	.549	.304 – .992
Group	.575	.29	1	4.049	.044*	1.736	.961 – 3.137
Load X Group	.428	.29	1	4.092	.043*	1.821	1.008 – 3.291

Note:
MLE = Maximum Likelihood Estimation
OR = Odds Ratio
* p < .05

Diagnostic group also significantly predicted awareness of the CS, χ^2 (1) = 4.049, p = .044 with participants in the ASD group being 1.7 times more likely to notice the critical stimulus (for maximum likelihood ratio tests, odds ratio and CI of odds ratio see Table 5.6). The interaction between perceptual load and diagnostic group was tested by comparing a full model that included all predictors (perceptual load, group, and their interaction), against a reduced model with only load and group as predictors. The likelihood ratio test revealed a significant interaction between perceptual load and group, χ^2 (1) = 4.092, p = .043, suggesting a different effect of perceptual load on detection between groups. In particular, whereas in the low perceptual load condition detection rates did not differ between groups (TD: 73% vs. ASD: 71%), χ^2 (1) = .013, p = .909, detection rates were significantly reduced for the

TD group compared to the ASD group in the high perceptual load condition (TD: 20% vs. ASD: 71%), χ^2 (1) = 8.128, p = .004.

An additional logistic regression analysis also confirmed that neither non-verbal ability scores (raw score on the Raven's Progressive Matrices) nor scores on the SCQ was a significant predictor (both p > .05) of awareness rates of the CS in the ASD group.

Comparing awareness of social auditory stimulus and neutral auditory stimulus

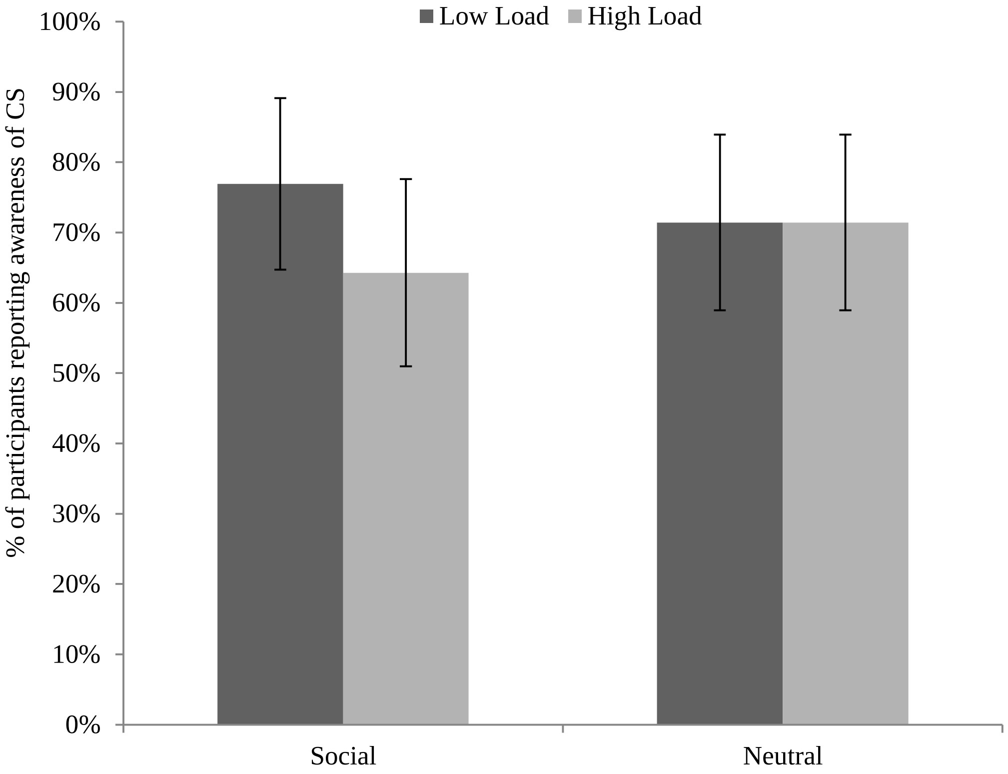
The findings from the last experiment (4) can be displayed alongside the results from experiment 3 to illustrate the effect of visual perceptual load on awareness of a social stimulus versus socially neutral stimulus for each group (ASD and control) separately.

ASD group

A 2x2 between-subjects ANOVA was used to analyse RTs according to experimental task (social vs. non-social), perceptual load (high vs. low), and an interaction term of task and load. The results indicated that ASD participants performed significantly slower in the high- compared to the low perceptual load condition, $F(1,51) = 27.934$, $p < .001$, $\eta_p^2 = .345$. There was no significant effect of task on RT, $F(1,51) = .830$, $p = .367$, $\eta_p^2 = .016$, and the interaction between group and load was also not significant, $F(1,51) = 1.314$, $p = .257$, $\eta_p^2 = .025$. This suggests that individuals with ASD performed similarly across tasks. There was also no significant main effect of task or perceptual load condition on RT difference scores (RToverall – RTcritical), nor a significant interaction effect of group and condition (maximum F-value = 1.697, smallest p-value = .199). Analysis of accuracy data partially confirmed previous results, as the effect of perceptual load approached significance, $F(1,51) = 3.647$, $p = .062$, $\eta_p^2 = .067$. There was no main effect of task, $F(1,51) = .344$, $p = .580$, $\eta_p^2 = .006$, and no interaction effect, $F(1,51) = .457$, $p = .502$, $\eta_p^2 = .009$ on accuracy.

As can be seen from Figure 5.5, awareness rates did not differ greatly as a function of task (social and neutral) and perceptual load or an interaction between the two. Statistical analyses confirmed this observation, with no significant effect of perceptual load (low vs. high) or task (social vs. neutral) on awareness, and no interaction effect of load and task on awareness (smallest p-value = .608).

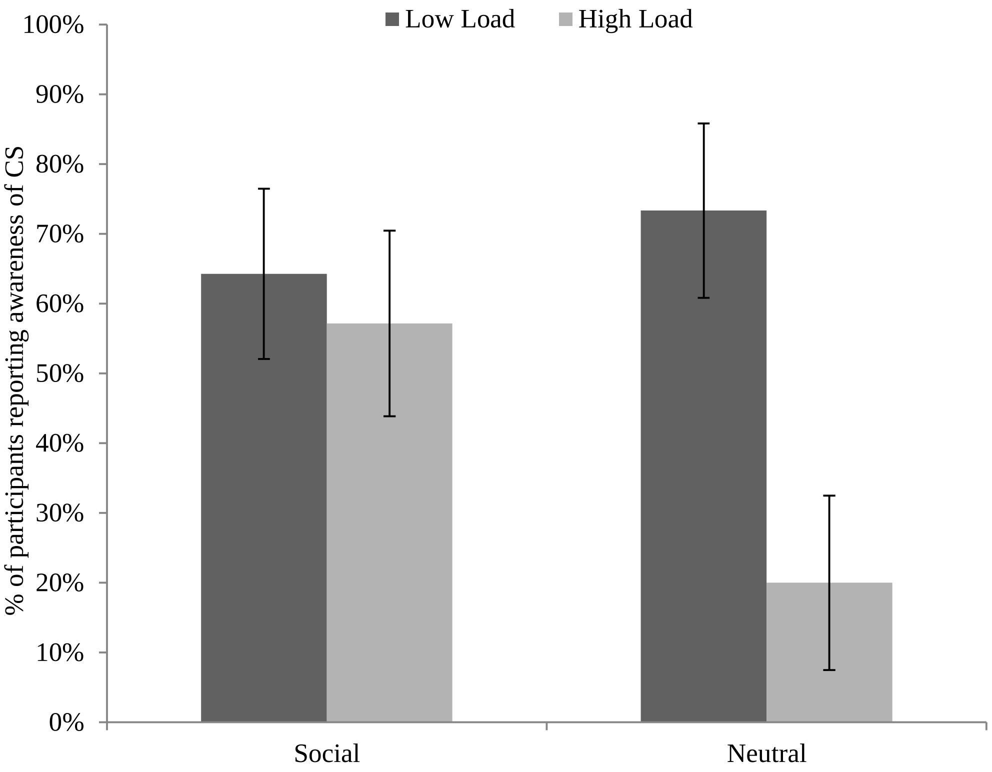
Figure 5.5 Percentage of individuals with ASD reporting awareness of the CS according to perceptual load and task (error bars: standard error)



TD group

A separate 2x2 between-subjects ANOVA was carried out for the TD group predicting RT performance from task (social vs. neutral) and perceptual load (low vs. high). As for the ASD group, the results showed that participants performed significantly slower in the high- compared to the low perceptual load condition, $F(1,54) = 44.999$, $p < .001$, $\eta_p^2 = .455$. There was also no significant effect of task on RT, $F(1,54) = .352$, $p = .555$, $\eta_p^2 = .006$, and the interaction between group and load was also not significant, $F(1,54) = 1.227$, $p = .273$, $\eta_p^2 = .022$. There was also no significant main effect of task or condition on RT difference scores (RToverall – RTcritical), nor a significant interaction effect of group and condition (maximum F-value = 1.025, smallest p-value = .333). Analysis of accuracy data confirmed previous results, with participants making significantly more errors in the high- compared to the low perceptual load condition, *F*(1,54) = 5.795, p = .02, η_p^2 = .097. There was no main effect of task, *F*(1,54) = .717, p = .401, η_p^2 = .013, and no interaction effect, *F*(1,514) = .161, p = .690, η_p^2 = .003 on accuracy.

Figure 5.6 Percentage of TD individuals reporting awareness of the CS according to perceptual load and task (error bars: standard error)



As can be seen from Figure 5.6, increasing the level of visual perceptual load had little effect on awareness of a social stimulus in TD individuals, yet performing a high perceptual load task reduced awareness of a neutral stimulus. This observation was confirmed statistically, with a significant interaction effect between perceptual load and task, χ^2 (1) = 7.848, p = .005.

Discussion

The findings indicated that on a task that featured a socially meaningless stimulus, increasing perceptual load resulted in significantly reduced awareness rates in TD adolescents, but not in adolescents with ASD who continued to report awareness of the CS. This therefore replicated the results from experiment 2.

More importantly, the findings from experiment 4, where the critical stimulus was a neutral auditory sound, provide crucial information that can be used to contrast the effect of perceptual load on awareness in tasks involving social stimuli. A distinct difference is seen between the pattern of awareness in TD participants for the speech sound (experiment 3) compared to the neutral sound (experiment 4) under high perceptual load. Whereas in experiment 4, a reduction in awareness of the CS in the TD group was observed in the high perceptual load condition, awareness of an unexpected speech sound was unaffected by an increase in the level of perceptual load. This disparity was shown to be statistically significant.

The same pattern of awareness of the CS is not seen for individuals with ASD. Awareness rates for both the social and neutral CS remained unaffected by the level of perceptual load. These findings will be fully discussed in the next section.

Overall discussion

For typically developing individuals, the current findings demonstrated that the level of visual perceptual load determined the incidence of inattentional deafness for an unexpected socially meaningless sound, but not for a speech sound. This parallels findings in the visual domain, where processing of distracting face stimuli has been shown to be unaffected by the visual perceptual load of the relevant task (Lavie et al., 2003; Remington, Campbell, et al., 2012). Crucially however, the current results show, for the first time, that an unexpected yet ecologically salient speech sound captures attention regardless of the level of visual perceptual load, whereas a neutral sound does not in the TD group. This provides preliminary evidence that in TD individuals, processing of unexpected auditory social stimuli in a cross-modal context of attention may also be automatic and mandatory, whereas processing of neutral auditory information relies on general capacity limits.

Considering the special biological and social significance of speech sounds could explain these findings. It may be adaptive that socially meaningful auditory information, unlike other neutral information, is processed irrespective of the level of visual perceptual load. Even if unexpected auditory information is not relevant for current task behaviours, as was the case in the current experiment, it can potentially carry important information including social cues (e.g. information on an individual's affect), which may be detrimental not to attend to.

Note at this point that the non-social critical stimulus was matched as closely as possible to the social stimulus on a number of acoustic properties including pitch, duration and intensity. Thus, whilst both stimuli had similar complex acoustic properties, the social stimulus retained its 'speechness' quality relative to the non-social stimulus. Any differences in awareness are therefore unlikely to be related to differences between the two sound stimuli in basic acoustic qualities.

Similar to the results of typically developing individuals, increasing perceptual load did not modulate awareness of the social CS in individuals with ASD. However, in the absence of any differences under high perceptual load in awareness of the neutral CS compared to the social CS, these findings do not necessarily imply that individuals with ASD also process unexpected speech sounds in any special way. An alternative explanation could be that in individuals with ASD, social auditory information captures attention similarly as socially neutral information, i.e. individuals with ASD treat social and non-social information in a similar manner. To further explore these issues, it would be interesting to measure the effect of visual perceptual load on awareness of a social vs. non-social stimulus in ASD at very high levels of perceptual load to see if there is a point at which a non-social stimulus CS does not reach awareness while a social stimulus does, or whether both types of stimuli suffer the same fate of not being noticed at higher levels of load.

Whereas both groups continued to report awareness of the social CS under high perceptual load, awareness of the neutral CS was significantly reduced for TD individuals but not for individuals with ASD in the high perceptual load condition. This replicates the findings reported earlier in experiment 2 and provides further support for an increased perceptual capacity in ASD that operates across sensory modalities. Importantly, increased rates of CS awareness in children with ASD, when visual perceptual load was high are not likely to be explained by deterioration in task performance on the line discrimination task. This is reflected by the absence of any group or interaction effects for both reaction time (RT) and accuracy measures suggests that both groups performed similarly on the task and across perceptual load conditions.

The RT and accuracy data also showed that the manipulation of perceptual load was effective across all participants, reflected by slower RT scores and higher error rates (index of higher processing demands) in the high perceptual load compared to the low perceptual load condition. Due to the constraints of the experimental paradigm, the previous experiment was not able to ascertain whether increased awareness of the CS in individuals with ASD was a result of the ASD group diverting attentional resources from the primary task to the unexpected auditory stimulus. A shift in attention of participants away from the visual task to the auditory modality would be reflected in a significant difference between RT on the critical trial and RT's on non-critical trials (i.e. experimental trials). Results from the current study suggest that this was unlikely to be the case. There were no group differences on RT-difference score that reflected the extent to which participant's RT slowed on the critical trial in relation to average RTs. Reduced awareness rates in TD children on the other hand cannot be attributed to the low intensity of the auditory stimulus. On both the critical and control trial, the auditory stimulus was played at hearing levels well above threshold and was therefore easily perceivable, and all participants noticed the auditory stimulus and were able to describe it on the control trial when their attention was not focused on the primary visual task. Perceptual thresholds of the CS did also not differ across groups, suggesting that any differences in awareness cannot simply be due to increased sensitivity to auditory signals. The observed group effect is also unlikely to be caused by any differences in cognitive abilities as all participants were carefully matched for performance on the Raven's Progressive Matrices.

Taken together, these findings provide evidence that in typically developing individuals, the capacity for socially meaningless stimuli is distinguishable from the capacity for social stimuli. In particular, the TD group demonstrated automatic and mandatory processing of the social stimuli at all levels of perceptual load, but not for an acoustically-matched neutral stimulus. Individuals with ASD did not show any differences in awareness for both stimuli, suggesting that both unexpected social and non-social auditory information captures attention regardless of level of perceptual load. In a task that featured a non-social critical stimulus, earlier findings in chapter 4 of an increased perceptual capacity in ASD were replicated. This was done using an improved experimental design, which further strengthens these findings.

Chapter 6 The effect of perceptual load on detection sensitivity in ASD

In the previous experiments, evidence of an increased perceptual capacity in individuals with ASD that operates across sensory modalities was presented. These conclusions were based on analyses of awareness reports for an unexpected, neutral auditory stimulus during an inattentional deafness task under varying levels of visual perceptual load. Whereas individuals with ASD continued to report awareness for an unexpected sound at high perceptual load, i.e. awareness rates remained high, awareness rates declined significantly in TD individuals under high visual perceptual load.

Because of the single-trial nature of the inattentional deafness paradigm, i.e. the auditory detection stimulus was only presented once per participant, measures of detection sensitivity (d’) and response criterion (c) could not be assessed in these experiments. However, it is possible that reduced awareness in conditions of high perceptual load in TD individuals may reflect the influence of a more stringent response criterion rather than a true reduction in perceptual detection. Detection sensitivity measures the detectability of a stimulus, whereas response criterion relates to a participant’s internal bias towards responding either with ‘stimulus present’ or ‘stimulus absent’. In addition, although the surprise question followed the critical trial immediately after recording the visual response, thereby minimising any confounding effects, alternative explanations in terms of rapid forgetting (Wolfe, 1999) or a weak memory trace (Barber & Folkard, 1972) cannot be completely ruled out.

Raveh and Lavie (2015) recently addressed these concerns in a study with TD adults by directly measuring the effect of visual perceptual load on perceptual sensitivity of an auditory tone using a dual-task paradigm. Measuring perceptual sensitivity (e.g. d’) has the advantage that its value does not depend upon the response criterion the subject is adopting, thereby providing a true measure of a subject’s sensitivity. Participants were required to perform a letter identification task at either low or high perceptual load and also report the presence of a critical stimulus (an auditory tone) presented on 50% of all trials, thus avoiding the delay involved in processing a surprise question as in a typical inattentional blindness/deafness task. Moreover, in one experiment, participants also had to make the detection response prior to the letter search task response, therefore ruling out the possibility of rapid forgetting or poorer encoding into memory during prolonged response times in the high perceptual load condition. The results demonstrated that despite participants anticipating and actively trying to detect the critical auditory stimulus, high perceptual load resulted in a reduction in sensitivity, while having no effect on response bias. The authors also showed that this pattern remained when participants had to make the detection response prior to the letter search task response. Together, these results suggest that in typically developing adults, a reduction in auditory awareness in conditions of high perceptual load neither reflects a change in response criterion, nor rapid forgetting.

In ASD, Remington, Swettenham, et al. (2012) examined the implications of an increased perceptual capacity for perceptual sensitivity of an expected visual stimulus at varying levels of perceptual load. The authors presented age-and IQ-matched adults with ASD and controls with a central letter search task (identify target letter ‘X’ or ‘N’). Perceptual load was manipulated by increasing the number of neutral letters in the task display, such that participants performed four different set sizes (1, 2, 4 and 6). In addition to the search task, participants also had to indicate the presence or absence of a peripheral shape presented simultaneously on 50% of all trials with the search task. The results showed that detection sensitivity declined as a function of perceptual load in TD individuals, yet remained unaffected in adults with ASD. This effect was observed despite no concurrent deterioration in accuracy or reaction time on the central letter search task. It was also found that the response criterion was not influenced by perceptual load, suggesting that the higher detection rate in individuals with ASD was not a result of a change in response criterion.

Experiment 5

Given these findings, the aim of the current experiment was to establish whether an increased perceptual capacity in ASD also has implications for auditory detection sensitivity in a cross-modal context of attention. To do so, a dual-task paradigm was adopted from Remington, Swettenham, et al. (2012) to examine how the perceptual load of a visual task can influence perceptual sensitivity of a critical auditory stimulus. Participants performed a visual search task while simultaneously attending to a target sound in noise. Perceptual load was manipulated by increasing the number of additional visual stimuli in the search display to create four different perceptual load conditions.

Because the additional stimulus was presented multiple times, the design allowed for a signal detection analysis of the data so that the effects of perceptual load on perceptual sensitivity could be assessed independently from any effects of response bias. In addition, the critical auditory stimulus in noise was adjusted to participant’s individual threshold. This was necessary to account for any individual differences in perceptual sensitivity that could bias the results. Sensory disturbances, especially in the auditory modality, are frequently reported in individuals with ASD. These can range from complete ignoring of sounds (Dawson et al., 1998) to oversensitivity to loud noises or particular sounds (Grandin, 1997; Jones et al., 2009; Rosenhall, Nordin, Sandström, Ahlsen, & Gillberg, 1999). By presenting participants with an auditory tone embedded in noise adjusted to their individual threshold, yet keeping the absolute difference between signal (target sound) and noise the same across all participants, the effect of perceptual load on auditory detection could be examined without any confounding effects of individual differences in perceptual sensitivity. It was predicted that both the ASD and TD group would show a reduction in sensitivity to the auditory stimulus as the perceptual load of the visual task increased. TD individuals however would experience this reduction in sensitivity at an earlier set size (i.e. at a lower level of perceptual load) than individuals with ASD, who would demonstrate greater sensitivity than controls at higher levels of perceptual load. At the highest level of perceptual load, both groups would show similar reduced sensitivity.

Method

Participants

20 typically developing (TD) adolescents and 19 adolescents with ASD were recruited. These participants were sampled equally across the two previous experiments based on their ability to perform the task at an adequate level (please refer to the Appendix on page 191 for a summary of how participants were distributed across experiments).

The same diagnostic and recruitment criteria applied as in the previous experiments. Parent report of ASD symptoms using the Lifetime version of the SCQ (Social Communication Questionnaire, Rutter et al. 2003) was obtained for all participants with ASD and all participants met the recommended cut-off score of 15.

Participants were excluded if their accuracy on the letter search task was lower than 50% or if their detection accuracy of the auditory stimulus was lower than 30% in either or both perceptual load conditions. On the basis of these exclusion criteria, three participants with ASD and three TD participants were removed prior to the analysis. The remaining 17 TD and 16 participants with ASD were matched for non-verbal ability (using the Raven’s Standard Progressive Matrices, Raven et al., 1998) and chronological age (see

Table 6.1 for descriptive statistics). Independent samples t-tests indicated that there were no significant differences between groups on any of these measures (maximum t-value = .519, minimum p-value = .607).

Table 6.1 Descriptive statistics for each group

Group	Statistic	CA (years : months)	Raven's Score	SCQ score
ASD (n= 16)	M	14:8	44.9	26
	SD	1:0	6.2	4.5
	Range	12:5 – 17:5	33 - 56	21 - 35
TD (n= 17)	M	14:5	45.8	
	SD	1:1	4.6	
	Range	11:7 – 15:5	36 - 54	

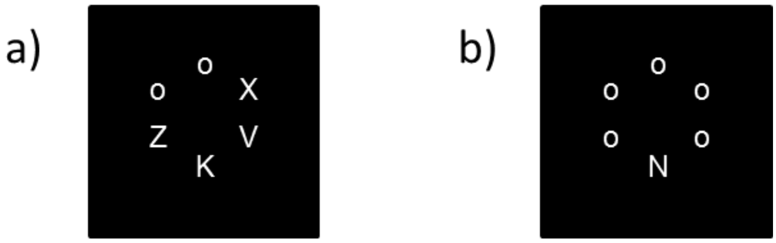
Note:
CA = Chronological Age
SCQ = Social Communication Questionnaire

Apparatus and Stimuli

Microsoft Visual Basic (version 6) was used to create computer-based stimuli that were presented on an IBM Lenovo Thinkpad 14.1" personal laptop. Viewing distance was 60cm. The task involved a dual-task paradigm that required participants to identify a visual target letter ('X' or 'N') presented in the middle of the screen and then indicate the presence or absence of an auditory tone embedded in noise.

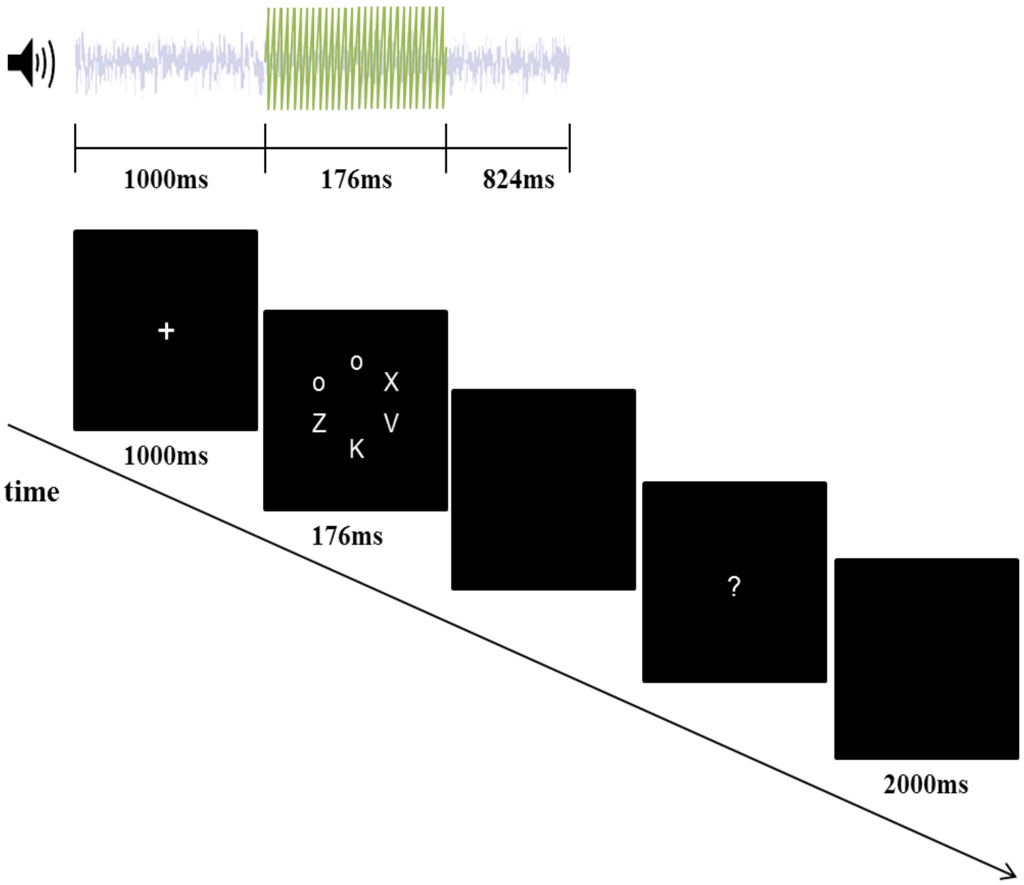
On each trial, six equally spaced letters were placed around the circumference of a circle, centered at fixation, with a radius of 1.7° visual angles (see Figure 6.1 for a visual presentation of the letter search display). The background of the display was black (RGB: 0, 0, 0) and the letters were white (RGB: 255, 255, 255). On each trial, one of the letters presented in the ring was the target letter (a capital letter 'X' or 'N', equally likely to appear). The target letter measured 0.6° x 0.6° visual angles and was presented randomly, but with equal probabilities, in one out of six possible locations. Depending on the condition, the other ring positions were occupied by perceptually similar non-target letters (H, K, V, Y or Z; 0.6° x 0.6° visual angles) or an easy to distinguish small letter *O* (0.2° x 0.2° visual angles). The perceptual load of the search task was manipulated by adding non-target letters to the display to create four different set sizes: one (target letter and five *O*'s), two (target letter, one non-target letter, and four *O*'s), four (target letter, three non-target letter, and two *O*'s), and six (target letter and five non-target letter).

Figure 6.1 Example of letter search display: (a) target is 'X' at set size four, (b) target is 'N' at set size one



On each trial, participants also had to indicate the presence or absence of an auditory target sound embedded in noise. Starting at the onset of each trial, a speech-shaped noise masker (48db SPL), which is noise with amplitudes at different frequencies to match those of natural speech (Nelson et al., 2003), was played continuously through a pair of Sennheiser HD 25-1-II stereo headphones for 2 seconds (see Figure 6.2). On half of the trials, simultaneously with the presentation of the letter-search task, an auditory target sound (i.e. a beep tone) was played together with the speech-shaped noise. On the other half of the trials, the noise continued to play until completion. The target sound was a saw-tooth wave (frequency range of 85-150Hz) and was matched for duration with the visual presentation time of the central letter search task (i.e. 176ms).

Figure 6.2 Example trial with an auditory tone present in noise (1) at set size four



Presentation of (a) the target sound + noise or (b) noise-only stimulus was randomised across trials. All sound files were prepared with Audition and SFSWin and calibrated prior to the experiment by a Bruel & Kjaer 4153 artificial ear together with an Ono Sokki CF-350Z spectrum analyser. To combine the saw-tooth wave and speech-shaped noise, a total of 25 Sine-to-noise-ratio (SNR) stimuli were created that ranged from -2db to -14db in 0.5db steps. The larger the SNR, the more difficult it was to detect the target sound in noise. Note that in this study, the masking noise is a speech-shaped noise instead of white noise (as in Raveh & Lavie, 2015). The reasons for this decision were two-fold. First, white noise is characterised by an equal energy distribution that is not representative of noise typically found in the environment, and is therefore not a very realistic masker for test signals, whereas speech-shaped noise simulates more closely real life situations (Taylor & Mueller, 2011). Second, speech-shaped noise is a better masker for low frequency sounds such as the saw-tooth wave used in this study (Nelson, Jin, Carney, & Nelson, 2003).

Participants performed a total of 196 trials, administered in four blocks according to each set size (1, 2, 4, and 6). Participants always completed one set size first, before moving on to the next set size. For each set size, a total of 48 trials were presented and presentation of both the visual target letter (‘X’ or ‘N’) and auditory stimulus (auditory tone + noise or noise-only) was randomised (visual and auditory stimuli were equally often presented). Presentation of blocks was randomised and counterbalanced across participants and participants were able to take breaks after each block.

Prior to performing the dual task paradigm, the perceptual threshold for the auditory stimulus in noise was established for each participant using a two alternative forced-choice (2AFC) adaptive threshold procedure. Each trial consisted of two pictures appearing on the screen (one left and one right) after each other which were accompanied by a noise masker. The target sound (beep tone + noise) appeared randomly with either the first or second picture. Participants indicated after each trial when they heard the target sound (first or second) and the experimenter entered their response via the keyboard. If participants produced two consecutive correct answers, the SNR was reduced by -0.5db. As soon as they provided an incorrect answer, the SNR was increased by 0.5db. A reduction in SNR thus made it more difficult to make out the target sound in noise, whereas an increase in SNR made it easier. Individual thresholds were based on an average of five reversals (point at which direction is changed, i.e. either when producing a correct answer followed by an incorrect answer or when producing 2 correct after an incorrect answer).

The threshold level for each participant subsequently informed the choice of the SNR mix used in the letter search task. This was achieved by increasing the SNR by 5 units (i.e. +2.5db) such that the individual SNR mix used in the main experiment was well above each individual’s threshold. So for example, someone who recorded a SNR threshold of -9.5db, this person would be presented with a SNR mix of -7.0db in the main experiment. Each participant was therefore presented with an auditory tone embedded in noise adjusted to their individual threshold, yet across participants, the absolute difference between signal (target sound) and noise was always the same.

Procedure

On each trial, together with a fixation cross that was displayed centrally for 1000ms, the speech-shaped noise started to play (see Figure 6.2). This was followed by the visual search array for 176ms, which could be accompanied either by the presence or absence of the target sound. A blank screen was then displayed until a response to the visual input was made. Immediately following this response, a white question mark was presented centrally at a size of 0.6º x 0.6º until a response is made regarding the presence or absence of the auditory stimulus. A blank screen was then displayed for 2000ms, after which the next trial began.

Participants were told that they would see a central ring made up of letters and that one letter would be either an X or an N. They were instructed to indicate as quickly but also as accurately as they can whether an ‘X’ or an ‘N’ is present (keypress of ‘X’ or ‘N’ for X and N respectively). They were then told that on some of the trials (50%), they would also hear a short beep tone hidden in noise whilst the ring of letters appeared on the screen. Participants always needed to first make the visual judgment (‘X’ or ‘N’) and then indicate via a separate keypress whether the sound in noise was present (press ‘S’) or absent (only noise; press ‘A’).

Following a set of practice trials, participants completed all four blocks one after the other and were able to take breaks in between blocks. For the letter search task, reaction time (RT) and discrimination accuracy was recorded, whereas for the auditory detection task only accuracy was recorded.

Results

Letter search task

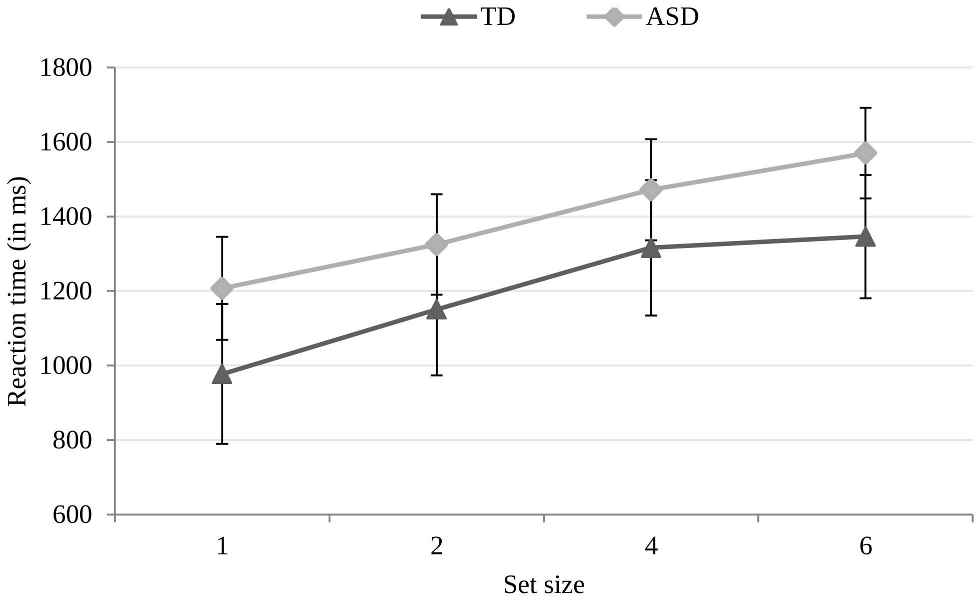
All incorrect trials (i.e. wrong target letter response) and trials with reaction times (RT) on the ring of letter task above 2500ms were discarded prior to analysis and average correct RTs were calculated (see Table 6.2 for descriptive summary of task performance).

Table 6.2 Means and standard deviations for reaction time (RT) and error rate according to diagnostic group and set size

		Reaction Time (in ms)		**Error Rate** (in %)	
Set size	**Statistic**	**ASD**	**TD**	**ASD**	**TD**
1	M	1207	977	6	6
	SD	(260)	(366)	(10)	(8)
2	M	1325	1150	4	6
	SD	(253)	(344)	(4)	(5)
4	M	1472	1316	14	15
	SD	(255)	(353)	(6)	(8)
6	M	1570	1346	27	26
	SD	(288)	(322)	(9)	(8)

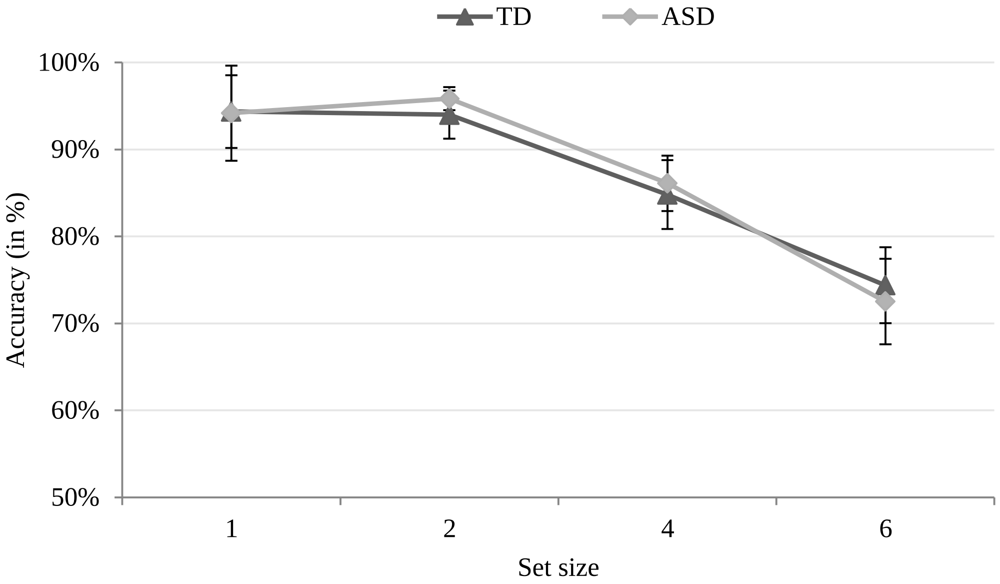
A mixed Analysis of Variance (ANOVA) with group (ASD vs. TD) as a between-subjects factor and set size (one, two, four, and six) as a within-subjects factor was subsequently performed on RT data. There was a significant main effect of set size, $F(3, 90) = 52.332$, $p < .001$, $\eta_p^2 = .636$, indicating that participants were slower to respond to trials with higher set sizes. This suggests that the manipulation of perceptual load was effective as significantly slower RT scores (index of higher processing demands) were observed as a function of increases in the perceptual load of the task. There was no significant effect of group, $F(1, 30) = 1.951$, $p = .173$, $\eta_p^2 = .06$, which means that overall, there was no difference in reaction times between groups. Any differences between groups are therefore unlikely to be due to a generalised reduction in processing speed within individuals with ASD. The interaction between set size and group was also not significant, $F(3, 90) = .442$, $p = .723$, $\eta_p^2 = .054$.

Figure 6.3 Mean Reaction Time (RT) as a function of set size and group (error bars: 95% CI)



A similar observation was made for accuracy data (see Figure 6.4), where task performance as indexed by accurate responses on the letter task declined significantly as a function of set size, *F*(2.5, 90) = 66.767, $p < .001$, $\eta_p^2 = .69$ (Huyn-Feldt adjusted degrees of freedom). The main effect of group on accuracy was not significant, *F*(1, 30) = .016, p = .899, $\eta_p^2 = .001$, as was the interaction between set size and group, *F*(2.5, 90) = .945, p = .410, $\eta_p^2 = .031$ (Huyn-Feldt adjusted degrees of freedom).

Figure 6.4 Mean accuracy rate (in %) as a function of set size and group (error bars: 95% CI)



Analysis of RT and accuracy data therefore suggests that the manipulation of perceptual load was successful and that participants were engaging with the task in the way that was intended.

Detection of the critical auditory stimulus

As before, all incorrect trials on the letter search task, as well as those trials with longer RTs than 2500ms were excluded prior to analysis. The percentage detection rate of the auditory stimulus (Figure 6.5), false alarm rate (Figure 6.6) and sensitivity (d') (Figure 6.7) for each group at each set size was calculated (for a descriptive summary of all measures see Table 6.3). The d' measure assesses detectability of a stimulus independent of a participant's response bias and is estimated using both the observed percentage detection rate and false alarm rate. It is calculated by taking into account the probability of a correct target response (a 'Hit') and the probability of incorrectly responding (i.e. respond present) when the target is absent (a 'False alarm'):

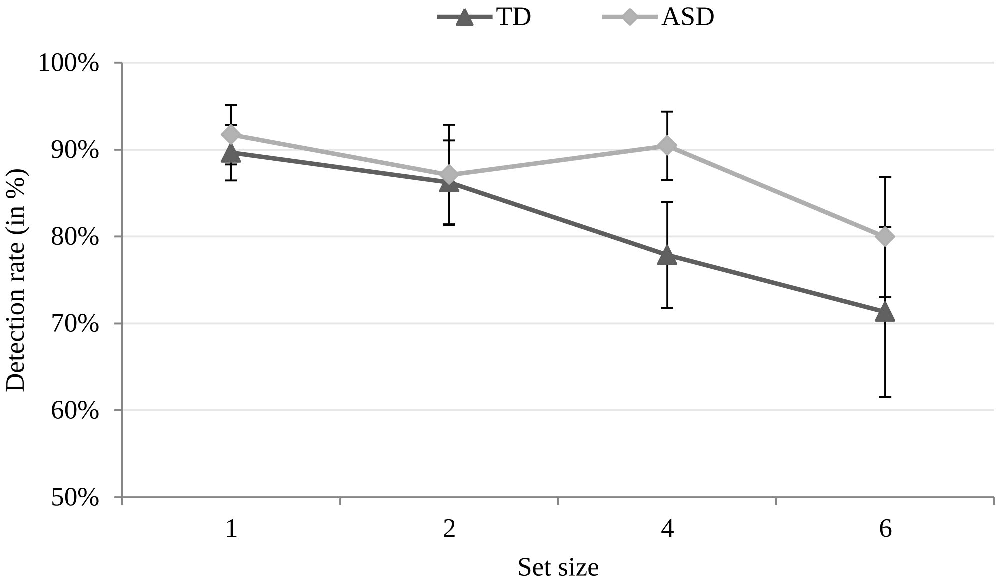
$d' = Z(Hit) - Z(FalseAlarm)$ where function $Z(p), p \in [0,1]$

Table 6.3 Detection rate, false alarm rate, detection sensitivity (*d'*) and response criterion (c) according to diagnostic group and set size

		Detection rate (in %)		**False alarm rate** (in %)		**Detection sensitivity** (d')		**Response criterion** (c)	
Set size	**Statistic**	**ASD**	**TD**	**ASD**	**TD**	**ASD**	**TD**	**ASD**	**TD**
1	M	91.7	89.6	10.3	12.3	2.93	2.75	-.03	0.03
	SD	(6.4)	(6.2)	(11.1)	(14.6)	(0.62)	(0.93)	(.37)	(.29)
2	M	87.1	86.2	11.0	12.5	2.76	2.49	0.07	0.03
	SD	(10.8)	(9.4)	(13.5)	(8.7)	(0.97)	(0.8)	(.37)	(.29)
4	M	90.4	77.9	14.3	18.5	2.65	1.81	-0.13	0.06
	SD	(7.4)	(11.8)	(11.8)	(11.3)	(0.76)	(0.63)	(.34)	(.3)
6	M	79.9	71.3	22.8	17.4	1.79	1.75	-0.09	0.25
	SD	(13.0)	(19.1)	(12.0)	(14.7)	(0.76)	(0.98)	(.36)	(.38)

A repeated measures ANOVA on the percentage detection rate indicated that there was a significant main effect of set size, *F*(3, 90) = 14.705, p < .001, η_p^2 = .329, suggesting that the auditory stimulus was detected less often as the perceptual load of the task increased. Post-hoc within-subjects contrasts revealed that a linear trend captured best this effect of set size, *F*(1, 30) = 29.736, p < .001, η_p^2 = .490. There was a significant main effect of group, *F*(1, 30) = 4.906, p = .035, η_p^2 = .141. Visual inspection of detection rates (see Figure 6.5) indicated that the ASD group reported higher detection rates than the TD group.

Figure 6.5 Detection rate of the auditory stimulus (in %) as a function of set size and group (error bars: 95% CI)

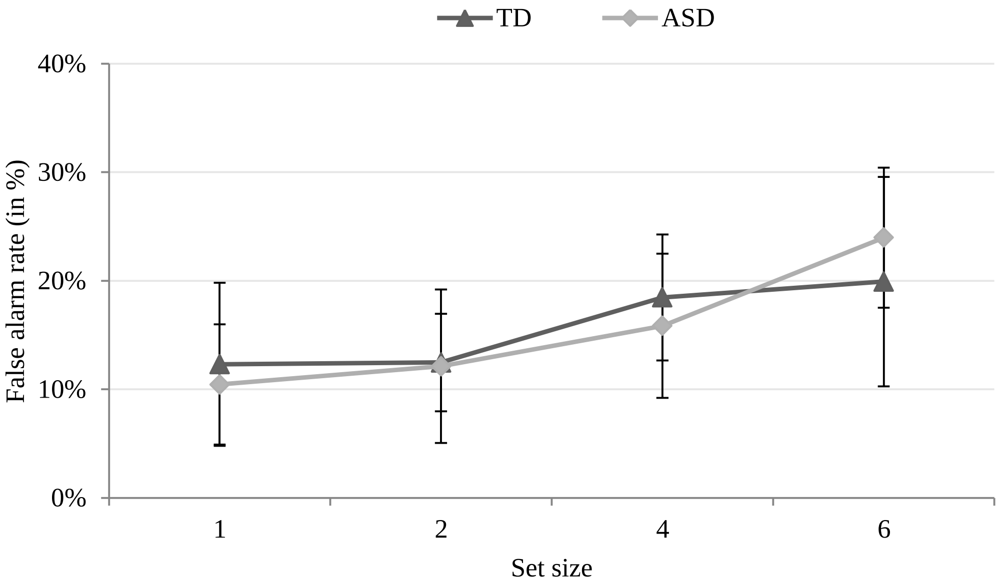


There was also a significant interaction between set size and group (*F*(3, 90) = 2.753, p = .047, η_p^2 = .084, suggesting that the difference in detection rates between the ASD and TD group was dependent on set size. Post-hoc ANOVA for each set size demonstrated that whilst there were no significant differences between groups in detection rates at set size 1(ASD = 91.7%, TD = 89.6%), *t*(30) = .967, p = .341 and set size 2 (ASD = 87.1%, TD = 86.2%), *t*(30) = .254, p = .802, the ASD group had significantly higher detection rates than the TD group at set size 4 (ASD = 90.4%, TD = 77.9%), *t*(27) = .37, p = .001. There was no significant difference in detection rates between groups at set size 6 (ASD = 79.9%, TD = 71.3%), *t*(30) = 1.518, p = .140.

False alarm rate

A repeated measures ANOVA revealed a significant main effect of set size, $F(3, 90) = 5.250$, $p = .002$, $\eta_p^2 = .149$, with the false alarm rates increasing linearly with set size (see Figure 6.6). This was to be expected, as an increase in task difficulty inevitably leads to a greater amount of guessing. There was no significant main effect of group, $F(1, 30) = .040$, $p = .843$, $\eta_p^2 = .001$, indicating that false alarm rates did not differ between groups. The interaction between set size and group was also not significant, $F(3, 90) = 1.281$, $p = .286$, $\eta_p^2 = .041$.

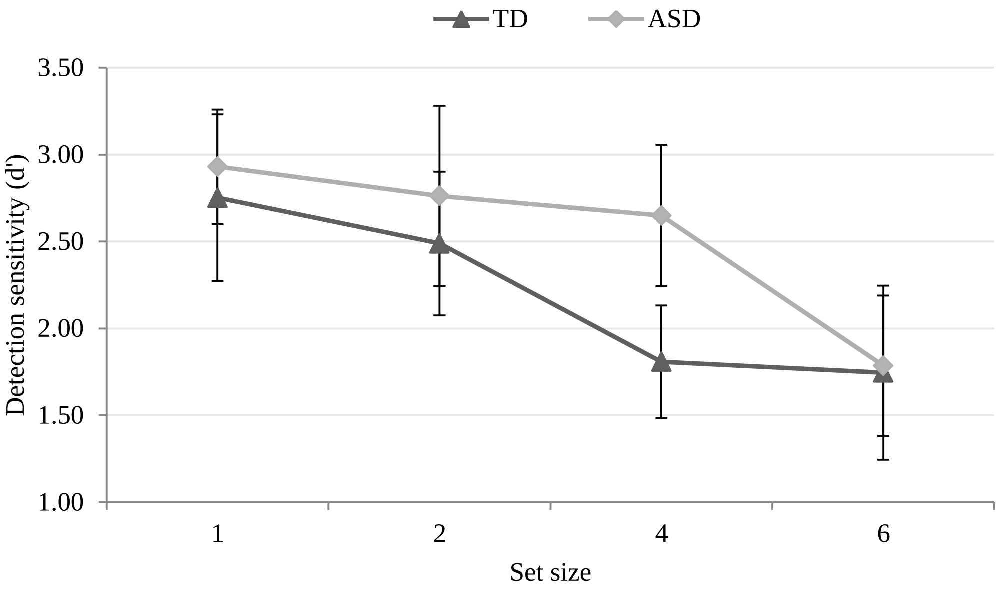
Figure 6.6 False alarm rate (in %) as a function of set size and group (error bars: 95% CI)



Detection sensitivity

The d’ measure, an index of sensitivity or discrimination, provides a more accurate reflection of task performance by taking into account both participant’s detection and false alarm rate. A repeated measures ANOVA on the d’ values for each participant at each set size revealed a significant main effect of set size, $F(3, 90) = 17.317$, $p < .001$, $\eta_p^2 = .366$, with detection sensitivity being lower at higher set sizes. There was no effect of group, $F(1, 30) = .950$, $p = .337$, $\eta_p^2 = .03$, which means that there was no overall difference in sensitivity levels between the two groups.

Figure 6.7 Detection sensitivity (d’) as a function of set size and group (error bars: 95% CI)



However, the interaction between set size and group was close to significance, *F*(3, 90) = 2.394, p = .074, η_p^2 = .074, indicating that the pattern of sensitivity is changing differently for the two groups as the perceptual load increased (see Figure 6.7). A priori specified t-tests showed that there was a significant difference in sensitivity between the two groups at set size 4 (*d’*; ASD = 2.65, TD = 1.81), *t*(30) = 3.411, p = .002, yet this difference disappeared at set size 6 (*d’*; ASD = 1.79, TD = 1.75), *t*(30) = .126, p = .9. There was also no significant difference between groups at set size 1 (*d’*; ASD = 2.93, TD = 2.75), *t*(30) = .621, p = .539 and set size 2 (*d’*; ASD = 2.76, TD = 4.88), *t*(30) = .871, p = .391.

Response criterion

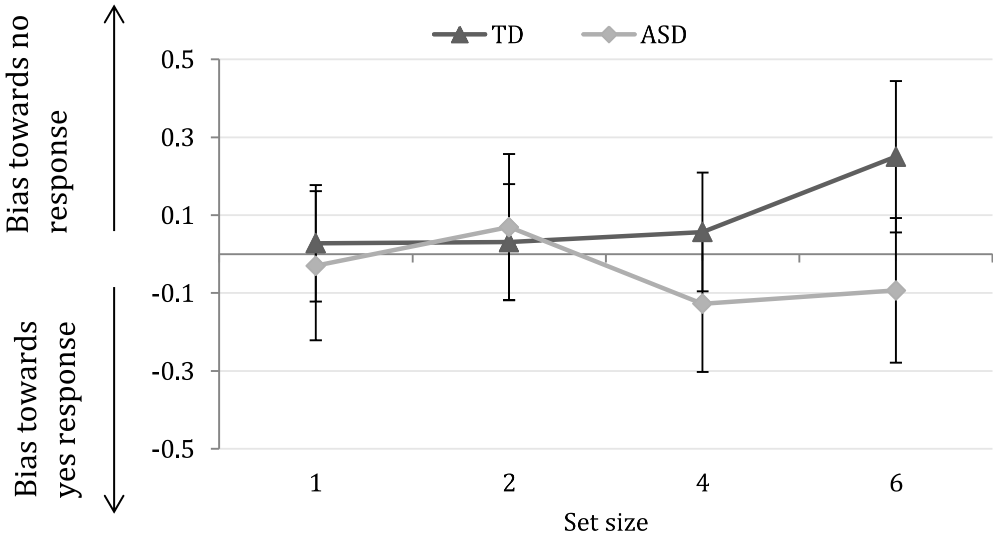
As for detection sensitivity, the response criterion (c) was calculated for each participant at each set size:

$$c = -\frac{\mathrm{Z(Hit)} - Z(FalseAlarm)}{2}$$ where function $Z(p), p \in [0,1]$

A response criterion with a value greater than 0 indicates a bias towards the no response, a value of less than 0 indicates a bias towards the yes response and the value of 0 indicates no bias towards yes or no (see Figure 6.8).

Using ANOVA, the results showed that the response criterion did not differ significantly across set sizes, *F*(2.7, 90) = .933, p = .422, η_p^2 = .03 (Huyn-Feldt adjusted degrees of freedom) or groups, *F*(1, 30) = 3.048, p = .091, η_p^2 = .092. The interaction between set size and group was close to significance, *F*(2.7, 90) = 2.507, p = .07, η_p^2 = .077 (Huyn-Feldt adjusted degrees of freedom). From Figure 6.8, it can be seen that this trend is likely to be driven by differences in response bias between groups at set size 6, with participants in the TD group adopting a more stringent response criterion (i.e. bias towards responding ‘no’) than the ASD group.

Figure 6.8 Response criterion for each group at each set size



Discussion

The results presented here demonstrate that individuals with ASD are characterised by an increased perceptual capacity on a cross-modal auditory detection task. When the perceptual load of the visual task was low (1 or 2 items in the central search array), detection rates for the auditory stimulus did not differ between groups. However, when the perceptual load was higher (4 items in the search array) auditory detection rates were significantly reduced in TD individuals compared to individuals with ASD, who maintained a high level of detection. At even higher levels of perceptual load (6 search array items), there was no difference in detection rates between groups. The fact that auditory detection rates in the ASD group were not affected by the perceptual load of the visual task until there were 6 items in the search array (compared to 4 items in the search array for the neurotypical group) suggests an increased perceptual capacity in ASD.

The signal detection analysis confirmed that the observed advantage in detection in individuals with ASD reflects a superior perceptual sensitivity rather than a shift towards a more lenient response criterion. This was shown by a significant difference between groups in detection sensitivity at higher perceptual load levels (set size 4). An alternative account of increased detection in the ASD group as a result of a tendency to respond with ‘stimulus present’ can therefore be ruled out.

There was also no difference between groups in central search task performance as indexed by target letter RTs. The absence of any difference therefore suggests that superior detection in ASD did not come at the expense of a general reduction in processing speed. Also recall that only correct trials were included for further analyses to ensure that participants were paying attention to the visual task whilst they also attended to the target sound. Could differences between groups in goal neglect (i.e. deprioritisation of detecting the target sound) account for the findings observed here? There are two reasons why this is unlikely. First, the auditory target sound was presented on 50% of all trials and was therefore highly expected. Indeed, on each trial, participants always had to indicate the presence or absence of the CS, before being able to move onto the next trial. Second, any form of goal neglect (i.e. participants forgot to attend to the target sound) would most likely occur at the highest level of perceptual load (set size 6), ostensibly requiring most attentional resources and hence putting a higher priority on the visual task. The fact that there were no differences in detection rates or sensitivity between groups in detection at this level of perceptual load clearly provides evidence that goal neglect is an unlikely explanation for the results.

The current findings converge with the findings of experiment two and four, where increasing the visual perceptual load of the task resulted in a reduction in awareness of an unexpected neutral auditory stimulus in TD individuals, but not in individuals with ASD. The present study thus provides further evidence of an increased perceptual capacity in ASD by showing how also detection of expected auditory information is only modulated at higher levels of perceptual load in ASD.

One potentially problematic issue that may have arisen in the current experiment concerns the use of a blocked design: where each block only contained trials of the same set size. A number of studies with typical adults using different converging operations (Handy & Mangun, 2000; Murray & Jones, 2002; Theeuwes et al., 2004) have shown that distractor interference depends on participants' anticipation of high-load or low-load displays irrespective of the actual display presented. Thus, based on these findings rather than bottom-up it is the top-down factors such as load anticipation that are most critical to performance. These differences in strategy rather than the level of perceptual load could have influenced the effects seen on detection rates and sensitivity. Other studies however have found the opposite (Brand-D'Abrescia & Lavie, 2007; Lavie, Lin, Zokaei, & Thoma, 2009; Macdonald & Lavie, 2008, 2011), namely that randomly intermixing low-and high load trials produces the same perceptual load effect as presenting participants with a blocked design. It would be important in a future study to explore the possibility of strategy effects within the dual-task paradigm used here in individuals with ASD.

Chapter 7 The effect of perceptual load versus target degradation on detection sensitivity in ASD

The findings presented in this thesis demonstrate that increasing the perceptual load of a visual task has a differential effect on auditory awareness rates in individuals with ASD compared to typically developing controls. This pattern of results has been found to be consistent across different measures of awareness, both when the additional stimulus was expected to appear on only some of the trials (Experiment 5), or was not expected to appear at all (e.g. Experiment 2, 4). These experiments also used different manipulations of perceptual load, either by increasing the number of stimuli among which a target letter had to be identified (i.e. the relevant search set size) or by increasing the processing requirements for the same stimuli in a single-element display (i.e. present a more subtle line discrimination task) (Lavie, 1995, 2005). A problematic issue that arises however is that an increase in perceptual load also typically involves an increase in task difficulty and associated slowing of overall RTs and increase in error rates. This was for example shown in the previous experiment, where higher set sizes produced prolonged RTs and higher error rates. One could therefore argue that the differential effect of higher perceptual load on awareness in individuals with ASD may be attributed to an increase in general task difficulty rather than reflecting load-specific effects on perceptual resources.

In an important experiment for load theory, Lavie and de Fockert (2003) attempted to separate the effects of perceptual load from the general effects of task difficulty on attention. Specifically, they contrasted the effects of perceptual load (by varying the search set size in the relevant task) with the effects of sensory degration (e.g. by reducing the contrast or size of a target) on distractor processing. Lavie and de Fockert proposed that whilst both manipulations will result in increased task difficulty, degrading the sensory quality of a target item should make discrimination more difficult (i.e. making identification of target items subject to sensory ‘data limits’) without putting any further demand on attentional ‘resource limits’ (Norman & Bobrow, 1975). They hypothesised that the extent to which distractors will be processed will critically depend on the type of manipulation of task difficulty:

increasing task difficulty by increasing perceptual load will lead to reduced distractor processing, whereas increasing task difficulty by degrading the target stimulus will not reduce distractor processing.

Participants performed a hybrid between a visual search task (Treisman & Gelade, 1980) and a flanker task (Eriksen & Eriksen, 1974), that required them to identify a relevant target letter (either X or N) while attempting to ignore a distracting letter in the periphery. This distractor could be either compatible (an X if target was X) or incompatible (an X distractor when the target was N, or vice versa) with the target response. Perceptual load of the task was varied by increasing the number of non-target letters in the central search array to create a low perceptual load condition (only target letter present) or high perceptual load condition (target letter + 7 neutral non-target letters). Participants also performed a condition of low perceptual load with a degraded target letter. In this condition, only the target letter was presented in the central search array (i.e. constituting a low perceptual load display), yet size and contrast of the target letter were reduced relative to the other conditions, thereby degrading the sensory input. The results indicated that both increasing perceptual load and target letter sensory degradation resulted in an increase in task difficulty as indexed by longer RTs and higher error rates compared to a low perceptual load condition that featured an intact target letter. However, whereas an increase in perceptual load resulted in reduced distractor processing, an increase in task difficulty had no effect on distractor processing. This was also observed when the presentation time of the target was decreased, when the target was followed by a mask, or when the eccentricity of the target was increased to reduce retinal acuity. These results therefore indicate that increasing task difficulty (via stimulus degradation) without increasing the perceptual load of the task is not sufficient to reduce distractor interference. Instead, it was shown that the extent to which distractors are processed critically depends on the level of perceptual load in the relevant task and available attentional resources.

A recent study by Benoni and Tsal (2012) however challenged these conclusions, proposing instead that dilution theory can account for the observed findings. According to dilution theory (Benoni & Tsal, 2012; Tsal & Benoni, 2010a, 2010b; Wilson et al., 2011), the reduction in distractor interference observed under high perceptual load (in tasks manipulating search set size) occurs as a result of the diluting effect of the distractor by neutral items, rather than exhaustion of attentional capacity. To demonstrate this, Tsal and Benoni (2010a) presented participants with a low perceptual load/high dilution search task, where the number of non-target items matched a typical high perceptual load display, but with these non-target items being clearly distinguishable from the target item (i.e. red target among white non-targets). In this condition, ostensibly a low load condition as the target “pops-out”, the mere presence of non-target items (neutral letters) was sufficient to eliminate distractor processing. According to Tsal and Benoni (2010a, 2010b), the features of the non-target search items (e.g. neutral letters) competed with those of the distractor, thus degrading the quality of its visual representation and leading to reduced distractor processing.

Benoni and Tsal (2012) investigated the predictions of dilution theory for manipulations of perceptual load and sensory degradation. They proposed that the differential effect of perceptual load compared to sensory degradation on distractor processing reported by Lavie and de Fockert (2003) could in fact be accounted for by dilution theory. That is, distractor interference is reduced in conditions of high task difficulty because neutral letters are added to the display that can dilute distractor processing (perceptual load), and not when task difficulty is increased but the target is presented alone without any other potentially diluting items (sensory degradation). Benoni and Tsal (2012) reasoned that if potentially diluting items are presented together with the degraded target, distractor processing should again be reduced. To measure this effect experimentally, Benoni and Tsal (2012) presented participants with a degraded low perceptual load/high display set size condition. This condition featured a degraded target stimulus that was surrounded by five non-target items (as in the high perceptual load condition). In line with their predictions, distractor interference effects were substantially reduced in this condition, and indeed identical to interence effects obsered at high perceptual load. This observation suggested to the authors that if dilution is controlled for, the effects of perceptual load and sensory degradation are identical on distractor processing.

Lavie and Torralbo (2010), in an earlier response to Tsal and Benoni (2010a), however have provided evidence against the dilution account, which in extension, also applies to the findings of Benoni and Tsal (2012). Crucial to this proposal is the idea that the processing of flanker items is related to a ‘spill-over’ of untapped attentional resources into the processing of distracting information (Lavie, 2005, 2010). In high set size conditions however, there are also other items in the display that can receive involuntary capacity spill-over of attention. For example, apart from the response competing distractor in the periphery, this could be the non-target letters in the search array. In cases where distractor interference is reduced or even eliminated, perceptual load theory would predict that non-target search items received the capacity spill-over rather than the peripheral distractor. This led Lavie and Torralbo (2010) to suggest that if the non-target letters received the spillover of attention in low perceptual load but high set size displays (as used in Benoni & Tsal, 2012), then replacing these non-target letters with distractors should reestablish the distractor interference effect.

In their study, a typical flanker task display was adapted such that two non-target letters in the search array were replaced by response competing letters. Each display consisted of six letters of which one was the target letter (X or N) presented in green. The other letters were either distractors or neutral letters presented in black. The results demonstrated that in this low perceptual load/high set size display, distractor interference effects are restored if the search array features response competing letters. This suggested to the authors that capacity in fact spilled over into processing of the non-target items in the search array, therefore ruling out an alternative explanation in terms of dilution (Lavie & Torralbo, 2010).

Lavie and Torralbo (2010) also point out that Tsal and Benoni’s (2010a) interpretation of perceptual load effects in terms of dilution only pertain to one specific measure of selective attention, that is, distractor response competition effects at different search set sizes. Dilution theory clearly cannot account for perceptual load effects observed in studies manipulating the processing requirements of the task (e.g. by presenting a more subtle line discrimination task), or when the irrelevant stimulus does not share any visual features that could be ‘diluted’ by adding neutral items to the search array (e.g. in the cross-modal auditory detectiont task employed here). The findings in this thesis can therefore be seen as providing ‘dilution-proof’ evidence for the effects of perceptual load on attention.

Experiment 6

Based on these considerations, it is now important to further investigate the effects of perceptual load and stimulus degradation within a cross-modal dual-task paradigm in individuals with ASD and a typically developing control group. Participants were required to perform the same dual-task as in the previous experiment, consisting of a central letter search task and an auditory detection task. Perceptual load was manipulated by adding neutral letters to the visual search array. That is, the target was either presented alone (low perceptual load condition), or together with five additional neutral letters (high perceptual load). The new condition of interest was that of low perceptual load with a degraded target letter. In this condition, the target was presented alone (as in the low perceptual load condition), yet the size and contrast were reduced relative to the ones used in the other conditions.

It was hypothesised that increasing both perceptual load and sensory degradation would result in increased RTs and error rates. However, only an increase in perceptual load would reduce detection sensitivity, whereas manipulating sensory degradation would have no effect on detection sensitivity. It was hypothesised that these effects are similar for both groups, based on the findings in the previous experiment that indicated equivalent detection sensitivity across groups at the highest level of perceptual load (set size 6).

Method

Participants

19 typically developing (TD) adolescents and 18 adolescents with ASD were recruited for this study. The majority of TD participants (14 out of 19) were newly recruited for this experiment, while most ASD participants (16 out of 18) were recruited from the previous study (please refer to the Appendix on page 189 for a summary of how participants were distributed across experiments).

The participants were diagnosed and recruited in the same manner as in the previous experiments. Parent report of ASD symptoms using the Lifetime version of the SCQ (Social Communication Questionnaire, Rutter et al. 2003) was obtained for all participants with ASD and all participants met the recommended cut-off score of 15. Participants were excluded if their accuracy on the letter search task was lower than 50% or if their detection accuracy of the auditory stimulus was lower than 30% in either or both perceptual load conditions. On the basis of these exclusion criteria, four participants with ASD and three TD participants were removed prior to the analysis. The remaining 16 TD and 14 ASD participants were matched for non-verbal ability (using the Raven's Standard Progressive Matrices, Raven et al., 1998) and chronological age (see Table 4.1 for descriptive statistics). Independent samples t-tests indicated that there were no significant differences between groups on any of these measures (maximum t-value = 1.534, minimum p-value = .136).

Table 7.1 Descriptive statistics for each group

Group	**Statistic**	**CA range** (years : months)	**Raven's Score**	**SCQ score**
ASD (n= 14)	M	14:8	45.4	25.3
	SD	1:7	6.1	5.4
	Range	12:6 – 17:5	37 – 56	18 - 35
TD (n= 16)	M	14:8	48.6	
	SD	0:6	5.6	
	Range	13:8 – 15:4	33 – 56	

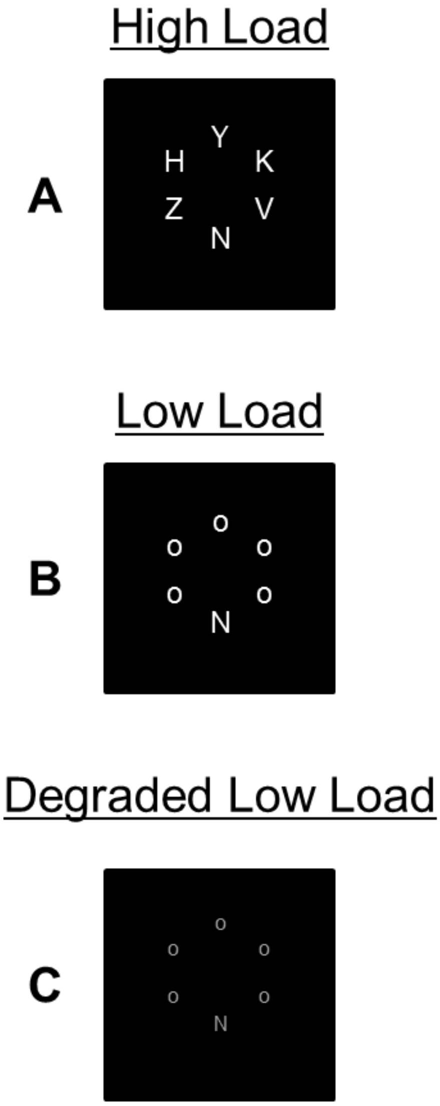
Note:
CA = Chronological Age
SCQ = Social Communication Questionnaire

Stimuli and Procedure

Microsoft Visual Basic (version 6) was used to create computer-based stimuli that were presented on an IBM Lenovo Thinkpad 14.1” personal laptop. Viewing distance was 60cm. Participants were presented with the same dual-task paradigm as in the previous experiment. The stimuli for set size 1 and set size 6 remained the same, with the target letter measuring 0.6° x 0.6° visual angles. Depending on the set size, the other ring positions were occupied by perceptually similar non-target letters (set size 6: H, K, V, Y or Z; 0.6° x 0.6° visual angles) or a small letter *O* (set size 1: 0.2° x 0.2° visual angles). As in the previous experiment, participants had to identify a visual target letter (‘X’ or ‘N’) presented in the central search array and then indicate the presence or absence of an auditory tone embedded in noise. The same target sound and speech-shaped noise stimuli were used.

However, new stimuli were created for the degraded low perceptual load condition. First, the size of the target letter was decreased to 0.2° x 0.2° visual angles and the lightness was reduced by 75% to make visual discrimination more difficult (see Figure 7.1 for an illustration). This manipulation has previously been shown to induce ‘data limits’, without inducing ‘resource limits’ (Lavie and de Fockert, 2003).

Figure 7.1 Example of a (A) high perceptual load, (B) low perceptual load, and (C) degraded low perceptual load trial



Participants performed a total of 145 trials, which were administered in three blocks according to each condition (low perceptual load, high perceptual load, degraded low load). Presentation of blocks was randomised and counterbalanced across participants and participants were able to take breaks after each block. For each set size, a total of 48 trials were presented and presentation of both the visual target letter (‘X’ or ‘N’) and auditory stimulus (auditory tone + noise or noise-only) was randomised. Participants always completed one condition first, before moving on to the next condition. The same procedure as in the previous experiment was used.

Prior to performing the dual-task paradigm, the perceptual threshold for the auditory stimulus in noise was also established for each participant using a two alternative forced-choice (2AFC) adaptive threshold procedure. The threshold level for each participant subsequently informed the choice of the SNR mix used in the letter search task. This was achieved by increasing the SNR by 5 units (i.e. +2.5db) such that the individual SNR mix used in the main experiment was well above each individual's threshold. So for example, someone who recorded a SNR threshold of -9.5db, this person would be presented with a SNR mix of -7.0db in the main experiment. Each participant was therefore presented with an auditory tone embedded in noise adjusted to their individual threshold, yet across participants, the absolute difference between signal (target sound) and noise was always the same.

Results

Effect of perceptual load and letter degradation on task difficulty

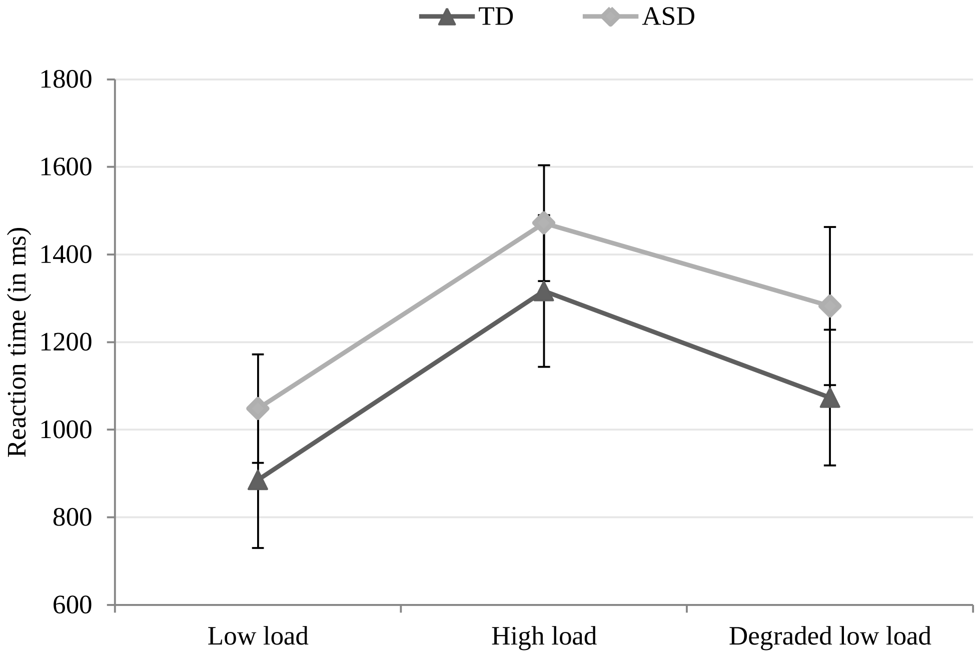
All incorrect trials (i.e. wrong target letter response) and trials with reaction times (RT) on the ring of letter task above 2500ms were discarded prior to analysis and average correct RTs were calculated (see Table 7.2 for a descriptive summary of task performance).

Table 7.2 Means and standard deviations for reaction time (RT) and error rate according to diagnostic group and condition

		Reaction Time (in ms)			**Error Rate** (in %)		
Condition	**Statistic**	**ASD**	**TD**	**Total** (overall)	**ASD**	**TD**	**Total** (overall)
Low Load	M	1048.1	885.3	961.3	5	9	7
	SD	(240.9)	(302.1)	(282.9)	(6)	(9)	(8)
High Load	M	1471.6	1316.6	1388.9	28	29	28
	SD	(256.7)	(336.5)	(307.1)	(10)	(17)	(14)
Degraded Low Load	M	1282.2	1073	1170.6	14	15	14
	SD	(351.5)	(301.3)	(337.1)	(15)	(11)	(13)

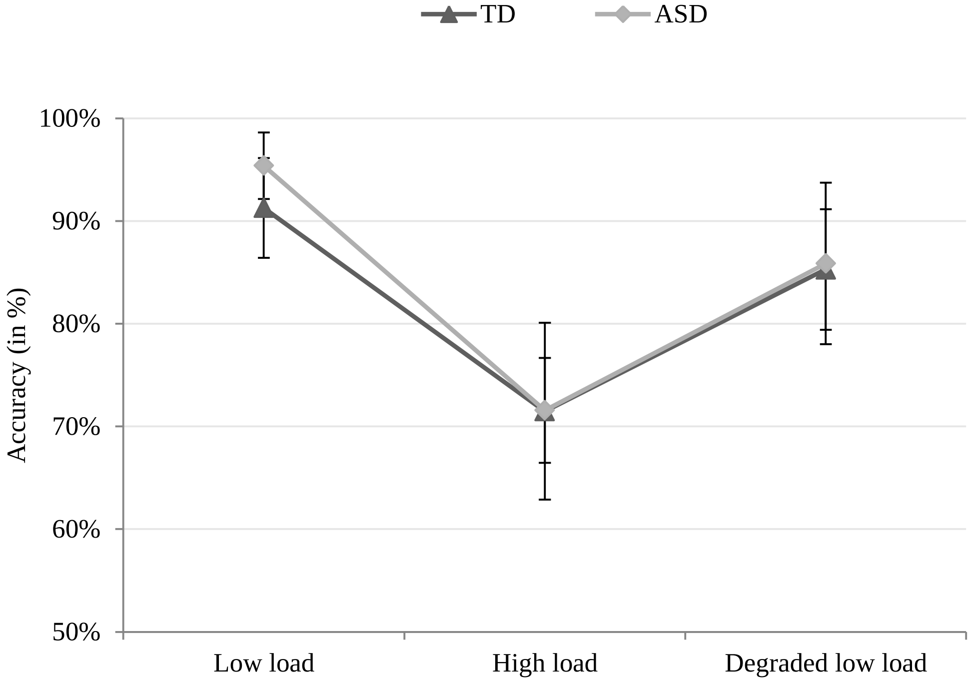
A mixed Analysis of Variance (ANOVA) with group (ASD vs. TD) as a between-subjects factor and condition (Low perceptual load, high perceptual load, and degraded low perceptual load) as a within-subjects factor was subsequently performed on RT data and error rates. These analyses revealed a significant main effect of condition on RTs, $F(2, 56) = 48.794$, $p < .001$, $\eta_p^2 = .635$, indicating that participants performed differently across conditions. Planned contrasts showed that RTs were significantly longer for high perceptual load displays ($M = 1388$, $SD = 307.1$) than for degraded low load displays ($M = 1170.6$, $SD = 337.1$), $t(29) = 4.614$, $p < .001$, which in turn produced longer RTs than low perceptual load displays ($M = 961.3$, $SD = 282.9$), $t(29) = 4.931$, $p < .001$. Significantly longer RTs were also observed in the high perceptual load condition compared to the low perceptual load condition, $t(29) = 11.423$, $p < .001$.There was no significant effect of group on RTs ($F(1, 28) = 3.182$, $p = .085$, $\eta_p^2 = .102$) and no significant interaction between group and condition ($F(2, 56) = .229$, $p = .796$, $\eta_p^2 = .008$).

Figure 7.2 Mean Reaction Time (RT) as a function of condition and group (error bars: 95% CI)



Similar effects were also observed for error rates. Participants differed significantly in error rates across conditions (*F*(2, 56) = 25.644, p < .001, η_p^2 = .478). Individual contrasts revealed that error rates were significantly higher in the high perceptual load condition (*M* = 28%, *SD* = 14%) than in the degraded low load condition (*M* = 14%, *SD* = 13%), *t*(29) = 3.952, p < .001, and low perceptual load condition (*M* = 7% , *SD* = 8%), *t*(29) = 7.148, p < .001. Error rates in the low perceptual load condition were also significantly lower than in the degraded low load condition, *t*(29) = 3.138, p = .004. There was no main effect of group on error rates (*F*(1, 28) = .362, p = .552, η_p^2 = .013) or interaction effect (*F*(2, 56) = .240, p = .788, η_p^2 = .008).

Figure 7.3 Mean accuracy rate (in %) according to condition and group (error bars: 95% CI)



The findings therefore suggest that both the manipulation of the perceptual load of the task and target letter degradation resulted in an increase in general task difficulty as indexed by longer RTs and reduced accuracy on the central letter task compared to a condition of low perceptual load with intact letter targets.

Detection of the critical auditory stimulus

As before, all incorrect trials on the letter search task, as well as those trials with longer RTs than 2500ms were excluded prior to analysis. The percentage detection rate of the auditory stimulus (Figure 7.4), false alarm rate (Figure 7.5) and sensitivity (*d'*) (Figure 7.6) for each group at each set size was calculated (for a descriptive summary of all measures see Table 7.3). The *d'* measure assesses detectability of a stimulus independent of a participant's response bias and is estimated using both the observed percentage detection rate and false alarm rate. It is calculated by taking into account the probability of a correct target response (a 'Hit') and the probability of incorrectly responding (i.e. respond present) when the target is absent (a ‘False alarm’):

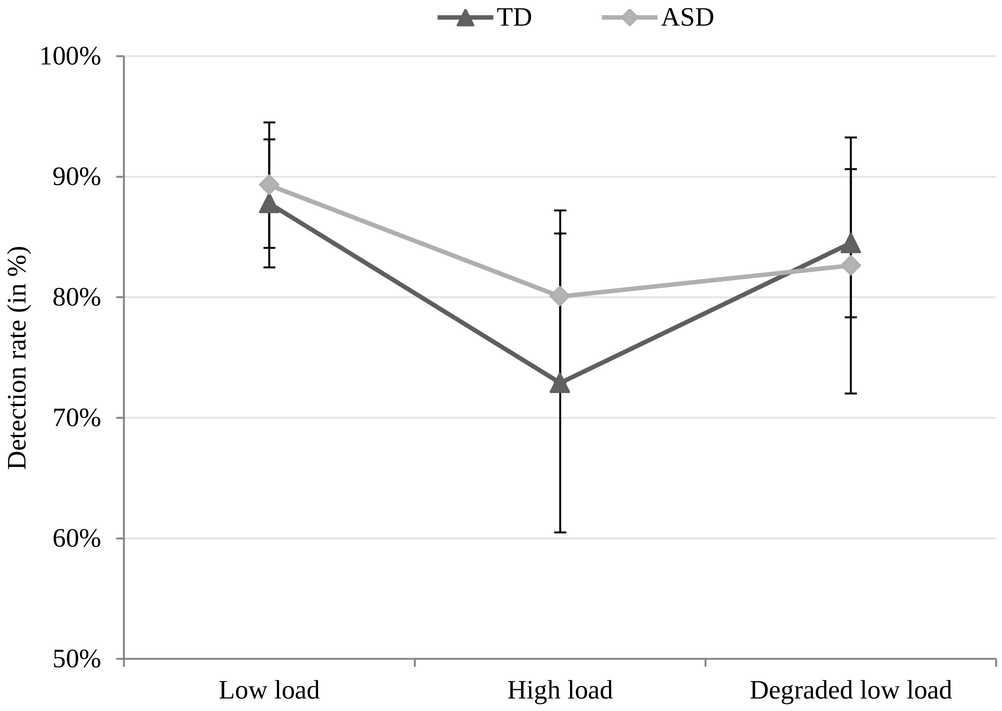
$d' = Z(Hit) - Z(FalseAlarm)$ where function $Z(p), p \in [0,1$

Table 7.3 Detection rate, false alarm rate, detection sensitivity (*d'*) and response criterion (c) according to condition and diagnostic group

		Detection rate (in %)			**False alarm rate** (in %)			**Detection sensitivity** (d')			**Criterion** (c)		
Condition	**Statistic**	**ASD**	**TD**	**Total**	**ASD**	**TD**	**Total**	**ASD**	**TD**	**Total**	**ASD**	**TD**	**Total**
Low Load	M	89.4	87.8	88.6	10.6	11.4	11.1	2.79	2.67	2.73	0.01	0.01	0.01
	SD	(10)	(10.3)	(10)	(11.3)	(10.5)	(10.7)	(0.68)	(0.85)	(.76)	(.39)	(.32)	(.34)
High Load	M	80.2	72.8	76.3	23.9	16.2	19.8	1.9	1.89	1.89	0.14	0.12	0.13
	SD	(13.7)	(24.1)	(20)	(18)	(14.4)	(16.3)	(1.24)	(1.1)	(1.14)	(.46)	(.43)	(.44)
Degraded Low Load	M	82.6	84.4	83.6	13.6	12.1	12.8	2.61	2.53	2.57	-.06	0.21	0.08
	SD	(20.7)	(11.9)	(16.3)	(18.4)	(12.3)	(15.2)	(1.31)	(0.79)	(1.05)	(.34)	(.44)	(.41)

A repeated measures ANOVA on the percentage detection rate with group (ASD vs. TD) and condition (low load, high load and degraded low load) indicated that there was a significant main effect of condition (*F*(2, 56) = 7.385, p = .001, η_p^2 = .209). Planned contrasts showed that detection rates were significantly reduced in the high perceptual load condition (*M* = 76.3%, *SD* = 20%) relative to the degraded low load condition (*M* = 83.6%, *SD* = 16.3%), *t*(29) = 2.258, p = .032, and low perceptual load condition (*M* = 88.6%, *SD* = 10%), *t*(29) = 3.353, p = .002. The difference in detection rates between the degraded low load and low perceptual load condition was close to significance, *t*(29) = 2.032, p = .051, with a trend towards lower detection rates in the degraded low load condition (difference of approximately 5% in detection rates). Neither the main effect of group (*F*(1, 28) = .272, p = .606, η_p^2 = .01), nor the interaction between group and condition was significant (*F*(2, 56) = 1.080, p = .347, η_p^2 = .037).

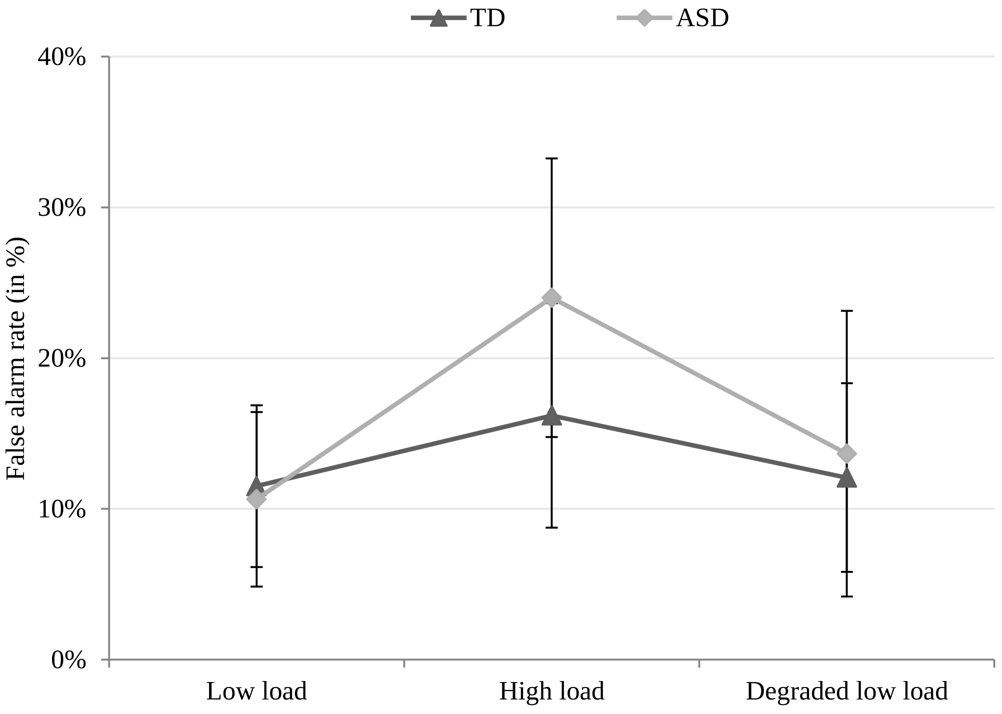
Figure 7.4 Detection rate of the auditory stimulus (in %) according to condition and group (error bars: 95% CI)



False alarm rate

A repeated measures ANOVA revealed a significant main effect of condition, *F*(2, 56) = 4.027, p = .023, η_p^2 = .126, with individual contrasts showing that this was due to a significantly larger false alarm rates in the high load (*M* = 19.8%, *SD*= 16.3%) compared to the low load condition (*M* = 11.1%, *SD* =10.7%), *t*(29) = 2.776, p = .01. There were no significant differences between low load and degraded low load displays (*M* = 12.8%, *SD = 15.2%), t*(29) = .567, p = .575. The difference in false alarm rates between high load and degraded low load was close to significance, *t*(29) = 1.867, p = .072. There was no main effect of group or interaction effect (maximum F-value = .864, minimum p-value = .427).

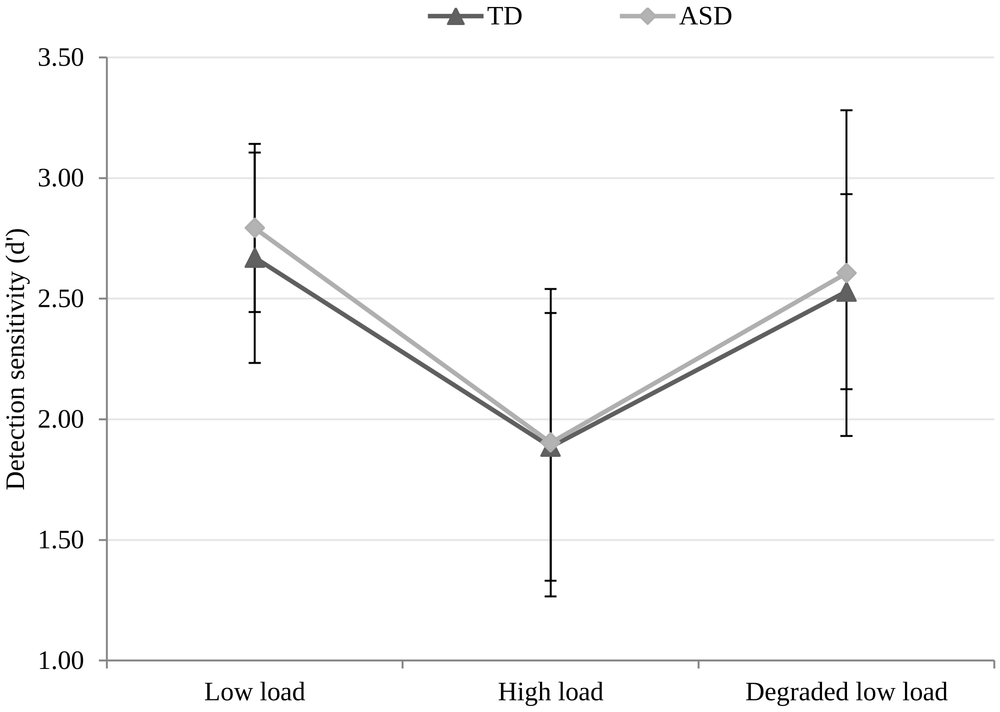
Figure 7.5 False alarm rate (in %) as a function of condition and group (error bars: 95% CI)



Detection sensitivity

A repeated measures ANOVA on the d' values for each participant in each condition was carried out. There was a significant main effect of condition (*F*(2, 56) = 10.554, p < .001, η_p^2 = .274), but no significant effect of group (*F*(1, 28) = .061, p = .807, η_p^2 = .002) or interaction between group and condition (*F*(2, 56) = .037, p = .964, η_p^2 = .001). In order to follow-up on the main effect of condition, planned contrasts showed that detection sensitivity was significantly reduced in the high perceptual load condition (*d'*: *M* = 1.89, *SD* = 1.14) relative to the degraded low load condition (*d'*: *M* = 2.57, *SD* = 1.05), *t*(29) = 3.677, p = .001, and low perceptual load condition (*d'*: *M* = 2.73, *SD* = .76), *t*(29) = 3.923, p < .001. Importantly, there was no significant difference in detection sensitivity between low perceptual load and degraded low load conditions, *t*(29) = .949, p = .350. This suggests that while an increase in perceptual load reduced perceptual sensitivity of an additional stimulus, increasing sensory degradation (i.e. increasing general task difficulty) had no effect on detection sensitivity.

Figure 7.6 Detection sensitivity (d') as a function of condition and group (error bars: 95% CI)

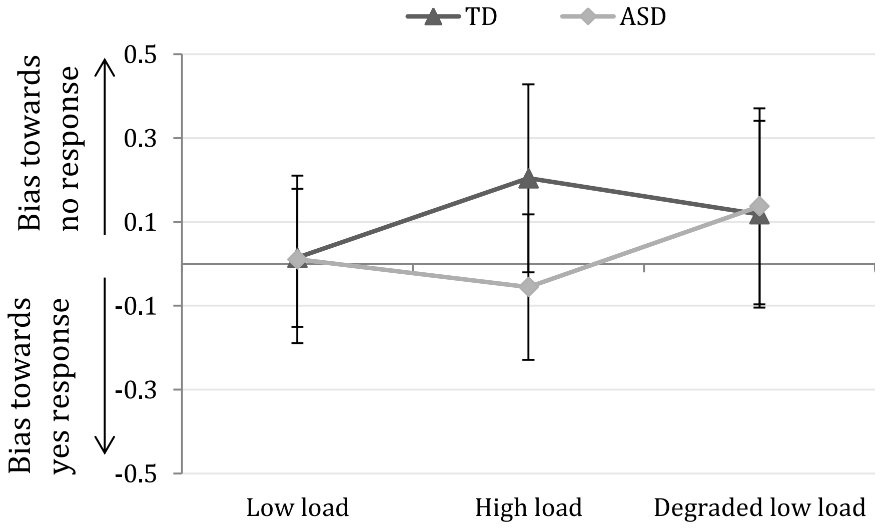


Response criterion

As for detection sensitivity, the response criterion (c) was calculated for each participant (see

Figure 7.7). Using ANOVA, the results showed that the response criterion did not differ significantly between conditions ($F(2, 56) = .834$, p = .440, $\eta_p^2 = .029$), or between groups ($F(1, 28) = .626$, p = .435, $\eta_p^2 = .022$). There was also no significant interaction effect ($F(2, 56) = 1.508$, p = .230, $\eta_p^2 = .051$).

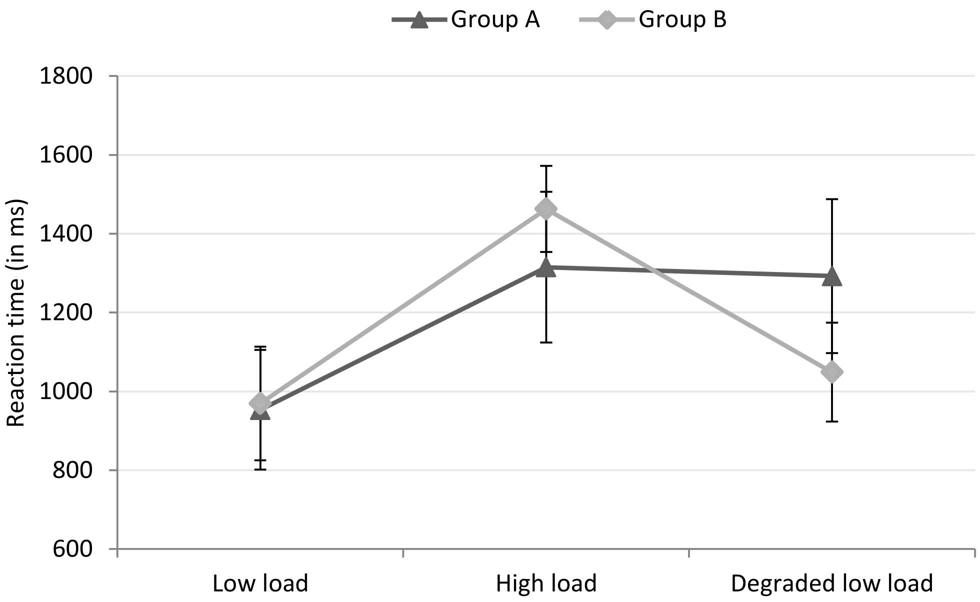
Figure 7.7 Response criterion (c) according to condition and group (error bars: 95% CI)



Analysis of relative speed between conditions

It is important to acknowledge that the high perceptual load condition showed a greater task difficulty effect compared to the degraded low load condition as reflected by significantly longer RTs and higher error rates. This might suggest that it is still higher task difficulty (as indexed by slower processing speed) that is driving the difference in detection sensitivity between these conditions. In order to further examine whether the relative speed difference between these conditions can account for the results on detection sensitivity, I re-analysed the results for detection sensitivity by factoring in the relative overall speed in these conditions.

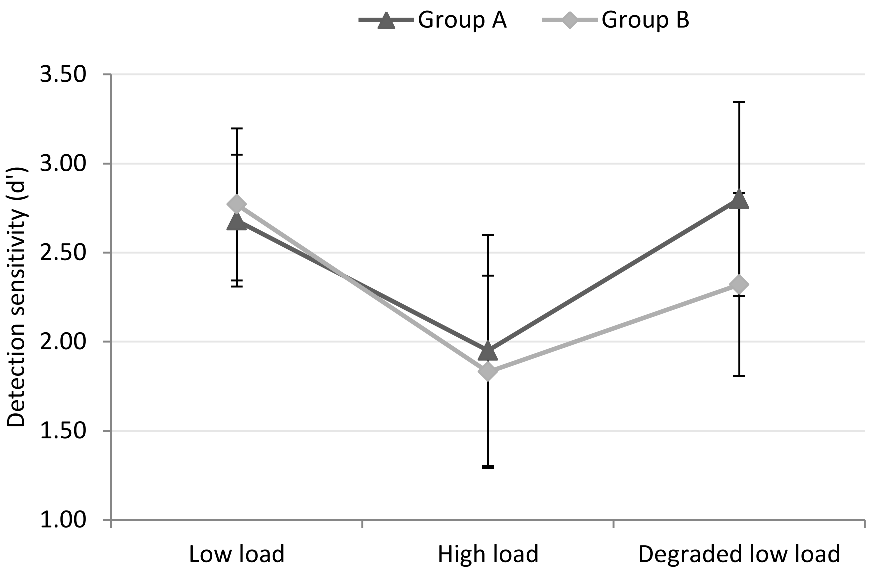
Figure 7.8 Mean RTs as a function of condition and relative speed in the high load compared to the degraded low load condition



All participants were divided into two groups using a median split procedure (high speed difference group, low speed difference group) of the RT difference score between the high perceptual load and degraded low load condition. Group A was characterised by slower RTs in the degraded low load compared to the high load condition (23ms difference), whereas group B was composed of individuals who were slower in the high load relative to the degraded low load condition (414ms difference) (see Figure 7.8). If the difference in processing speed (i.e. effect of task difficulty) between the high perceptual load and degraded low load condition can account for the results on detection sensitivity, then we would expect a significant interaction between group (Group A, Group B) and condition (low load, high load, degraded low load). In other words, Group B (high speed difference) should show a difference in detection sensitivity between the degraded low load and high perceptual load condition, whereas Group A (no speed difference) should demonstrate no difference in detection sensitivity between these conditions.

Inspection of *d'* values however suggest the opposite (see Figure 7.9). Group A (no difference in speed between conditions) actually demonstrated a stronger effect on detection sensitivity than Group B (high speed difference). An ANOVA confirmed this by showing no significant interaction effect of condition (low load, high load, degraded low load) and group (group A vs. group B) on detection sensitivity, *F*(2, 56) = 1.219, p = .303, η_p^2 = .042. Recall that the above analysis showed that while detection sensitivity was significantly reduced in the high perceptual load condition compared to low perceptual load and degraded low load condition, degraded low load did not result in a significant reduction in detection sensitivity compared to the low perceptual load condition. This analysis therefore rules out an alternative explanation of the differential effect of perceptual load compared to sensory degradation on detection sensitivity in terms of relative processing speed between these conditions.

Figure 7.9 Mean detection sensitivity as a function of condition and relative speed in the high load compared to the degraded low load condition



Discussion

The findings demonstrated that detection sensitivity for an additional auditory stimulus depended upon the type of processing demand imposed on participants in a visual task. Increasing the visual perceptual load by varying the relevant search set size resulted in a reduction in detection sensitivity. In contrast, increasing general task difficulty by altering the sensory quality of the target stimulus (by reducing its size and contrast) did not reduce sensitivity. Although both manipulations resulted in longer RTs and higher error rates compared to a low perceptual load condition with an intact target stimulus, only an increase in perceptual load significantly reduced detection sensitivity. Support for this conclusion was also derived from an additional analysis that split the sample according to relative processing speed. One group (group A) was characterised by longer RTs in the degraded low load compared to the high load condition, whereas group B was composed of individuals who had longer RTs in the high load relative to the degraded low load condition. An additional analysis showed that these groups produced similar effects of condition on detection sensitivity, suggesting that relative difference in processing speed between these conditions cannot account for the findings. In summary, these findings therefore indicate that the reduction in sensitivity at high levels of perceptual load cannot simply be attributed to a general increase in task difficulty.

The differential effects of perceptual load and sensory degradation on attention were also shown to be equivalent across groups. This clearly suggests that the ability of both groups to also attend to an additional stimulus critically depended upon the level of perceptual load in the relevant task and available attentional resources rather than being influenced by general task difficulty. By extension, the current results indicate that the finding of increased awareness at high levels of perceptual load in individuals with ASD reported in this thesis is unlikely to be the result of any effect of task difficulty on attention. This therefore provides further support for the hypothesis that individuals with ASD are characterised by an increased perceptual capacity. The implications of this finding in ASD will be discussed in full in the following chapter. Note that in the high perceptual load condition, groups did not differ on detection measures (i.e. detection rate and detection sensitivity). This was to be expected given the findings in the previous experiment that demonstrated that detection was similar across groups at the highest level of perceptual load (also set size 6). In fact, sensitivity at a group level was very similar across experiments at the hightest set size (ASD: *d'* = 1.9 vs. *d'*= 1.8; TD: *d'* = 1.9 vs. *d'* = 1.8). This observation therefore further adds to the robustness of the conclusions presented here.

In accordance with Lavie and de Fockert (2003), the current results have shown that the effects of perceptual load can be distinguished from more general effects of task difficulty on attention. This was demonstrated using a dual-task paradigm requiring participants to perform a visual search task whilst also detecting an additional auditory stimulus. Importantly however, the current experimental set-up provided a ‘dilution-free’ test of the predictions of perceptual load theory. According to Dilution theory, the reduction in distractor processing observed in high perceptual load conditions is the result of the diluting effect of non-target items on processing the distractor (e.g. Tsal & Benoni, 2010a). However in this study, the additional stimulus was neither a distractor, nor was it presented in the visual modality and hence did not share any visual features with the neutral letter items that could have diluted its processing. Given that the auditory stimulus (beep sound) also did not share any semantic information with the neutral letters (e.g. K, V, H, Y or Z) further supports the conclusions drawn here. Taken together, the current findings confirmed the load-specific effects on perceptual resources within a cross-modal context of selective attention in both typically developing adolescents and adolescents with ASD. Perceptual load theory therefore remains the most parsimoneous theory to account for the results obtained in this thesis.

Chapter 8 General discussion

As outlined in chapter two, altered patterns of perception and attention are often associated with the phenotype of autism. Many of these findings are based on research in the visual domain, and illustrate the various changes underlying these cognitive processes. A review of the relevant literature revealed that atypicalities are observed across a range of different attentional components. This includes for example arousal (Rogers & Ozonoff, 2005), orienting (Bowler, 2007; Townsend, Courchesne, et al., 1996), disengaging and shifting attention (Courchesne, Townsend, Akshoomoff, et al., 1994; Reed & McCarthy, 2012), and deficits in selectivity and filtering (Adams & Jarrold, 2012; Burack, 1994; Lovaas & Schreibman, 1971; Mann & Walker, 2003). The expression of these attentional abnormalities in ASD is, however, often diverse and contradictory. In addition, relatively little work has focused on whether these atypical patterns of attention also translate to cross-modal contexts of selective attention.

Based on recent advances in research on visual selective attention in ASD that proposed that individuals with ASD are characterised by an increased perceptual capacity, this thesis investigated patterns of cross-modal selective attention in children and adolescents with ASD. The increased perceptual capacity account (Remington, Swettenham, et al., 2012; Remington et al., 2009; Swettenham et al., 2014) posits that while people have a finite capacity for processing perceptual information, this capacity seems to be enhanced in individuals with ASD. Preliminary support for this account suggested that an increased perceptual capacity in ASD can lead to enhanced awareness of additional information presented simultaneously during performance of a visual search task (Remington, Swettenham, et al., 2012) or perceptual judgment task (Swettenham et al., 2014), but can also lead to increased distractor processing (Remington et al., 2009). By applying Lavie’s perceptual load theory of attention (Lavie, 1995), I reasoned that children and adolescents with ASD would also show enhanced auditory awareness across a range of cross-modal experiments that manipulated the level of visual perceptual load.

Prior to these experiments on individuals with ASD, it was important to address the developmental effects of visual perceptual load on auditory awareness in a sample of neurotypical children, adolescents and adults. An inattentional deafness task similar to that used by Macdonald and Lavie (2011), but adapted to suit younger participants, was used. Participants from different age groups (5-6 years, 9-10 years, 14-15 years and adults) performed either a low perceptual load (more gross) or high perceptual load (more subtle) line-length discrimination task. On a critical trial, an unexpected auditory stimulus was played concurrently with the visual stimulus and participants were asked whether they had noticed anything else. On a subsequent control trial, participants were told to ignore the cross stimulus. Only those participants who successfully identified the auditory stimulus on the control trial were included in further analyses.

In line with the initial predictions, the results indicated that with increasing age, participants reported more often the presence of an additional, but unexpected auditory stimulus whilst being engaged in a visual discrimination task. It was also found that increasing the perceptual load of the task reduced awareness for children, but not adolescents and adults. Together, these findings suggested that awareness for stimuli outside the focus of attention increased with age, and older children have an increased perceptual capacity compared to younger children. The differential effect of visual perceptual load on awareness in younger children therefore reflected the smaller capacity in children compared to adolescents and adults being disproportionately taxed by an increase in perceptual load. An alternative explanation of these results in terms of a trade-off in line discrimination accuracy could also be ruled out. There were no differences in task performance between perceptual load conditions for all age groups, including the youngest age groups. The results from the first experiment therefore demonstrated how typical development involves the maturation of perceptual capacity and its relevance for inattentional deafness rates at different levels of visual perceptual load.

The next chapter investigated the effect of visual perceptual load on auditory awareness (i.e. inattentional deafness rates) in children with ASD and a neurotypical comparison group matched on chronological age and non-verbal ability scores. Based on the findings in the previous chapter that visual perceptual load modulated the incidence of inattentional deafness in typically developing children and the recent findings suggesting that perceptual capacity is increased in ASD (Remington, Swettenham, et al., 2012; Remington et al., 2009; Swettenham et al., 2014), it was hypothesised that children with ASD would also show a differential effect of visual perceptual load on auditory awareness. If autism is characterised by an increased perceptual capacity that allocates resources across sensory modalities, then performing a high visual perceptual load task should leave processing capacities available to also attend to and detect an additional auditory stimulus. In typically developing individuals however, this capacity should be exhausted at high perceptual load resulting in reduced awareness for an unexpected auditory stimulus (critical stimulus: CS) presented on a critical trial.

Participants were presented with the same inattentional deafness paradigm as in the previous experiment. As predicted, children with ASD demonstrated greater awareness overall and a reduced effect of visual perceptual load on CS awareness compared to typically developing children. Whereas awareness for the CS continued to be high in children with ASD even at high levels of perceptual load, TD children experienced a significant drop in awareness rates as a function of perceptual load. This suggested that children with ASD had processing resources left-over to attend to the auditory stimulus. The findings from this experiment therefore extended existing work on the effect of perceptual load on visual selective attention in ASD to show that also in cross-modal contexts of attention, individuals with ASD have an increased perceptual capacity.

A number of observations provided further support for this conclusion. For example, despite equally high task performance as controls, children with ASD demonstrated increased CS awareness when the level of visual perceptual load was high. This indicated that increased CS awareness could not be explained by a deterioration in task performance on the line discrimination task. Still, it has to be noted that task performance was only indexed by participant’s accuracy and not reaction time. The small number of trials and therefore larger variability in reaction times across trials makes it unlikely that with this task design, reaction time would have been a reliable measure of task performance. While it was important for this study to keep trials to a minimum in order to ensure that as many children as possible continued to engage with the task, it limits the conclusions drawn from the data on task performance. Overall cognitive abilities (non-verbal ability scores) and ASD symptomatology (SCQ scores) were also not able to account for the increased awareness rates of the CS in the ASD group, suggesting that the results were not simply driven by a subgroup of more able children with ASD (i.e. those with higher non-verbal ability scores and lower SCQ scores).

Having examined the cross-modal effects of attention on awareness of a neutral, socially-meaningless auditory stimulus, the purpose of the following chapter was to examine these cross-modal effects for social attention, and in particular, the effects of visual perceptual load on awareness of a speech sound. There is some evidence that in the visual domain, adults with ASD do not seem to prioritise processing of social information over processing of other information. Whereas in typically developing individuals, processing of distracting visual social stimuli (i.e. faces) has been shown to be unaffected by the perceptual load of the relevant task (Lavie et al., 2003), in individuals with ASD, processing of distractor faces was only evident at low-, but not at high levels of perceptual load (Remington, Campbell, et al., 2012). This may suggest that typically developing individuals possess a dedicated capacity for social stimuli, which however is absent in individuals with ASD. In other words, in TD individuals, there are extra processing resources for social stimuli regardless of the level of perceptual load, which may not be the case however in individuals with ASD.

In light of such evidence, it was hypothesised that increasing the perceptual load of the visual task would not affect awareness of an unexpected speech sound in TD individuals, i.e. awareness rates will remain high across perceptual load conditions, yet increasing perceptual load would reduce awareness rates of a speech sound in individuals with ASD. A new sample of participants performed a similar inattentional deafness task as in the previous experiments, which was however improved in a number of ways. First, to control for alternative accounts in terms of rapid forgetting or a weak memory trace of the auditory stimulus (Wolfe, 1999), the surprise question was presented after a short and fixed amount of time following the critical trial. Second, the number of trials was increased to allow measurement of participant’s reaction time to obtain a more nuanced measure of task performance. This also permitted us to evaluate whether increased awareness rates in the ASD group in the previous experiment might have been a consequence of them diverting attentional resources from the visual to the auditory modality. And lastly, participants were required to perform a perceptual threshold task following the main experiment that measured perceptual sensitivity of the auditory stimulus to ascertain whether any differences in awareness relate to higher sensitivity to the auditory stimulus. The results demonstrated that for both groups, awareness of a speech sound was not affected by the level of perceptual load in the visual task, i.e. both the ASD and TD group continued to report the presence of an unexpected speech sound despite an increase in the level of perceptual load. For the TD group, this pattern of awareness at high perceptual load was considerably different to the previous experiment, where a reduction in awareness of a neutral stimulus was seen at high perceptual load. This provided preliminary support for the notion that in typically developing individuals, speech stimuli capture attention regardless of the level of perceptual load.

While these results were expected for TD individuals, they were somewhat unexpected for individuals with ASD, who showed high awareness rates for the speech sound across perceptual load conditions. However, based on these findings, it is difficult to say whether individuals with ASD also processed the social CS differently than the neutral CS presented in the previous experiment. An additional experiment was required to further investigate this issue. To more confidently determine whether speech sounds indeed capture attention differently than neutral sounds, these results were compared to data from an identical task that used a carefully matched neutral sound instead (matched on a number of acoustic properties including pitch, frequency range and intensity). On this task, the pattern of awareness in experiment 2 was replicated: increasing the perceptual load of the task resulted in significantly reduced awareness rates in TD adolescents, but not in adolescents with ASD who continued to report awareness of the CS. Comparing these two experiments suggested that in the TD group, an unexpected yet ecologically salient speech sound captured attention regardless of the level of visual perceptual load, whereas a neutral sound did not. This disparity was shown to be statistically significant. For the first time, these findings provided evidence that in TD individuals, processing of unexpected auditory social stimuli in a cross-modal context of attention may also be automatic and mandatory, whereas processing of neutral auditory information relies on general capacity limits. A possible explanation for this finding could relate to the special biological and social significance of speech sounds. It may be crucial for adaptive behaviour that socially meaningful auditory information, unlike other neutral information, is processed regardless of the level of visual perceptual load. Even if unexpected auditory information is not relevant for current task behaviour, as was the case in the current experiment, it can potentially carry important information including social cues that could be disadvantageous not to attend to. The results for the ASD group however were less clear. In the absence of any differences in awareness under high perceptual load of the neutral CS compared to the social CS, it is difficult to tell whether individuals with ASD also processed the unexpected speech sound in any special way. It may be that social auditory information captures attention similarly as socially neutral information, i.e. individuals with ASD treat social and non-social information in a similar manner. To further explore these issues, it would be interesting to measure the effect of visual perceptual load on awareness of a social vs. socially neutral stimulus in ASD at very high levels of perceptual load to see if there is a point at which a socially neutral stimulus CS does not reach awareness while a social stimulus does, or whether both types of stimuli suffer the same fate of not being noticed at higher levels of perceptual load. Experiment four also replicated the previous finding of a differential effect of visual perceptual load on awareness of a neutral CS in individuals with ASD, providing further support for the hypothesis of an increased perceptual capacity in ASD that operates across sensory modalities. With the addition of more robust performance measures (i.e. reaction time), as well as sensitivity measures (i.e. perceptual load threshold task), the findings from this experiment further strengthened these conclusions. There were no group or interaction effects for these measures, suggesting that both groups performed similarly on the task and across perceptual load conditions. Both groups did also not differ in perceptual thresholds. Any differences in awareness between groups are therefore unlikely to be the result of differences in sensitivity to auditory signals.

The aim of Experiment 5 was to establish whether an increased perceptual capacity in ASD also has implications for auditory detection sensitivity. The increased perceptual capacity account would predict that increased awareness in conditions of high perceptual load in individuals with ASD reflects a perceptual detection advantage rather than a more lenient response criterion. However, given the single-trial nature of the inattentional deafness paradigm used in the previous experiments, measures of detection sensitivity (d’) and response criterion (c) could not be assessed. In addition, although the surprise question followed the critical trial immediately after recording the visual response, thereby minimising any confounding effects, alternative explanations in terms of rapid forgetting (Wolfe, 1999) or a weak memory trace (Barber & Folkard, 1972) cannot be completely ruled out. To further investigate the effects of visual perceptual load for cross-modal selective attention in ASD, a dual-task paradigm was adapted from Remington, Swettenham, et al. (2012) to examine how the perceptual load of a visual task can influence perceptual sensitivity of a critical auditory stimulus. Participants performed a visual search task (search a central array for a target letter X or N) while simultaneously attending to a target sound embedded in noise. Perceptual load in this task, in contrast to the previous experiments, was manipulated by increasing the number of similar non-target letter stimuli in the search display. Because the additional stimulus was presented multiple times, the design allowed for a signal detection analysis of the data so that the effects of perceptual load on perceptual sensitivity could be assessed independently from any effects of response bias. In order to account for any individual differences in perceptual sensitivity that could bias the results, the auditory target stimulus in noise was adjusted to participant’s individual perceptual threshold. By presenting participants with an auditory tone embedded in noise adjusted to their individual threshold, yet keeping the absolute difference between signal (target sound) and noise the same across all participants, the effect of perceptual load on auditory detection could be examined without any confounding effects of individual differences in perceptual sensitivity.

In line with predictions, the results indicated that at the lowest levels of perceptual load (1 or 2 items in the central search array), detection rates for the auditory stimulus did not differ between groups. At higher levels of perceptual load when 4 additional items were presented in the search array, auditory detection rates were significantly reduced in TD adolescents compared to adolescents with ASD, who maintained a high level of detection. At the highest level of perceptual load (6 search array items), the ASD group showed the same modulation of awareness as a function of perceptual load as the TD group. The fact that auditory detection rates in the ASD group were not affected by the perceptual load of the visual task until there were 6 items in the search array (compared to 4 items in the search array for the neurotypical group) suggests an increased perceptual capacity in ASD. Signal detection measures also confirmed that the observed advantage in detection in individuals with ASD reflects a superior perceptual sensitivity rather than a shift towards a more lenient response criterion. This was shown by a significant difference between groups in detection sensitivity at higher perceptual load levels (set size 4). An alternative account of increased detection in the ASD group as a result of a tendency to respond with ‘stimulus present’ was therefore ruled out. Although individuals with ASD demonstrated superior detection at higher levels of perceptual load, they showed equivalent performance as controls at the highest level of perceptual load. This indicated that if the level of perceptual load is high enough, the perceptual capacity of individuals with ASD was exhausted and resulted in early selection and therefore reduced detection of the auditory stimulus.

In all experiments presented so-far, an increase in error rates or reaction time was taken as evidence for a successful manipulation of perceptual load. While this is in line with previous manipulations of perceptual load (e.g. Lavie & Cox, 1997), it also reflects an increase in task difficulty. Thus, potentially, one could argue that the differential effect of higher perceptual load on awareness in individuals with ASD can be attributed to an increase in general task difficulty rather than reflecting load-specific effects on perceptual resources. In the final experiment, it was therefore important to separate the effects of perceptual load on attention from the more general effects of task difficulty on attention. In this study, participants were required to perform the same dual-task as in the previous experiment, consisting of a central letter search task and an auditory detection task. Three conditions of interest were created: a low perceptual load condition (target letter presented alone), a high perceptual load condition (target letter + five additional neutral letters), and a low perceptual load with a degraded target letter condition. This new condition featured a target letter presented alone (as in the low perceptual load condition), yet the size and contrast were reduced relative to the ones used in the other conditions. It was predicted that in line with previous findings on neurotypical adults (Lavie & de Fockert, 2003) that increasing both perceptual load and sensory degradation would result in increased RTs and error rates. However, only an increase in perceptual load would reduce detection sensitivity, whereas manipulating sensory degradation would have no effect on detection sensitivity. These effects were hypothesised to be similar for both groups.

The results indicated that the extent to which detection sensitivity was modulated depended upon the type of processing demand imposed on participants in the visual task. Increasing the visual perceptual load of the task by varying the relevant search set size resulted in a reduction in detection sensitivity (i.e. increasing data “resource limits” (Lavie, 2005, 2010). In contrast, increasing general task difficulty by altering the sensory quality of the target stimulus (i.e. altering sensory “data limits” by reducing its size and contrast) did not reduce sensitivity. Although both manipulations resulted in longer RTs and higher error rates compared to a low perceptual load condition with an intact target stimulus, only an increase in perceptual load modulated detection sensitivity. Task difficulty in turn disrupted task performance while having no effect on auditory processing. It was also shown that when controlling for relative speed difference between these conditions, the differential effect of perceptual load on detection sensitivity compared to sensory degradation still remained. These findings therefore indicated that the reduction in sensitivity at high levels of perceptual load cannot simply be attributed to a general increase in task difficulty. This effect was also shown to be equivalent across groups, meaning that the extent to which participants were able to attend to an additional stimulus critically depended upon the level of perceptual load in the relevant task and available attentional resources, rather than any differences in more general task difficulty. The finding of load-specific effects on attention also provided further support for the hypothesis that individuals with ASD are characterised by an increased perceptual capacity. That is, increased awareness at high levels of perceptual load in individuals with ASD reported in earlier experiments is not the result of a differential effect of task difficulty on attention.

It is also important to highlight that the experimental set-up of all experiments presented in this thesis provided a ‘dilution-free’ test of the predictions of perceptual load theory. According to Dilution theory, the reduction in distractor processing observed in high perceptual load conditions is the result of the diluting effect of non-target items on processing the distractor (e.g. Tsal & Benoni, 2010a). However, in all studies reported here, the additional stimulus was neither a distractor, nor was it presented in the visual modality and hence did not share any visual features with the neutral letter items that could have diluted its processing. Indeed, the auditory stimulus (either a non-social or social sound) also did not share any semantic information with the neutral letters (e.g. K, V, H, Y or Z) that could have influenced its processing (in experiment 5 & 6). This therefore further supports the conclusions drawn here.

Taken together, the current findings confirmed the load-specific effects on perceptual resources within a cross-modal context of selective attention in both typically developing adolescents and adolescents with ASD. Perceptual load theory therefore remains the most parsimoneous theory to account for the results obtained in this thesis.

Increased perceptual capacity in ASD - Implications

In everyday situations, attention is required to operate in a multisensory environment where incoming sensory information is rarely confined to a single modality. For example, in one instance we find ourselves concentrating on a visual task, e.g. reading a book, whilst simultaneously being exposed to other information from other modalities – such as people talking loudly nearby. Successful adaptive functioning in these situations requires effective attention to select the information that is relevant and ignore what is irrelevant. Clinicians and parents however often report that individuals with ASD are able to perform in a well-controlled environment, yet experience difficulties and even distress if the environment features too many sensory stimuli (Marco, Hinkley, Hill, & Nagarajan, 2011). How do the findings presented within this thesis fit with these behavioural observations?

Although the results from experiment 2, 4, and 5 suggest that an increased perceptual capacity can be conceived as a perceptual advantage rather than a deficit, being able to process more information can also have adverse effects. Perceptual load theory posits that while attention is a limited capacity system, all stimuli falling within this limit are processed regardless of whether they are irrelevant and potentially distracting. Being able to process more information at once, particularly if that information is distracting, would necessarily lead to over-arousal, anxiety and distress. An interesting case study in this context is Temple Grandin, an author with autism. She described how minor background noises distracted her: “I still have problems with losing my train of thought when distracting noises occur. If a pager goes off when I am giving a lecture, it fully captures my attention and I completely forget what I was talking about" (Grandin, 1995, p. 67-68). The evidence presented within this thesis would suggest that these behaviours might be related to an increased perceptual capacity that operates across sensory modalities.

The increased perceptual capacity account might also be able to provide some insight into why individuals with ASD have been found to demonstrate higher distractibility in situations of multiple auditory inputs. Teder-Sälejärvi, Pierce, Courchesne, and Hillyard (2005) for example found that individuals with ASD have more difficulty selectively attending to a target stimulus whilst ignoring distracting noise bursts relative to controls. When presented with eight sound sources and a continuous stream of sounds, individuals with ASD were slower and less accurate at identifying a target signal from a specific spatial location, but performed as accurate as controls on a less demanding task with only three sound sources. ERP results also confirmed this finding, with broader N1 and shallower P3 peaks in the autism compared to the control group, indicative of a diminished ability to attend to one sound source among many (Teder-Sälejärvi et al., 2005). The finding that individuals with ASD were slower and less accurate than typically developing subjects when presented with eight sound sources indicates that they were processing competing information, despite being told to ignore them. Interestingly, the more demanding condition with eight sound sources could potentially reflect a high perceptual load condition, whereas the less demanding condition with three sound sources might represent a low perceptual load task. The finding of equivalent performance between groups in the less demanding task, yet higher distractibility in individuals with ASD relative to controls on a more demanding task would fit with the increased perceptual capacity account. An increased perceptual capacity in ASD would allow enhanced processing of auditory information even if it interferes with the relevant task. It is however also important to stress that because participants were required to segregate sounds from multiple input streams, an underlying impairment in auditory streaming abilities might have also been responsible for these results.

In another study, Hismjatullina (2006) presented a set of experiments that measured selective attention in the auditory modality in children with ASD and various matched control groups. When presenting participants with a dichotic listening task, she observed no differences between groups in reaction times, yet significantly higher error rates in the ASD group. Although the authors mentioned that they are unsure as to how reaction times can be unaffected whilst error rates were increased, this pattern of results would in fact be predicted by an increased perceptual capacity account. The observation that reaction times were unaffected (i.e. subjects were still able to attend to the relevant stream), whilst error rates were increased (i.e. reflecting processing of information in the unattended channel), suggests that individuals with ASD had processing resources left-over to also attend to the unattended stream.

In the speech domain, individuals with ASD are also reported to have difficulty focussing on spoken target sentences embedded in background speech noise (Alcántara, Weisblatt, Moore, & Bolton, 2004). This was reflected in higher speech reception thresholds, particularly for background noises that contained temporal dips. Plaisted, Saksida, Alcántara, and Weisblatt (2003) suggested that this might be due to a wider than normal auditory filter in individuals with ASD, making them more susceptible to masking by interfering sounds. While it is difficult to ascertain whether higher distractibility by background noise could also relate to an increased perceptual capacity, it would be worthwhile to pursue this question in the future. Taken together, the conclusions presented in this thesis could potentially account for some of the findings on selective attention in ASD in the auditory modality. It would therefore be important for future studies to re-examine these findings in light of perceptual load theory. In both the auditory streaming task and dichotic listening task for example, different conditions of perceptual load could be created to examine processing of distracting information at different levels of perceptual load.

Opposing predictions for the effect of perceptual load in the auditory modality alone however comes from a recent study on typical adults that found that increasing auditory perceptual load had no effect on auditory distractor processing. Murphy, Fraenkel, and Dalton (2013) asked participants to respond to a target letter (P or T, spoken in a female voice) presented at random positions within a sequence of spoken letters at either high perceptual load (e.g. A, P, G, C, H, J) or low perceptual load (e.g. X, X, X, P, X, X). These letters were played one after the other through central speakers. A distractor letter (congruent or incongruent to the target letter, spoken in a male voice) was played on two thirds of the trials through either a left- or right speaker. While the target letter could be presented on any position, apart from the first and last position in the sequence, the distractor was always presented at the mid-point of the sequence in between the third and the fourth letter sound. Interference effects (i.e. longer RTs) that reflect distractor processing were observed across participants on incongruent trials compared to congruent trials. This effect was found to be similar across perceptual load conditions, suggesting that increasing auditory perceptual load did not reduce auditory distractor processing. However, there are several potential reasons why this effect was not observed. For example, the sequence of letters was always spoken in a female voice, whereas the distractor letter was always spoken in a male voice. It is plausible that this has led to a distractor "pop-out" effect, as the target and distractor letter differed in one important phonological feature (i.e. gender). In addition, given that the letter sequence was presented serially (i.e. one letter after each other) and presentation of the distractor and target letter only overlapped on two letter items (between the third and the fourth letter sound), it is likely that the high perceptual load condition did not impose a high enough demand on resources to exhaust capacity. The absence of a reduction in distractor processing at high levels of perceptual load could thus potentially be attributed to a range of other factors unrelated to perceptual load. An alternative manipulation of perceptual load by increasing the complexity of operations might be more applicable to investigate load effects in the auditory modality. For example, one could ask participants to judge two syllables presented together on either pitch (low perceptual load) or pitch and semantic content (high perceptual load). This would control for some of the limitations outlined above.

On a range of auditory processing tasks, individuals with ASD often display enhanced performance on tasks that require processing of simple, low-level auditory stimuli (see Haesen, Boets, & Wagemans, 2011; O'Connor, 2012 for a review). For example, compared to typically developing children, children with ASD often show superior pitch processing (Heaton, Hermelin, & Pring, 1998), including superior pitch memory and labelling (Heaton, 2003), frequency categorisation ('high/low' judgments) and frequency discrimination ('same/different' judgments). This superior processing has been shown for pure tones (Bonnel et al., 2010; Bonnel, Mottron, Peretz, Trudel, & Gallun, 2003; Jones et al., 2009; O'Riordan & Passetti, 2006), complex tones (Järvinen-Pasley & Heaton, 2007) and speech stimuli (Järvinen-

Pasley, Wallace, Ramus, Happé, & Heaton, 2008). In addition, there is some evidence of auditory hyperacuity in ASD (Ney, 1979; Talay-Ongan & Wood, 2000), which may hint at over-arousal in the auditory modality. Musical savants are also more common in individuals with ASD compared to the non-clinical population (Rimland & Fein, 1988). Consistent with the behavioural findings, the majority of electrophysiological studies using event-related potentials (ERPs) also found larger auditory mismatch negativity (MNM) amplitudes and shorter MMN latencies to changes in pitch in individuals with ASD, indicative of enhanced neural processing of auditory stimuli at the pre-attentive level (Ceponiene et al., 2003; Ferri, Elia, Agarwal, Lanuzza, Musumeci, & Pennisi, 2003; Gomot, Giard, Adrien, Barthelemy, & Bruneau, 2002). However, these findings are not unequivocal, with others reporting longer MMN latencies in children with ASD, particularly in response to infrequent speech stimuli (Jansson-Verkasalo et al., 2005; Kuhl et al., 2005; Lepistö et al., 2006). Could an increased perceptual capacity in ASD also lead to enhanced perceptual auditory processing? As the studies outlined above relate to a variety of different processes and mechanisms, it is important to not overstate the possible contribution of an increased perceptual capacity in ASD for these results. It may however be conceivable that an increased perceptual capacity in ASD interacts with the development of other perceptual mechanisms to give rise to these atypical patterns of behaviour.

Whilst the findings presented in this thesis suggest a perceptual advantage for children and adolescents with ASD attending to information in two sensory modalities, there is some evidence in the literature that suggests that perceptual processing may be impaired in ASD when participants are required to integrate stimuli from different sensory modalities (see Marco et al. 2011, for a review). Whereas typically developing individuals generally benefit from the presentation of multisensory stimuli, showing enhanced performance on detection and discrimination tasks (Perrott, Saberi, Brown and Strybel, 1990; Spence and Driver, 1997; Stein, London, Wilkinson and Price, 1996), individuals with ASD often show reduced behavioural facilitation and reduced cortical activation in response to multisensory stimuli (Russo et al. 2010; Brandwein et al. 2013). Brandwein et al. (2013) for example, found that children with ASD were slower to respond to audio-visual (AV) stimulus pairs on a simple reaction time task than TD children, and showed less widespread cortical activation in the AV condition, particularly at early stages of information processing. Integration of multisensory stimuli in the context of speech perception also seems to be impaired in ASD. For example, individuals with ASD are reported to be less susceptible to the McGurk effect (De Gelder et al. 1991; Smith and Bennetto, 2007, but also see Iarocci et al. 2010; Williams et al. 2004), in which the simultaneous presentation of a speech sound (e.g. /ba/) with an incongruent visual stimulus (e.g. /va/) can result in inaccurate auditory perceptions. These findings indicate that individuals with ASD do not integrate visual and auditory information in the same manner as TD children. Others however have suggested that these differences are due to poorer lip reading abilities in ASD (Iarocci et al. 2010; Williams et al. 2004), as well as the confounding effects of using social (e.g. faces) and/or linguistic stimuli, which are inherently more difficult for individuals with ASD to process. Indeed, when using basic, non-social stimuli, Van der Smagt et al. (2007) found that children with ASD were as susceptible as TD children to the sound-induced double-flash illusion where the number of beeps has been shown to produce the percept of additional illusory flashes (Shams et al. 2002). However, the experiments in this thesis and the above work on multisensory integration (MSI) in ASD differ considerably in terms of task requirements. While both the MSI tasks and the current experiments involve the processing of simultaneously presented stimuli from different sensory modalities, a typical MSI task is a perceptual task where perception of a stimulus in one modality is enhanced by the presence of a stimulus in another modality through a process of integration. Both the inattentional deafness procedure as well as the dual-task paradigm employed here, however, are selective attention tasks where the additional auditory stimulus does not facilitate the processing of the visual stimulus (or vice versa). Instead, the emphasis is on whether an unexpected and therefore genuinely unattended auditory stimulus captures attention (experiment 2, 3, 4) or an additional and expected stimulus can also be attended to (experiment 5, 6) according to the level of visual perceptual load of a central task.

Psychological theories

How do the findings reported within this thesis relate to cognitive theories of autism such as weak central coherence (WCC) and enhanced perceptual functioning (EPF)? As outlined in chapter 1, WCC considers a deficit in extracting the overall ‘gestalt’ of a stimulus to be a central feature of autism, resulting in a tendency or cognitive bias to process local parts of information (Frith, 1989a). In support of this, several studies have found superior performance of individuals with ASD on tasks where a preference for local processing and/or resistance to process the overall gestalt is advantageous for performance such as the Navon task (Plaisted et al., 1999) and the embedded figures task (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). The EPF account also proposes that individuals with ASD are characterised by a more locally biased perceptual processing style, but in turn does not predict a weakness in global processing. Instead, EPF suggests that lower-order cognitive processes take precedence over the development of higher-order processes. Thus, according to this account, superior performance in individuals with ASD is the result of enhanced low-level perception rather than a weak global processing style.

These theories fit some of the results obtained in this thesis. At high perceptual load for example, individuals with ASD demonstrated enhanced perceptual processing compared to typically developing controls. According to both WCC and EPF, these findings could be interpreted in terms of enhanced attention to detail rather than increased perceptual capacity. However, both accounts would also predict that enhanced processing of low-level detail is observable across all perceptual load conditions, including low perceptual load. Yet in all experiments presented in this thesis, enhanced processing at low levels of perceptual load in individuals was not observed, reflected by equivalent awareness rates for an unexpected critical stimulus (experiment 2, 4), as well as similar detection rates and detection sensitivity (experiment 5, 6) at low levels of perceptual load.

Could the differential pattern of findings be related to reduced top-down influences in individuals with ASD (e.g. Greenaway & Plaisted, 2005)? Top-down processing is important to determine what stimuli are attended to and involves higher-order processes such as working memory, expectations and prior knowledge. It is also considered to be a more active and adaptive form of processing compared to bottom-up processing, which is driven by salient stimulus features in an automatic fashion and is therefore more passive and reflexive (Loth, Gómez, & Happé, 2010). Lavie and colleagues extended perceptual load theory to also account for these top-down effects of attention (Lavie et al., 2004). They proposed that successful focused attention depends on two mechanisms of selective attention. The first is a perceptual selection mechanism that details how distractor interference can be prevented in conditions of high perceptual load. This is a rather passive mechanism whereby distractor processing is dependent on a 'spill-over' of untapped attentional resources. Performing a high perceptual load task simply leaves no resources available for any additional distractor processing. The second mechanism is an executive cognitive control mechanism that is required to minimise interference from distractor stimuli when these are perceived (as in low perceptual load conditions). This mechanism is a more active mechanism of cognitive control that depends on higher cognitive functions such as working memory to 'shield' task performance from distractor interference by maintaining current task priorities and goal-directed behaviour. Contrary to the predicted effect of perceptual load on focussed attention, loading these control functions (e.g. by increasing working memory load) disrupts the ability to prioritise processing of task-relevant information and instead leads to increased distractor processing (Lavie et al., 2004). Lavie et al. (2004) demonstrated this effect experimentally. When participants were asked to remember a large set of digits (6 item set) prior to performing a trial on a typical flanker task, response interference effects were increased compared to when participants only had to remember one digit. Thus, whereas high perceptual load leads to less distraction, a high level of load on cognitive control functions leads to more distraction (Lavie, 2010).

Could differences in cognitive control between TD individuals and individuals with ASD account for the findings reported within this thesis? While some cognitive control is necessary to keep task priorities online, it is important to stress that active cognitive control functions only determine selective attention when (1) additional information is interfering with a target response (i.e. in form of a potent distractor) and (2) the distractor is perceived as in low perceptual load displays (Lavie et al., 2004). In all experiments within this thesis however, the additional stimulus was not interfering with the target response and instead was required to be attended to. Cognitive control functions in these task situations should therefore not have had an effect on detection rates. Furthermore, if we assume that the working memory load of the task (i.e. keeping task instructions in mind) disproportionally taxed the individuals with ASD more than the TD subjects, then we would expect impaired task performance in individuals with ASD across perceptual conditions (given that task instructions remained constant across conditions). This however was not observed, as indicated by the absence of any group differences on task performance measures such as reaction times and accuracy rates across experiments. Although a cognitive control deficit in ASD cannot account for the findings observed within this thesis, it will be important in future research to explore the interplay between perceptual load and working memory load in ASD.

Future work

A number of potential studies have already been mentioned in this discussion. For example, it would be important to ascertain whether an increased perceptual capacity in ASD that has been shown to be a factor in visual selective attention (Remington, Swettenham, et al., 2012; Remington et al., 2009; Swettenham et al., 2014) and cross-modal selective attention (evidence presented in this thesis), is also relevant for auditory-only contexts of selective attention. In this respect, existing dichotic listening paradigms could be manipulated to test the predictions of an increased perceptual capacity. For example, an unexpected word or syllable that is easily discriminable when attended to could be presented in the unattended channel whilst participants perform either a low perceptual load or high perceptual load categorisation task in the attended channel. Alternatively, response competing distracting words could be presented in the unattended channel and the extent to which perceptual load modulates interference from these words is measured. Prior to carrying out these experiments with individuals with ASD however, it would be important to ascertain whether these effects of auditory perceptual load can be observed in the typically developing population.

In addition, a direct test of perceptual capacity of individuals with ASD would be desirable to rule out a host of alternative explanations (i.e. task difficulty, top-down factors). In this regard, a study could measure how individual differences in visual short-term memory can predict performance on a range of visual and cross-modal selective attention tasks. It should also be highlighted that the samples across experiments in this thesis only included participants with ASD with IQs within the typical range. To date there have been no studies examining perceptual capacity in children with ASD who also have learning difficulties.

A limitation of the current research is the use of a blocked design across experiments, where each block only contained trials of the same level of perceptual load. In typical adults, it has been shown that distractor interference depends on participants' anticipation of high-load or low-load displays irrespective of the actual display presented (Handy & Mangun, 2000; Murray & Jones, 2002; Theeuwes et al., 2004). Thus, based on these findings rather than bottom-up it is the top-down factors such as load anticipation that are most critical to performance. These differences in strategy rather than the level of perceptual load could have influenced the effects seen on awareness of a critical stimulus and detection rates/sensitivity. However, it must also be noted that other studies have found the opposite (Brand-D'Abrescia & Lavie, 2007; Lavie et al., 2009), including those that have used similar paradigms such as the dual-task paradigm (Macdonald & Lavie, 2008) or inattentional deafness paradigm (Macdonald & Lavie, 2011). In these studies, randomly intermixing low- and high load trials produced the same perceptual load effect as presenting participants with a blocked design. It would nonetheless be important in a future study to explore the possibility of strategy effects within both the dual-task paradigm and inattentional deafness paradigm used here in individuals with ASD.

There is some preliminary evidence in the literature that points to the underlying neural mechanisms of an increased perceptual capacity in ASD. One candidate is larger extrastriate population receptive field maps in individuals with autism (Schwarzkopf et al., 2014). Clearly, further work particularly in children is required to better understand these neural underpinnings. The use of complementary techniques (e.g. EEG) would also help to investigate these effects. For example, the dual-task paradigm used in experiment 5 & 6 could be adapted to measure attentional effects related to different ERP markers (e.g. P300).

Lastly, an enhanced perceptual capacity also seems to correlate with autistic traits in the typical population, where individuals with higher AQ scores reported greater interference effects by distractors at high levels of perceptual load (Bayliss

& Kritikos, 2011). Although this may suggest that an increased perceptual capacity is part of the broader autism phenotype, further work is required in this area.

Conclusion

The work presented here used the Perceptual Load Theory of Attention and Cognitive Control to investigate cross-modal selective attention in children and adolescents with ASD. Recent advances in visual selective attention suggest that autism is characterised by an increased perceptual capacity. The current work tested the predictions of this increased perceptual capacity account in ASD for cross-modal contexts of selective attention. Across a range of experiments, the level of visual perceptual load was manipulated using converging operational definitions of perceptual load. It was shown that individuals with ASD continued to report awareness of both unexpected and expected auditory information even at high levels of visual perceptual load. This pattern of awareness was distinctively different to typically developing individuals matched on age and non-verbal ability scores, who showed a reduction of awareness at high levels of perceptual load and also experienced this reduction at a lower level of perceptual load than individuals with ASD.

The findings therefore demonstrated that in cross-modal contexts of attention, individuals with ASD are characterised by an increased perceptual capacity. Whilst this can be seen as a perceptual advantage rather than a deficit, being able to process more information can have important implications for everyday adaptive functioning in a multisensory environment for individuals with ASD. For example, these findings might provide an explanation for the common observation by parents and clinicians that children with ASD experience difficulties and even distress if the environment features too many sensory stimuli. An increased perceptual capacity in ASD that operates across sensory modalities would allow children with ASD to process more sensory information at any one time, even if in some circumstances this information is distracting for their current task behaviour.

In addition, the work presented here might be able to shed light on some of the atypicalities reported in ASD that relate to both higher distractibility on auditory processing tasks, but also savant-like abilities in some individuals. Future educational and therapeutic programmes could therefore aim to exploit the advantages of such an enhancement, but equally provide a learning environment within which the potentially detrimental effects are minimised.

Appendix

Table 8.1 Distribution of participants across experiments

	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6
Exp.1	-					
Exp. 2	TD: 44	-				
Exp. 3	-	-	-			
Exp. 4	-	-	-	-		
Exp. 5	-	-	ASD: 9 TD: 10	ASD: 10 TD: 10	-	
Exp. 6	-	-	ASD: 9 TD: 10	ASD: 9 TD: 9	ASD: 16 TD: 5	-

Note: This table provides a summary of the cross-over of participants across experiments. For example, 44 typically developing (TD) participants who performed in Experiment 1 also provided data in Experiment 2 (see Method section on page 80 for further detail).

Furthermore, 9 ASD (and 10 TD) participants who performed in Experiment 3 also performed in Experiment 5. 10 ASD participants who performed in Experiment 4 also performed in Experiment 5. Thus, the sample of participants in Experiment 5 was made up equally of participants who performed in Experiment 3 and 4. 16 ASD (and 5 TD) participants who also performed in Experiment 5 provided data in Experiment 6.

References

Abrams, Daniel A, Lynch, Charles J, Cheng, Katherine M, Phillips, Jennifer, Supekar, Kaustubh, Ryali, Srikanth, . . . Menon, Vinod. (2013). Underconnectivity between voice-selective cortex and reward circuitry in children with autism. *Proceedings of the National Academy of Sciences, 110*(29), 12060-12065.

Adams, N. C., & Jarrold, C. (2012). Inhibition in autism: children with autism have difficulty inhibiting irrelevant distractors but not prepotent responses. *Journal of Autism and Developmental Disorders*, *42*(6), 1052-1063. doi: 10.1007/s10803-011-1345-3

Alcántara, José I, Weisblatt, Emma J L, Moore, Brian C J, & Bolton, Patrick F. (2004). Speech-in-noise perception in high-functioning individuals with autism or Asperger's syndrome. *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 45*(6), 1107-1114. doi: 10.1111/j.1469-7610.2004.t01-1-00303.x

Alegria, Jésus, & Noirot, E. (1978). Neonate orientation behaviour towards human voice. *International Journal of Behavioral Development, 1*(4), 291-312.

Allen, Greg, & Courchesne, Eric. (2001). Attention function and dysfunction in autism. *Frontiers in Bioscience, 6*, 105-119. doi: 10.1002/mus.23684

Allport, D Alan, Antonis, Barbara, & Reynolds, Patricia. (1972). On the division of attention: A disproof of the single channel hypothesis. *The Quarterly Journal of Experimental Psychology, 24*(2), 225-235.

Amaral, David G, Schumann, Cynthia Mills, & Nordahl, Christine Wu. (2008). Neuroanatomy of autism. *Trends in Neurosciences, 31*(3), 137-145.

American Psychiatric Association. (1994). *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.). Washington DC: American Psychiatric Association.

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders (DSM-5®)*: American Psychiatric Pub.

Asperger, H. (1944). The "autistic psychopathy" in childhood. *Archiv Fur Psychiatrie Und Nervenkrankheiten, 117*(1), 76-136. doi: 10.1007/Bf01837709

Bahrami, Bahador, Carmel, David, Walsh, Vincent, Rees, Geraint, & Lavie, Nilli. (2008). Unconscious orientation processing depends on perceptual load. *Journal of Vision, 8*(3), 1-10.

Bahrami, Bahador, Lavie, Nilli, & Rees, Geraint. (2007). Attentional load modulates responses of human primary visual cortex to invisible stimuli. *Current Biology, 17*(6), 509-513.

Bailey, Aea, Luthert, P, Dean, A, Harding, B, Janota, I, Montgomery, M, . . . Lantos, P. (1998). A clinicopathological study of autism. *Brain, 121*(5), 889-905.

Bailey, Anthony, Le Couteur, A, Gottesman, I, Bolton, P, Simonoff, E, Yuzda, E, & Rutter, M. (1995). Autism as a strongly genetic disorder: evidence from a British twin study. *Psychological Medicine, 25*(1), 63-77.

Baird, G., Simonoff, E., Pickles, A., Chandler, S., Loucas, T., Meldrum, D., & Charman, T. (2006). Prevalence of disorders of the autism spectrum in a population cohort of children in South Thames: the Special Needs and Autism Project (SNAP). *Lancet, 368*(9531), 210-215. doi: 10.1016/S0140-6736(06)69041-7

Baird, Gillian, Douglas, Hannah Rose, & Murphy, M Stephen. (2011). Recognising and diagnosing autism in children and young people: summary of NICE guidance. *BMJ, 343*.

Baranek, Grace T. (1999). Autism during infancy: A retrospective video analysis of sensory-motor and social behaviors at 9–12 months of age. *Journal of Autism and Developmental Disorders, 29*(3), 213-224.

Barber, Paul J, & Folkard, Simon. (1972). Reaction time under stimulus uncertainty with response certainty. *Journal of Experimental Psychology, 93*(1), 138.

Baron-Cohen, Simon. (1989). The autistic child’s theory of mind: A case of specific developmental delay. *Journal of Child Psychology and Psychiatry, 30*, 285-298.

Baron-Cohen, Simon, Ashwin, Emma, Ashwin, Chris, Tavassoli, Teresa, & Chakrabarti, Bhismadev. (2009). Talent in autism: hyper-systemizing, hyper-attention to detail and sensory hypersensitivity. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1522), 1377-1383.

Baron-Cohen, Simon, Leslie, Alan M, & Frith, Uta. (1985). Does the autistic child have a “theory of mind”? *Cognition, 21*(1), 37-46.

Baron-Cohen, Simon, Lombardo, Michael, Tager-Flusberg, Helen, & Cohen, Donald. (2013). *Understanding Other Minds: Perspectives from developmental social neuroscience*: OUP Oxford.

Baron-Cohen, Simon, Lombardo, Michael V, Auyeung, Bonnie, Ashwin, Emma, Chakrabarti, Bhismadev, & Knickmeyer, Rebecca. (2011). Why are autism spectrum conditions more prevalent in males. *PLoS Biol, 9*(6), e1001081.

Baron-Cohen, Simon, Scott, Fiona J, Allison, Carrie, Williams, Joanna, Bolton, Patrick, Matthews, Fiona E, & Brayne, Carol. (2009). Prevalence of autism-spectrum conditions: UK school-based population study. *The British Journal of Psychiatry, 194*(6), 500-509.

Baron-Cohen, Simon, Wheelwright, Sally, Skinner, Richard, Martin, Joanne, & Clubley, Emma. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, malesand females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5-17.

Bayliss, Andrew P, & Kritikos, Ada. (2011). Brief report: perceptual load and the Autism Spectrum in typically developed individuals. *Journal of Autism and Developmental Disorders, 41*(11), 1573-1578. doi: 10.1007/s10803-010-1159-8

Begeer, Sander, Mandell, David, Wijnker-Holmes, Bernadette, Venderbosch, Stance, Rem, Dorien, Stekelenburg, Fred, & Koot, Hans M. (2013). Sex differences in the timing of identification among children and adults with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 43*(5), 1151-1156.

Belin, Pascal, Zatorre, Robert J, Lafaille, Philippe, Ahad, Pierre, & Pike, Bruce. (2000). Voice-selective areas in human auditory cortex. *Nature, 403*(6767), 309-312.

Bennetto, Loisa, Pennington, Bruce F., & Rogers, Sally J. (1996). Intact and Impaired Memory Functions in Autism. *Child Development, 67*(4), 1816-1835.

Benoni, Hanna, & Tsal, Yehoshua. (2012). Controlling for dilution while manipulating load: perceptual and sensory limitations are just two aspects of task difficulty. *Psychonomic Bulletin & Review, 19*(4), 631-638. doi: 10.3758/s13423-012-0244-8

Binder, Jeffrey R, Frost, Julie A, Hammeke, Thomas A, Bellgowan, Patrick SF, Springer, Jane A, Kaufman, Jacqueline N, & Possing, Edward T. (2000). Human temporal lobe activation by speech and nonspeech sounds. *Cerebral Cortex, 10*(5), 512-528.

Birch, Susan AJ, & Bloom, Paul. (2003). Children Are Cursed An Asymmetric Bias in Mental-State Attribution. *Psychological Science, 14*(3), 283-286.

Boddaert, Nathalie, Belin, Pascal, Chabane, Nadia, Poline, Jean-Baptiste, Barthélémy, Catherine, Mouren-Simeoni, Marie-Christine, . . . Zilbovicius, Mônica. (2014). Perception of complex sounds: abnormal pattern of cortical activation in autism. *American Journal of Psychiatry*.

Bonnel, Anna, McAdams, Stephen, Smith, Bennett, Berthiaume, Claude, Bertone, Armando, Ciocca, Valter, . . . Mottron, Laurent. (2010). Enhanced pure-tone pitch discrimination among persons with autism but not Asperger syndrome. *Neuropsychologia, 48*(9), 2465-2475. doi: 10.1016/j.neuropsychologia.2010.04.020

Bonnel, Anne-Marie Anna, Mottron, Laurent, Peretz, Isabelle, Trudel, Manon, & Gallun, Erick. (2003). Enhanced pitch sensitivity in individuals with autism: a signal detection analysis. *Journal of Cognitive Neuroscience, 15*(2), 226-235. doi: 10.1162/089892903321208169

Bowler, Dermot. (2007). *Autism spectrum disorders: Psychological theory and research*: John Wiley & Sons.

Bowler, Dermot M. (1992). "Theory of mind" in Asperger's syndrome. *Child Psychology & Psychiatry & Allied Disciplines, 33*(5), 877-893.

Bowler, Dermot M, & Worley, Kierron. (1994). Susceptibility to social influence in adults with Asperger's syndrome: A research note. *Journal of Child Psychology and Psychiatry, 35*(4), 689-697. doi: 10.1111/j.1469-7610.1994.tb01214.x

Brand-D'Abrescia, Murielle, & Lavie, Nilli. (2007). Distractor effects during. *Psychonomic Bulletin & Review, 14*(6), 1153-1157.

Brand-D’Abrescia, Muriele, & Lavie, Nilli. (2008). Task coordination between and within sensory modalities: Effects on distraction. *Perception & Psychophysics, 70*(3), 508-515.

Broadbent, DE. (1958). *Perception and Communication*. London: Pergamon Press.

Brosnan, Mark J, Scott, Fiona J, Fox, Simone, & Pye, Jackie. (2004). Gestalt processing in autism: Failure to process perceptual relationships and the implications for contextual understanding. *Journal of Child Psychology and Psychiatry, 45*(3), 459-469.

Brownell, Hiram, & Martino, Gail. (1998). Deficits in Inference and Social Cognition: The Effects of Right Hemisphere Brain Damage *Right hemisphere language comprehension: Perspectives from cognitive neuroscience* (pp. 309).

Brugha, T, McManus, S, Meltzer, H, Smith, J, Scott, FJ, Purdon, S, . . . Bankart, J. (2009). Autism spectrum disorders in adults living in households throughout England: Report from the adult psychiatric morbidity survey 2007. *The Health & Social Care Information Centre, Social Care Statistics*.

Bryson, Susan E, Wainwright-Sharp, J Ann, & Smith, Isabel M. (1990). Autism: a developmental spatial neglect syndrome? *Advances in Psychology, 69*, 405-427.

Burack, JA, Enns, JT, Stauder, JEA, Mottron, L, & Randolph, B. (1997). Attention and Autism: Behavioral and electrophysiological evidence. *Handbook of Autism and Pervasive Developmental Disorders, 2*, 226-247.

Burack, JA, & Iarocci, G. (1995). *Visual filtering and covert orienting in autism.* Paper presented at the meeting of the Society of Research in Child development, Indianapolis, IN.

Burack, JA, Iarocci, G, Mottron, L, Stauder, JE, Robaey, P, & Brennan, JM. (1996). *Visual filtering in persons with autism: A developmental perspective.* Paper presented at the 26th International Congress of Psychology.

Burack, Jacob A. (1994). Selective attention deficits in persons with autism: preliminary evidence of an inefficient attentional lens. *Journal of Abnormal Psychology, 103*(3), 535-543. doi: 10.1037/0021-843X.103.3.535

Carmel, David, Saker, Pascal, Rees, Geraint, & Lavie, Nilli. (2007). Perceptual load modulates conscious flicker perception. *Journal of Vision, 7*(14), 1-13. doi: 10.1167/7.14.14.Introduction

Carmel, David, Thorne, Jeremy D, Rees, Geraint, & Lavie, Nilli. (2011). Perceptual load alters visual excitability. *Journal of Experimental Psychology: Human Perception and Performance, 37*(5), 1350. doi: 10.1037/a0024320

Carper, Ruth A, & Courchesne, Eric. (2005). Localized enlargement of the frontal cortex in early autism. *Biological Psychiatry, 57*(2), 126-133.

Cartwright-Finch, Ula, & Lavie, Nilli. (2007). The role of perceptual load in inattentional blindness. *Cognition, 102*(3), 321-340. doi: 10.1016/j.cognition.2006.01.002

Casey, BJ, Gordon, CT, Mannheim, Glenn B, & Rumsey, Judith M. (1993). Dysfunctional attention in autistic savants. *Journal of Clinical and Experimental Neuropsychology, 15*(6), 933-946. doi: 10.1080/01688639308402609

CDC. (2014). Prevalence of autism spectrum disorders among children aged 8 years: autism and developmental disabilities monitoring network, 11 sites, United States, 2010. *MMWR Surveillance Summaries, 63*(2), 1–22.

Ceponiene, R, Lepistö, T, Shestakova, a, Vanhala, R, Alku, P, Näätänen, R, & Yaguchi, K. (2003). Speech-sound-selective auditory impairment in children with autism: they can perceive but do not attend. *Proceedings of the National Academy of Sciences of the United States of America, 100*(9), 5567-5572. doi: 10.1073/pnas.0835631100

Channon, Shelley, Pratt, Polly, & Robertson, Mary M. (2003). Executive function, memory, and learning in Tourette's syndrome. *Neuropsychology, 17*(2), 247.

Cherry, E Colin. (1953). Some experiments on the recognition of speech, with one and with two ears. *The Journal of the acoustical society of America, 25*(5), 975-979.

Christ, Shawn E, Holt, Daniel D, White, Desirée A, & Green, Leonard. (2007). Inhibitory control in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 37*(6), 1155-1165. doi: 10.1007/s10803-006-0259-y

Christ, Shawn E, Kester, Lindsay E, Bodner, Kimberly E, & Miles, Judith H. (2011). Evidence for selective inhibitory impairment in individuals with autism spectrum disorder. *Neuropsychology, 25*(6), 690-701. doi: 10.1037/a0024256

Ciesielski, K.T., Courchesne, Eric, & Elmasian, Robert. (1990). Effects of focused selective attention tasks on event-related potentials in autistic and normal individuals. *Electroencephalography and Clinical Neurophysiology, 75*(3), 207-220. doi: 10.1016/0013-4694(90)90174-I

Ciesielski, Kristina T, Knight, Jeanne E, Prince, Ronald J, Harris, Richard J, & Handmaker, Stanley D. (1995). Event-related potentials in cross-modal divided attention in autism. *Neuropsychologia, 33*(2), 225-246.

Comalli Jr, Peter E, Wapner, Seymour, & Werner, Heinz. (1962). Interference effects of Stroop color-word test in childhood, adulthood, and aging. *The Journal of Genetic Psychology, 100*(1), 47-53.

Constantino, John N, Davis, Sandra A, Todd, Richard D, Schindler, Matthew K, Gross, Maggie M, Brophy, Susan L, . . . Reich, Wendy. (2003). Validation of a brief quantitative measure of autistic traits: comparison of the social responsiveness scale with the autism diagnostic interview-revised. *Journal of Autism and Developmental Disorder, 33*(4), 427-433.

Constantino, John N, & Todd, Richard D. (2003). Autistic traits in the general population: a twin study. *Archives of General Psychiatry, 60*(5), 524-530.

Constantino, John N., Zhang, Yi, Frazier, Thomas, Abbacchi, Anna M., & Law, Paul. (2010). Sibling Recurrence and the Genetic Epidemiology of Autism. *American Journal of Psychiatry, 167*(11), 1349-1356. doi: doi:10.1176/appi.ajp.2010.09101470

Corteen, RS, & Dunn, D. (1974). Shock-associated words in a nonattended message: A test for momentary awareness. *Journal of Experimental Psychology, 102*(6), 1143-1144. doi: Doi 10.1037/H0036362

Coslett, H Branch, Brashear, HR, & Heilman, Kenneth M. (1984). Pure word deafness after bilateral primary auditory cortex infarcts. *Neurology, 34*(3), 347-347.

Courchesne, E. (2002). Abnormal early brain development in autism. *Molecular psychiatry, 7,* S21.

Courchesne, E., Press, G. A., & Yeung-Courchesne, R. (1993). Parietal lobe abnormalities detected with MR in patients with infantile autism. *AJR Am J Roentgenol, 160*(2), 387-393. doi: 10.2214/ajr.160.2.8424359

Courchesne, Eric. (1997). Brainstem, cerebellar and limbic neuroanatomical abnormalities in autism. *Current opinion in neurobiology, 7*(2), 269-278.

Courchesne, Eric, Campbell, Kathleen, & Solso, Stephanie. (2011). Brain growth across the life span in autism: age-specific changes in anatomical pathology. *Brain research, 1380,* 138-145.

Courchesne, Eric, Karns, CM, Davis, HR, Ziccardi, R, Carper, RA, Tigue, ZD, . . . Lord, C. (2001). Unusual brain growth patterns in early life in patients with autistic disorder an MRI study. *Neurology, 57*(2), 245-254.

Courchesne, Eric, Kilman, Beverly A, Galambos, Robert, & Lincoln, Alan J. (1984). Autism: processing of novel auditory information assessed by event-related brain potentials. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section, 59*(3), 238-248.

Courchesne, Eric, Lincoln, Alan J, Kilman, Beverly A, & Galambos, Robert. (1985). Event-related brain potential correlates of the processing of novel visual and auditory information in autism. *Journal of Autism and Developmental Disorders, 15*(1), 55-76.

Courchesne, Eric, & Pierce, Karen. (2005). Why the frontal cortex in autism might be talking only to itself: local over-connectivity but long-distance disconnection. *Current opinion in neurobiology, 15*(2), 225-230.

Courchesne, Eric, Townsend, Jeanne, Akshoomoff, Natacha A, Saitoh, Osamu, Yeung-Courchesne, Rachel, Lincoln, Alan J, . . . Lau, Lily. (1994). Impairment in shifting attention in autistic and cerebellar patients. *Behavioral neuroscience, 108*(5), 848-865.

Courchesne, Eric, Townsend, Jeanne, & Saitoh, Osamu. (1994). The brain in infantile autism Posterior fossa structures are abnormal. *Neurology, 44*(2), 214-223.

Dawson, Geraldine, Bernier, Raphael, & Ring, Robert H. (2012). Social attention: a possible early indicator of efficacy in autism clinical trials. *Journal of Neurodevelopmental Disorders, 4*(1), 11.

Dawson, Geraldine, Finley, Charles, Phillips, Sheila, Galpert, Larry, & Lewy, Art. (1988). Reduced P3 amplitude of the event-related brain potential: Its relationship to language ability in austism. *Journal of Autism and Developmental Disorders, 18*(4), 493-504.

Dawson, Geraldine, Meltzoff, Andrew N, Osterling, Julie, Rinaldi, Julie, & Brown, Emily. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism and Developmental Disorders, 28*(6), 479-485.

Dawson, Geraldine, Toth, Karen, Abbott, Robert, Osterling, Julie, Munson, Jeff, Estes, Annette, & Liaw, Jane. (2004). Early social attention impairments in autism: social orienting, joint attention, and attention to distress. *Developmental Psychology, 40*(2), 271.

Day, Mary Carol, & Stone, C Addison. (1980). Children's use of perceptual set. *Journal of Experimental Child Psychology, 29*(3), 428-445.

DeCasper, Anthony J, & Fifer, William P. (1980). Of human bonding: Newborns prefer their mothers' voices. *Science, 208*(4448), 1174-1176.

Deutsch, J Anthony, & Deutsch, Diana. (1963). Attention: some theoretical considerations. *Psychological Review, 70*(1), 80-90. doi: Doi 10.1037/H0039515

Dick, Frederic, Saygin, Ayse Pinar, Galati, Gaspare, Pitzalis, Sabrina, Bentrovato, Simone, D'Amico, Simona, . . . Pizzamiglio, Luigi. (2007). What is involved and what is necessary for complex linguistic and nonlinguistic auditory processing: evidence from functional magnetic resonance imaging and lesion data. *Journal of Cognitive Neuroscience, 19*(5), 799-816.

Driver, Jon, & Vuilleumier, Patrik. (2001). Perceptual awareness and its loss in unilateral neglect and extinction. *Cognition, 79*(1), 39-88.

Dumoulin, Serge O, & Wandell, Brian A. (2008). Population receptive field estimates in human visual cortex. *Neuroimage, 39*(2), 647-660.

Duncan, J. (1986). Disorganization of Behavior after Frontal-Lobe Damage. *Cognitive Neuropsychology, 3*(3), 271-290. doi: Doi 10.1080/02643298608253360

Duncan, John, Martens, Sander, & Ward, Robert. (1997). Within but not between sensory modalities. *Nature, 387*, 809.

Ecker, Christine, Bookheimer, Susan Y, & Murphy, Declan GM. (2015). Neuroimaging in autism spectrum disorder: brain structure and function across the lifespan. *The Lancet Neurology*.

Eimas, Peter D, Siqueland, Einar R, Jusczyk, Peter, & Vigorito, James. (1971). Speech perception in infants. *Science, 171*(3968), 303-306.

Ellis, A. W. (1989). Neuro-cognitive processing of faces and voices. In A. W. Young & H. D. D. Ellis (Eds.), *Handbook of research on face processing* (pp. 207–215). North-Holland, The Netherlands: Elsevier Science Publishers B.V.

Enns, James T, & Akhtar, Nameera. (1989). A developmental study of filtering in visual attention. *Child Development*, 1188-1199.

Enns, James T, & Girgus, Joan S. (1985). Perceptual grouping and spatial distortion: A developmental study. *Developmental Psychology, 21*(2), 241.

Eriksen, Barbara A, & Eriksen, Charles W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*(1), 143-149. doi: 10.3758/BF03203267

Ernst, M, Zametkin, AJ, Matochik, JA, Pascualvaca, D, & Cohen, RM. (1997). Low medial prefrontal dopaminergic activity in autistic children. *The Lancet, 350*(9078), 638.

Ethofer, Thomas, Van De Ville, Dimitri, Scherer, Klaus, & Vuilleumier, Patrik. (2009). Decoding of emotional information in voice-sensitive cortices. *Current Biology, 19*(12), 1028-1033.

Fecteau, Shirley, Armony, Jorge L, Joanette, Yves, & Belin, Pascal. (2004). Is voice processing species-specific in human auditory cortex? An fMRI study. *NeuroImage, 23*(3), 840-848.

Fecteau, Shirley, Armony, Jorge L, Joanette, Yves, & Belin, Pascal. (2005). Sensitivity to voice in human prefrontal cortex. *Journal of Neurophysiology, 94*(3), 2251-2254.

Fein, Deborah, Tinder, Paula, & Waterhouse, Lynn. (1979). Stimulus generalization in autistic and normal children. *Journal of Child Psychology and Psychiatry, 20*(4), 325-335. doi: 10.1111/j.1469-7610.1979.tb00518.x

Ferri, Raffaele, Elia, Maurizio, Agarwal, Nivedita, Lanuzza, Bartolo, Musumeci, Sebastiano A, & Pennisi, Giovanni. (2003). The mismatch negativity and the P3a components of the auditory event-related potentials in autistic low-functioning subjects. *Clinical Neurophysiology, 114*(9), 1671-1680.

Fitousi, Daniel, & Wenger, Michael J. (2011). Processing capacity under perceptual and cognitive load: A closer look at load theory. *Journal of Experimental Psychology: Human Perception and Performance, 37*(3), 781.

Fodor, Jerry A. (1983). *The modularity of mind: An essay on faculty psychology*: MIT press.

Folstein, S., & Rutter, M. (1977). Infantile-Autism - Genetic Study of 21 Twin Pairs. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 18*(4), 297-321.

Fombonne, Eric. (2003). Epidemiological surveys of autism and other pervasive developmental disorders: an update. *Journal of Autism and Developmental Disorders, 33*(4), 365-382.

Frith, Uta. (1989a). *Autism: Explaining the enigma*. Oxford: Blackwell.

Frith, Uta. (1989b). A new look at language and communication in autism. *International Journal of Language & Communication Disorders, 24*(2), 123-150.

Frith, Uta, & Snowling, Maggie. (1983). Reading for meaning and reading for sound in autistic and dyslexic children. *British Journal of Developmental Psychology, 1*(4), 329-342.

Garner, Wendell R, & Felfoldy, Gary L. (1970). Integrality of stimulus dimensions in various types of information processing. *Cognitive psychology, 1*(3), 225-241.

Garretson, HelenBray, Fein, Deborah, & Waterhouse, Lynn. (1990). Sustained attention in children with autism. *Journal of Autism and Developmental Disorders, 20*(1), 101-114. doi: 10.1007/bf02206860

Gervais, Hélène, Belin, Pascal, Boddaert, Nathalie, Leboyer, Marion, Coez, Arnaud, Sfaello, Ignacio, . . . Zilbovicius, Mônica. (2004). Abnormal cortical voice processing in autism. *Nature neuroscience, 7*(8), 801-802.

Geurts, H. M., Verte, S., Oosterlaan, J., Roeyers, H., & Sergeant, J. A. (2004). How specific are executive functioning deficits in attention deficit hyperactivity disorder and autism? *Journal of Child Psychology and Psychiatry, 45*(4), 836-854.

Geurts, Hilde M, Corbett, Blythe, & Solomon, Marjorie. (2009). The paradox of cognitive flexibility in autism. *Trends in Cognitive Sciences, 13*(2), 74-82.

Geurts, Hilde M, Luman, Mariolein, & Van Meel, Catharina S. (2008). What's in a game: the effect of social motivation on interference control in boys with ADHD and autism spectrum disorders. *Journal of Child Psychology and Psychiatry, 49*(8), 848-857. doi: 10.1111/j.1469-7610.2008.01916.x

Glenn, Sheila M, Cunningham, Cliff C, & Joyce, Paul F. (1981). A study of auditory preferences in nonhandicapped infants and infants with Down's syndrome. *Child Development*, 1303-1307.

Goldstein, G, Johnson, C R, & Minshew, N J. (2001). Attentional processes in autism. *Journal of Autism and Developmental Disorders, 31*(4), 433-440.

Goldstone, Robert L. (1998). Perceptual learning. *Annual review of psychology, 49*(1), 585-612.

Gomot, Marie, Giard, Marie-Hélène, Adrien, Jean-Louis, Barthelemy, Catherine, & Bruneau, Nicole. (2002). Hypersensitivity to acoustic change in children with autism: electrophysiological evidence of left frontal cortex dysfunctioning. *Psychophysiology, 39*(05), 577-584.

Grandin, Temple. (1995). Thinking in picture. *Thinking in picture*.

Grandin, Temple. (1997). A personal perspective of autism. *Handbook of Autism and Pervasive Developmental Disorders, Volume 2, Third Edition*, 1276-1286.

Grandjean, Didier, Sander, David, Pourtois, Gilles, Schwartz, Sophie, Seghier, Mohamed L, Scherer, Klaus R, & Vuilleumier, Patrik. (2005). The voices of wrath: brain responses to angry prosody in meaningless speech. *Nature Neuroscience, 8*(2), 145-146.

Greenaway, Rebecca, & Plaisted, Kate. (2005). Top-down attentional modulation in autistic spectrum disorders is stimulus-specific. *Psychological Science, 16*(12), 987-994.

Gregory, BL, & Plaisted-Grant, KC. (2013). The autism-spectrum quotient and visual search: shallow and deep autistic endophenotypes. *Journal of Autism and Developmental Disorders*, 1-10.

Griffith, Elizabeth M, Pennington, Bruce F, Wehner, Elizabeth A, & Rogers, Sally J. (1999). Executive functions in young children with autism. *Child Development*, 817-832.

Grinter, Emma J, Maybery, Murray T, Van Beek, Pia L, Pellicano, Elizabeth, Badcock, Johanna C, & Badcock, David R. (2009). Global visual processing and self-rated autistic-like traits. *Journal of Autism and Developmental Disorders, 39*(9), 1278-1290.

Grossmann, Tobias, Oberecker, Regine, Koch, Stefan Paul, & Friederici, Angela D. (2010). The developmental origins of voice processing in the human brain. *Neuron, 65*(6), 852-858.

Grzadzinski, Rebecca, Huerta, Marisela, & Lord, Catherine. (2013). DSM-5 and autism spectrum disorders (ASDs): an opportunity for identifying ASD subtypes. *Molecular Autism, 4*(1), 12. doi: 10.1186/2040-2392-4-12

Guttentag, Robert E, & Ornstein, Peter A. (1990). Attentional capacity and children's memory strategy use. *Advances in Psychology, 69*, 305-320.

Haesen, Birgitt, Boets, Bart, & Wagemans, Johan. (2011). A review of behavioural and electrophysiological studies on auditory processing and speech perception in autism spectrum disorders. *Research in Autism Spectrum Disorders, 5*(2), 701-714. doi: 10.1016/j.rasd.2010.11.006

Hallmayer, Joachim, Cleveland, Sue, Torres, Andrea, Phillips, Jennifer, Cohen, Brianne, Torigoe, Tiffany, . . . Smith, Karen. (2011). Genetic heritability and shared environmental factors among twin pairs with autism. *Archives of General Psychiatry, 68*(11), 1095-1102.

Hanauer, Julie B, & Brooks, Patricia J. (2003). Developmental change in the cross-modal Stroop effect. *Perception & Psychophysics, 65*(3), 359-366.

Handy, Todd C, & Mangun, George R. (2000). Attention and spatial selection: Electrophysiological evidence for modulation by perceptual load. *Perception & Psychophysics, 62*(1), 175-186.

Happé, Francesca, Briskman, J, & Frith, Uta. (2001). Exploring the cognitive phenotype of autism: weak “central coherence” in parents and siblings of children with autism: I. Experimental tests. *Journal of Child Psychology and Psychiatry, 42*(3), 299-307.

Happé, Francesca, & Frith, Uta. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36*(1), 5-25. doi: 10.1007/s10803-005-0039-0

Happé, Francesca GE. (1994). An advanced test of theory of mind: Understanding of story characters' thoughts and feelings by able autistic, mentally handicapped, and normal children and adults. *Journal of Autism and Developmental Disorders, 24*(2), 129-154.

Happé, Francesca GE. (1996). Studying weak central coherence at low levels: children with autism do not succumb to visual illusions. A research note. *Journal of Child Psychology and Psychiatry, 37*(7), 873-877. doi: 10.1111/j.1469-7610.1996.tb01483.x

Hardan, A. Y., Muddasani, S., Vemulapalli, M., Keshavan, M. S., & Minshew, N. J. (2006). An MRI study of increased cortical thickness in autism. *Am J Psychiatry, 163*(7), 1290-1292. doi: 10.1176/appi.ajp.163.7.1290

Hartman, David E, & Danhauer, Jeffrey L. (1976). Perceptual features of speech for males in four perceived age decades. *The Journal of the acoustical society of America, 59*(3), 713-715.

Heaton, Pamela. (2003). Pitch memory, labelling and disembedding in autism. *Journal of Child Psychology and Psychiatry, 44*(4), 543-551. doi: 10.1111/1469-7610.00143

Heaton, Pamela, Hermelin, Beate, & Pring, Linda. (1998). Autism and pitch processing: A precursor for savant musical ability? *Music perception*, 291-305.

Hesling, Isabelle, Dilharreguy, Bixente, Peppé, Sue, Amirault, Marion, Bouvard, Manuel, & Allard, Michèle. (2010). The integration of prosodic speech in high functioning autism: a preliminary fMRI study.

Hessels, Roy S, Hooge, Ignace T C, Snijders, Tineke M, & Kemner, Chantal. (2014). Is there a limit to the superiority of individuals with ASD in visual search? *Journal of Autism and Developmental Disorders, 44*(2), 443-451. doi: 10.1007/s10803-013-1886-8

Hill, Elisabeth L. (2004). Executive dysfunction in autism☆. *Trends in Cognitive Sciences, 8*(1), 26-32. doi: 10.1016/j.tics.2003.11.003

Hismjatullina, Anna Anna Nikolaevna. (2006). *A study of selective attention in young autistic subjects.* University of Missouri--Columbia.

Horwitz, Barry, Rumsey, Judith M, Grady, Cheryl L, & Rapoport, Stanley I. (1988). The cerebral metabolic landscape in autism: intercorrelations of regional glucose utilization. *Archives of neurology, 45*(7), 749-755.

Huang-Pollock, Cynthia L., Carr, Thomas H., & Nigg, Joel T. (2002). Development of selective attention: Perceptual load influences early versus late attentional selection in children and adults. *Developmental Psychology, 38*(3), 363-375. doi: 10.1037//0012-1649.38.3.363

Humphries, Colin, Willard, Kimberley, Buchsbaum, Bradley, & Hickok, Gregory. (2001). Role of anterior temporal cortex in auditory sentence comprehension: an fMRI study. *Neuroreport, 12*(8), 1749-1752.

Hutt, Corinne, Hutt, SJ, Lee, Douglas, & Ounsted, Christopher. (1964). Arousal and childhood autism.

Iarocci, Grace, & Burack, Jacob A. (2004). Intact covert orienting to peripheral cues among children with autism. *Journal of Autism and Developmental Disorders, 34*(3), 257-264. doi: Doi 10.1023/B:Jadd.0000029548.84041.69

Jansson-Verkasalo, Eira, Kujala, T, Jussila, Katja, Mattila, Marja-Leena, Moilanen, Irma, Näätänen, R, . . . Korpilahti, P. (2005). Similarities in the phenotype of the auditory neural substrate in children with Asperger syndrome and their parents. *European Journal of Neuroscience, 22*(4), 986-990.

Jarrold, Christopher, Gilchrist, Iain D, & Bender, Alison. (2005). Embedded figures detection in autism and typical development: preliminary evidence of a double dissociation in relationships with visual search. *Developmental Science, 8*(4), 344-351. doi: 10.1111/j.1467-7687.2005.00422.x

Järvinen-Pasley, Anna, & Heaton, Pamela. (2007). Evidence for reduced domain-specificity in auditory processing in autism. *Developmental Science, 10*(6), 786-793. doi: 10.1111/j.1467-7687.2007.00637.x

Järvinen-Pasley, Anna, Wallace, Gregory L, Ramus, Franck, Happé, Francesca, & Heaton, Pamela. (2008). Enhanced perceptual processing of speech in autism. *Developmental Science, 11*(1), 109-121. doi: 10.1111/j.1467-7687.2007.00644.x

Jerger, Susan, Martin, Randi C, & Pirozzolo, Francis J. (1988). A developmental study of the auditory Stroop effect. *Brain and Language, 35*(1), 86-104.

Jerger, Susan, Pirozzolo, Francis, Jerger, James, Elizondo, Rodolfo, Desai, Shevon, Wright, Elizabeth, & Reynosa, Raymond. (1993). Developmental trends in the interaction between auditory and linguistic processing. *Perception & Psychophysics, 54*(3), 310-320.

Jerger, Susan, Stout, Gayle, Kent, Marilyn, Albritton, Elizabeth, Loiselle, Louise, Blondeau, Rebecca, & Jorgenson, Sheryl. (1993). Auditory Stroop effects in children with hearing impairment. *Journal of Speech, Language, and Hearing Research, 36*(5), 1083-1096.

Joanisse, Marc F, & Gati, Joseph S. (2003). Overlapping neural regions for processing rapid temporal cues in speech and nonspeech signals ☆ . *NeuroImage, 19*(1), 64-79.

Johnson, Mark H. (2012). Executive function and developmental disorders: the flip side of the coin. *Trends in Cognitive Sciences, 16*(9), 454-457.

Jolliffe, T, & Baron-Cohen, S. (1997). Are people with autism and Asperger syndrome faster than normal on the Embedded Figures Test? *Journal of Child Psychology and Psychiatry, 38*(5), 527- 534. doi: 10.1111/j.1469-7610 .1997.tb01539.x

Jolliffe, Therese, & Baron-Cohen, Simon. (1999). A test of central coherence theory: Linguistic processing in high-functioning adults with autism or Asperger syndrome: Is local coherence impaired? *Cognition, 71*(2), 149-185. doi: Doi 10.1016/S0010-0277(99)00022-0

Jones, Catherine R G, Happé, Francesca, Baird, Gillian, Simonoff, Emily, Marsden, Anita J S, Tregay, Jenifer, . . . Charman, Tony. (2009). Auditory discrimination and auditory sensory behaviours in autism spectrum disorders. *Neuropsychologia, 47*(13), 2850-2858. doi: 10.1016/j.neuropsychologia.2009.06.015

Joseph, Robert M, Keehn, Brandon, Connolly, Christine, Wolfe, Jeremy M, & Horowitz, Todd S. (2009). Why is visual search superior in autism spectrum disorder? *Developmental Science, 12*(6), 1083-1096.

Jusczyk, Peter W, & Bertoncini, Josiane. (1988). Viewing the development of speech perception as an innately guided learning process. *Language and Speech, 31*(3), 217-238.

Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin, 109*(3), 490-501.

Kanner, L. (1943). Autistic Disturbances of Affective Contact. *Nervous Child, 2*(3), 217-250.

Keller, Timothy A, Kana, Rajesh K, & Just, Marcel Adam. (2007). A developmental study of the structural integrity of white matter in autism. *Neuroreport, 18*(1), 23-27.

Kemner, C, Verbaten, M N, Cuperus, J M, Camfferman, G, & van Engeland, H. (1995). Auditory event-related brain potentials in autistic children and three different control groups. *Biological psychiatry, 38*(3), 150-165. doi: 10.1016/0006-3223(94)00247-Z

Kinsbourne, M. (1987). Brain mechanisms and memory. *Hum Neurobiol, 6*(2), 81-92.

Kisilevsky, Barbara S, Hains, Sylvia MJ, Lee, Kang, Xie, Xing, Huang, Hefeng, Ye, Hai Hui, . . . Wang, Zengping. (2003). Effects of experience on fetal voice recognition. *Psychological Science, 14*(3), 220-224.

Klin, Ami. (1991). Young autistic children's listening preferences in regard to speech: a possible characterization of the symptom of social withdrawal. *Journal of Autism and Developmental Disorders, 21*(1), 29-42.

Klin, Ami. (1992). Listening preferences in regard to speech in four children with developmental disabilities. *Journal of Child Psychology and Psychiatry, 33*(4), 763-769.

Klin, Ami, Jones, Warren, Schultz, Robert, Volkmar, Fred, & Cohen, Donald. (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry, 59*(9), 809-816.

Koch, Christof, & Tsuchiya, Naotsugu. (2007). Attention and consciousness: two distinct brain processes. *Trends in Cognitive Sciences*, *11*(1), 16-22.

Kok, Albert. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38*(3), 557-577.

Kriegstein, Katharina V, & Giraud, Anne-Lise. (2004). Distinct functional substrates along the right superior temporal sulcus for the processing of voices. *NeuroImage, 22*(2), 948-955.

Kuhl, Patricia K, Coffey-Corina, Sharon, Padden, Denise, & Dawson, Geraldine. (2005). Links between social and linguistic processing of speech in preschool children with autism: behavioral and electrophysiological measures. *Developmental Science, 8*(1), F1-F12.

Lainhart, Janet E, Piven, Joseph, Wzorek, Maryann, Landa, Rebecca, Santangelo, Susan L, Coon, Hilary, & Folstein, Susan E. (1997). Macrocephaly in children and adults with autism. *Journal of the American Academy of Child & Adolescent Psychiatry, 36*(2), 282-290.

Landry, Oriane, Mitchell, Peter L., & Burack, Jacob A. (2009). Orienting of visual attention among persons with autism spectrum disorders: reading versus responding to symbolic cues. *Journal of Child Psychology and Psychiatry, 50*(7), 862-870. doi: 10.1111/j.1469-7610.2008.02049.x

Landry, Reginald, & Bryson, Susan E. (2004). Impaired disengagement of attention in young children with autism. *Journal of Child Psychology and Psychiatry, 45*(6), 1115-1122.

Lass, Norman J, Hughes, Karen R, Bowyer, Melanie D, Waters, Lucille T, & Bourne, Victoria T. (1976). Speaker sex identification from voiced, whispered, and filtered isolated vowels. *The Journal of the acoustical society of America, 59*(3), 675-678.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology. Human Perception and Performance, 21(3)*(3), 451-468. doi: 10.1037/0096-1523.21.3.451

Lavie, N. (2000). Selective attention and cognitive control: Dissociating attentional functions through different types of load. *Control of Cognitive Processes: Attention and Performance Xviii*, 175-194.

Lavie, N. (2005). Distracted and confused?: selective attention under load. *Trends in Cognitive Sciences*, *9*(2), 75-82. doi: 10.1016/j.tics.2004.12.004

Lavie, N. (2010). Attention, Distraction, and Cognitive Control Under Load. *Current Directions in Psychological Science, 19*(3), 143-148. doi: 10.1177/0963721410370295

Lavie, N., Beck, Diane M, & Konstantinou, Nikos. (2014). Blinded by the load : attention , awareness and the role of perceptual load Blinded by the load :

attention , awareness and the role of perceptual load. *Philos Trans R Soc Lond B Biol Sci, 369*(1641), 20130205. doi: 10.1098/rstb.2013.0205

Lavie, N., & Cox, Sally. (1997). On the efficiency of visual selective attention: Efficient visual search leads to inefficient distractor rejection. *Psychological Science, 8*(5), 395-396. doi: DOI 10.1111/j.1467-9280.1997.tb00432.x

Lavie, N., & de Fockert, Jan W. (2003). Contrasting effects of sensory limits and capacity limits in visual selective attention. *Perception & Psychophysics, 65*(2), 202-212. doi: 10.3758/BF03194795

Lavie, N., & Fox, Elaine. (2000). The role of perceptual load in negative priming. *Journal of Experimental Psychology: Human Perception and Performance, 26*(3), 1038-1052.

Lavie, N., Hirst, Aleksandra, de Fockert, Jan W, & Viding, Essi. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General, 133*(3), 339-354. doi: 10.1037/0096-3445.133.3.339

Lavie, N., Lin, Zhicheng, Zokaei, Nahid, & Thoma, Volker. (2009). The role of perceptual load in object recognition. *Journal of Experimental Psychology. Human Perception and Performance, 35*(5), 1346-1358. doi: 10.1037/a0016454

Lavie, N., Ro, T., & Russell, C. (2003). The Role of Perceptual Load in Processing Distractor Faces. *Psychological Science, 14*(5), 510-515. doi: 10.1111/1467-9280.03453

Lavie, N., & Torralbo, Ana. (2010). Dilution: atheoretical burden or just load? A reply to Tsal and Benoni (2010). *Journal of Experimental Psychology. Human Perception and Performance, 36*(6), 1657-1664; discussion 1665-1658. doi: 10.1037/a0020733

Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & Psychophysics, 56*(2), 183-197. doi: 10.3758/BF03213897

Lepistö, T, Silokallio, S, Nieminen-von Wendt, T, Alku, P, Näätänen, R, & Kujala, T. (2006). Auditory perception and attention as reflected by the brain event-related potentials in children with Asperger syndrome. *Clinical Neurophysiology, 117*(10), 2161-2171.

Lepistö, Tuulia, Kujala, Teija, Vanhala, Raija, Alku, Paavo, Huotilainen, Minna, & Näätänen, Risto. (2005). The discrimination of and orienting to speech and non-speech sounds in children with autism. *Brain research, 1066*(1), 147-157.

Lepistö, Tuulia, Nieminen-von Wendt, Taina, von Wendt, Lennart, Näätänen, Risto, & Kujala, Teija. (2007). Auditory cortical change detection in adults with Asperger syndrome. *Neuroscience Letters, 414*(2), 136-140.

Leslie, Alan M, & Frith, Uta. (1987). Metarepresentation and autism: How not to lose one's marbles. *Cognition, 27*(3), 291-294. doi: Doi 10.1016/S0010-0277(87)80014-8

Lewis, James W, Wightman, Frederic L, Brefczynski, Julie A, Phinney, Raymond E, Binder, Jeffrey R, & DeYoe, Edgar A. (2004). Human brain regions involved in recognizing environmental sounds. *Cerebral Cortex, 14*(9), 1008-1021.

Liberman, Alvin M, & Mattingly, Ignatius G. (1985). The motor theory of speech perception revised. *Cognition, 21*(1), 1-36.

Liebenthal, Einat, Binder, Jeffrey R, Spitzer, Stephanie M, Possing, Edward T, & Medler, David A. (2005). Neural substrates of phonemic perception. *Cerebral Cortex, 15*(10), 1621-1631.

Linville, Sue Ellen. (1996). The sound of senescence. *Journal of voice, 10*(2), 190-200.

Lopez, Brian R, Lincoln, Alan J, Ozonoff, Sally, & Lai, Zona. (2005). Examining the relationship between executive functions and restricted, repetitive symptoms of autistic disorder. *Journal of Autism and Developmental Disorders, 35*(4), 445-460.

Lord, Catherine, Petkova, Eva, Hus, Vanessa, Gan, Weijin, Lu, Feihan, Martin, Donna M, . . . Gerdts, Jennifer. (2012). A multisite study of the clinical diagnosis of different autism spectrum disorders. *Archives of General Psychiatry, 69*(3), 306-313.

Loth, Eva, Gómez, Juan Carlos, & Happé, Francesca. (2010). When seeing depends on knowing: adults with Autism Spectrum Conditions show diminished top-down processes in the visual perception of degraded faces but not degraded objects. *Neuropsychologia, 48*(5), 1227-1236. doi: 10.1016/j.neuropsychologia.2009.12.023

Lovaas, O Ivar, & Schreibman, Laura. (1971). Stimulus overselectivity of autistic children in a two stimulus situation. *Behaviour research and therapy, 9*(4), 305-310.

Macdonald, James S P, & Lavie, Nilli. (2008). Load induced blindness. *Journal of Experimental Psychology. Human perception and performance, 34*(5), 1078-1091. doi: 10.1037/0096-1523.34.5.1078

Macdonald, James S P, & Lavie, Nilli. (2011). Visual perceptual load induces inattentional deafness. *Attention, Perception & Psychophysics, 73*(6), 1780-1789. doi: 10.3758/s13414-011-0144-4

Mack, Arien, & Rock, Irvin. (1998). *Inattentional blindness*: The MIT Press.

MacLeod, Colin M. (1991). Half a century of research on the Stroop effect: an integrative review. *Psychological Bulletin, 109*(2), 163.

Mann, Tania A, & Walker, Peter. (2003). Autism and a deficit in broadening the spread of visual attention. *Journal of Child Psychology and Psychiatry, 44*(2), 274-284.

Marco, Elysa Jill, Hinkley, Leighton B N, Hill, Susanna Shan, & Nagarajan, Srikantan S. (2011). Sensory Processing in Autism: A Review of Neurophysiologic Findings. *Pediatric Research, 69*(5 Pt 2), 48R-54R. doi: 10.1203/PDR.0b013e3182130c54

Matusz, Pawel J, Broadbent, Hannah, Ferrari, Jessica, Forrest, Benjamin, Merkley, Rebecca, & Scerif, Gaia. (2015). Multi-modal distraction: Insights from children’s limited attention. *Cognition, 136*, 156-165. doi: 10.1016/j.cognition.2014.11.031

Maylor, Elizabeth A, & Lavie, Nilli. (1998). The influence of perceptual load on age differences in selective attention. *Psychology and aging, 13*(4), 563.

McAvinue, Laura P, Habekost, Thomas, Johnson, Katherine A, Kyllingsbæk, Søren, Vangkilde, Signe, Bundesen, Claus, & Robertson, Ian H. (2012). Sustained attention, attentional selectivity, and attentional capacity across the lifespan. *Attention, Perception, & Psychophysics, 74*(8), 1570-1582.

Mehler, Jacques, Jusczyk, Peter, Lambertz, Ghislaine, Halsted, Nilofar, Bertoncini, Josiane, & Amiel-Tison, Claudine. (1988). A precursor of language acquisition in young infants. *Cognition, 29*(2), 143-178.

Memmert, Daniel. (2006). The effects of eye movements, age, and expertise on inattentional blindness. *Consciousness and Cognition, 15*, 620-627. doi: 10.1016/j.concog.2006.01.001

Ming, Xue, Julu, Peter OO, Brimacombe, Michael, Connor, Susan, & Daniels, Mary L. (2005). Reduced cardiac parasympathetic activity in children with autism. *Brain and Development, 27*(7), 509-516.

Moon, Christine, Cooper, Robin Panneton, & Fifer, William P. (1993). Two-day-olds prefer their native language. *Infant Behavior and Development, 16*(4), 495-500.

Moray, Neville. (1959). Attention in dichotic listening: Affective cues and the influence of instructions. *The Quarterly Journal of Experimental Psychology, 11*(1), 56-60.

Mottron, Laurent, Bouvet, Lucie, Bonnel, Anna, Samson, Fabienne, Burack, Jacob A, Dawson, Michelle, & Heaton, Pamela. (2013). Veridical mapping in the development of exceptional autistic abilities. *Neuroscience & Biobehavioral Reviews, 37*(2), 209-228.

Mottron, Laurent, & Burack, Jacob A. (2001). Enhanced perceptual functioning in the development of autism.

Mottron, Laurent, Dawson, Michelle, Soulieres, Isabelle, Hubert, Benedicte, & Burack, Jake. (2006). Enhanced perceptual functioning in autism: an update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders, 36*(1), 27-43. doi: 10.1007/s10803-005-0040-7

Mullennix, John W, Johnson, Keith A, Topcu ‐ Durgun, Meral, & Farnsworth, Lynn M. (1995). The perceptual representation of voice gender. *The Journal of the acoustical society of America, 98*(6), 3080-3095.

Murphy, Sandra, Fraenkel, Nick, & Dalton, Polly. (2013). Perceptual load does not modulate auditory distractor processing. *Cognition, 129*, 345-355. doi: 10.1016/j.cognition.2013.07.014

Murray, Janice E, & Jones, Craig. (2002). Attention to local form information can prevent access to semantic information. *The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology, 55*(2), 609-625. doi: 10.1080/02724980143000370

Narain, C, Scott, Sophie K, Wise, Richard JS, Rosen, Stuart, Leff, Alexander, Iversen, SD, & Matthews, PM. (2003). Defining a left-lateralized response specific to intelligible speech using fMRI. *Cerebral Cortex, 13*(12), 1362-1368.

Navon, David. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive psychology, 9*(3), 353-383.

Neisser, Ulric. (1979). The control of information pickup in selective looking. *Perception and its development: A tribute to Eleanor J. Gibson*, 201-219.

Neisser, ULRICH. (1969). *Selective reading: a method for the study of visual attention.* Paper presented at the 19th International Congress of Psychology, London.

Nelson, Peggy B, Jin, Su-Hyun, Carney, Arlene Earley, & Nelson, David A. (2003). Understanding speech in modulated interference: Cochlear implant users and normal-hearing listeners. *The Journal of the acoustical society of America, 113*(2), 961-968.

Ney, Philip G. (1979). A psychopathogenesis of autism. *Child psychiatry and human development, 9*(4), 195-205.

Norman, Donald A, & Bobrow, Daniel G. (1975). On data-limited and resource-limited processes. *Cognitive psychology, 7*(1), 44-64.

O'Riordan, Michelle. (2004). Superior visual search in adults with autism. *Autism, 8*, 229-248. doi: 10.1177/1362361304045219

O'Riordan, Michelle, & Passetti, Filippo. (2006). Discrimination in autism within different sensory modalities. *Journal of Autism and Developmental Disorders, 36*(5), 665-675. doi: 10.1007/s10803-006-0106-1

O'Riordan, Michelle, & Plaisted, Kate. (2001). Enhanced discrimination in autism. *The Quarterly Journal of Experimental Psychology: Section A, 54*(4), 961-979.

O'Riordan, Michelle, Plaisted, Kate, Driver, Jon, & Baron-Cohen, Simon. (2001). Superior Visual Search in Autism. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 719-730. doi: 10.1037/0096-1523.27.3.719

O'Roak, Brian J. (2008). Autism genetics: strategies, challenges, and opportunities. *Autism Research, 1*(1), 4-17.

O’Connor, K. (2012). Auditory processing in autism spectrum disorder: a review. *Neuroscience & Biobehavioral Reviews, 36*(2), 836-854. doi: 10.1016/j.neubiorev.2011.11.008

Ockleford, Elizabeth M, Vince, Margaret A, Layton, Claire, & Reader, Margaret R. (1988). Responses of neonates to parents' and others' voices. *Early human development, 18*(1), 27-36.

Ohta, Haruhisa, Yamada, Takashi, Watanabe, Hiromi, Kanai, Chieko, Tanaka, Eizaburo, Ohno, Taisei, . . . Hashimoto, Ryu-Ichiro. (2012). An fMRI study of reduced perceptual load-dependent modulation of task-irrelevant activity in adults with autism spectrum conditions. *NeuroImage, 61*, 1176-1187. doi: 10.1016/j.neuroimage.2012.03.042

Ornitz, E. M., & Ritvo, E. R. (1976). The syndrome of autism: a critical review. *American Journal of Psychiatry, 133*(6), 609-621. doi: doi:10.1176/ajp.133.6.609

Osterling, Julie A, Dawson, Geraldine, & Munson, Jeffrey A. (2002). Early recognition of 1-year-old infants with autism spectrum disorder versus mental retardation. *Development and psychopathology, 14*(02), 239-251.

Osterling, Julie, & Dawson, Geraldine. (1994). Early recognition of children with autism: A study of first birthday home videotapes. *Journal of Autism and Developmental Disorders, 24*(3), 247-257.

Ozonoff, Sally, & Jensen, Jenise. (1999). Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders, 29*(2), 171-177.

Ozonoff, Sally, & McEvoy, Robin E. (1994). A longitudinal study of executive function and theory of mind development in autism. *Development and psychopathology, 6*(03), 415-431.

Ozonoff, Sally, Pennington, Bruce F, & Rogers, Sally J. (1991). Executive function deficits in high-functioning autistic individuals: relationship to theory of mind. *Journal of Child Psychology and Psychiatry, 32*(7), 1081-1105.

Ozonoff, Sally, Strayer, David L, McMahon, William M, & Filloux, Francis. (1994). Executive function abilities in autism and Tourette syndrome: An information processing approach. *Journal of Child Psychology and Psychiatry, 35*(6), 1015-1032.

Ozonoff, Sally, Young, Gregory S, Carter, Alice, Messinger, Daniel, Yirmiya, Nurit, Zwaigenbaum, Lonnie, . . . Dobkins, Karen. (2011). Recurrence risk for autism spectrum disorders: a Baby Siblings Research Consortium study. *Pediatrics, 128*(3), e488-e495.

Palkovitz, Robin J, & Wiesenfeld, Alan R. (1980). Differential autonomic responses of autistic and normal children. *Journal of Autism and Developmental Disorders, 10*(3), 347-360.

Parks, Nathan A, Hilimire, Matthew R, & Corballis, Paul M. (2009). Visual perceptual load modulates an auditory microreflex. *Psychophysiology, 46*(3), 498-501.

Parks, Nathan A, Hilimire, Matthew R, & Corballis, Paul M. (2011). Steady-state signatures of visual perceptual load, multimodal distractor filtering, and neural competition. *Journal of Cognitive Neuroscience, 23*(5), 1113-1124.

Pascualvaca, Daisy M, Fantie, Bryan D, Papageorgiou, Maria, & Mirsky, Allan F. (1998). Attentional capacities in children with autism: Is there a general deficit in shifting focus? *Journal of Autism and Developmental Disorders, 28*(6), 467-478.

Paul, Rhea, Chawarska, Katarzyna, Fowler, Carol, Cicchetti, Domenic, & Volkmar, Fred. (2007). "Listen my children and you shall hear": Auditory preferences in toddlers with autism spectrum disorders. *Journal of Speech, Language, and Hearing Research, 50*(5), 1350-1364.

Pennington, Bruce F, & Ozonoff, Sally. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry, 37*(1), 51-87.

Perrodin, Catherine, Kayser, Christoph, Logothetis, Nikos K, & Petkov, Christopher I. (2011). Voice cells in the primate temporal lobe. *Current Biology, 21*(16), 1408-1415.

Petkov, Christopher I, Kayser, Christoph, Steudel, Thomas, Whittingstall, Kevin, Augath, Mark, & Logothetis, Nikos K. (2008). A voice region in the monkey brain. *Nature neuroscience, 11*(3), 367-374.

Plaisted, K, Swettenham, J, & Rees, L. (1999). Children with autism show local precedence in a divided attention task and global precedence in a selective attention task. *Journal of Child Psychology and Psychiatry, 40*(05), 733-742. doi: doi:10.1111/1469-7610.00489

Plaisted, Kate, O'Riordan, Michelle, & Baron-Cohen, Simon. (1998). Enhanced visual search for a conjunctive target in autism: A research note. *Journal of*

Child Psychology and Psychiatry, 39(5), 777-783. doi: 10.1017/S0021963098002613

Plaisted, Kate, Saksida, Lisa, Alcántara, José, & Weisblatt, Emma. (2003). Towards an understanding of the mechanisms of weak central coherence effects: experiments in visual configural learning and auditory perception. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 358*, 375-386. doi: 10.1098/rstb.2002.1211

Ploog, Bertram O, & Kim, Nina. (2007). Assessment of stimulus overselectivity with tactile compound stimuli in children with autism. *Journal of Autism and Developmental Disorders, 37*(8), 1514-1524.

Plude, Dana J, & Enns, Jim T. (1994). The development of selective attention : A life-span overview. *Acta Psychologica, 86*, 227-272.

Portas, Chiara Maria, Rees, G, Howseman, AM, Josephs, O, Turner, Rl, & Frith, CD. (1998). A specific role for the thalamus in mediating the interaction of attention and arousal in humans. *The Journal of Neuroscience, 18*(21), 8979-8989.

Posner, Michael I, & Cohen, Yoav. (1984). Components of visual orienting. *Attention and performance X: Control of language processes, 32*, 531-556.

Premack, David, & Woodruff, Guy. (1978). Does the chimpanzee have a theory of mind? *Behavioral and brain sciences, 1*(04), 515-526.

Price, Cathy, Thierry, Guillaume, & Griffiths, Tim. (2005). Speech-specific auditory processing: where is it? *Trends in Cognitive Sciences, 9*(6), 271-276.

Prior, Margot, & Hoffmann, Wendy. (1990). Brief report: Neuropsychological testing of autistic children through an exploration with frontal lobe tests. *Journal of Autism and Developmental Disorders, 20*(4), 581-590.

Raveh, Dana, & Lavie, Nilli. (2015). Load-induced inattentional deafness. *Attention, Perception, & Psychophysics, 77*(2), 483-492. doi: 10.3758/s13414-014-0776-2

Raven, J, Raven, J C, & Court, J H. (1998). *Manual for Raven's progressive matrices and vocabulary scales - Section 1: General overview*. Oxford, United Kingdom: Oxford Psychologists Press.

Reed, Phil, & McCarthy, Julia. (2012). Cross-modal attention-switching is impaired in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 42*(6), 947-953. doi: 10.1007/s10803-011-1324-8

Rees, G, Frith, C D, & Lavie, N. (1997). Modulating irrelevant motion perception by varying attentional load in an unrelated task. *Science, 278*, 1616-1619.

Remez, Robert E, Rubin, Philip E, Pisoni, David B, & Carrell, Thomas D. (1981). Speech perception without traditional speech cues. *Science, 212*(4497), 947-949.

Remington, Anna, Campbell, Ruth, & Swettenham, John. (2012). Attentional status of faces for people with autism spectrum disorder. *Autism, 16,* 59-73. doi: 10.1177/1362361311409257

Remington, Anna, Cartwright-Finch, Ula, & Lavie, Nilli. (2014). I can see clearly now: the effects of age and perceptual load on inattentional blindness. *Frontiers in Human Neuroscience, 8,* 229. doi: 10.3389/fnhum.2014.00229

Remington, Anna M, Swettenham, John G, & Lavie, Nilli. (2012). Lightening the load: Perceptual load impairs visual detection in typical adults but not in autism. *Journal of abnormal psychology, 121*(2), 544-551.

Remington, Anna, Swettenham, John, Campbell, Ruth, & Coleman, Mike. (2009). Selective attention and perceptual load in autism spectrum disorder. *Psychological Science, 20*(11), 1388-1393.

Reynolds, Barry S, Newsom, Crighton D, & Lovaas, O Ivar. (1974). Auditory overselectivity in autistic children. *Journal of Abnormal Child Psychology, 2*(4), 253-263.

Ridderinkhof, K R, & van der Stelt, O. (2000). Attention and selection in the growing child: views derived from developmental psychophysiology. *Biological psychology, 54,* 55-106.

Rimland, Bernard. (1964). Infantile autism: The syndrome and its implications for a neural theory of behavior.

Rimland, Bernard, & Fein, Deborah (1988). Special talents of autistic savants. . In L. K. Obler & D. Fein (Eds.), *The exceptional brain: Neuropsychology of talent and special abilities* (pp. 474-492). New York: Guildford Press.

Rincover, Arnold, & Ducharme, Joseph M. (1987). Variables influencing stimulus overselectivity and" tunnel vision" in developmentally delayed children. *American Journal of Mental Deficiency*.

Robinson, Elise B, Munir, Kerim, Munafò, Marcus R, Hughes, Michael, McCormick, Marie C, & Koenen, Karestan C. (2011). Stability of autistic traits in the general population: further evidence for a continuum of impairment. *Journal of the American Academy of Child & Adolescent Psychiatry, 50*(4), 376-384.

Rogers, Sally J, & Ozonoff, Sally. (2005). Annotation: What do we know about sensory dysfunction in autism? A critical review of the empirical evidence. *Journal of Child Psychology and Psychiatry, 46*(12), 1255-1268.

Ropar, Danielle, & Mitchell, Peter. (2001). Susceptibility to Illusions and Performance on Visuospatial Tasks in Individuals with Autism. *The Journal of Child Psychology and Psychiatry and Allied Disciplines, 42*(04), 539-549.

Rosen, Stuart, & Iverson, Paul. (2007). Constructing adequate non‐speech analogues: what is special about speech anyway? *Developmental Science, 10*(2), 165-168.

Rosenhall, Ulf, Nordin, Viviann, Sandström, Mikael, Ahlsen, Gunilla, & Gillberg, Christopher. (1999). Autism and hearing loss. *Journal of Autism and Developmental Disorders, 29*(5), 349-357.

Rosvold, H Enger, Mirsky, Allan F, Sarason, Irwin, Bransome Jr, Edwin D, & Beck, Lloyd H. (1956). A continuous performance test of brain damage. *Journal of consulting psychology, 20*(5), 343.

Rumsey, Judith M, & Hamburger, Susan D. (1990). Neuropsychological divergence of high-level autism and severe dyslexia. *Journal of Autism and Developmental Disorders, 20*(2), 155-168.

Russell, Ginny, Steer, Colin, & Golding, Jean. (2011). Social and demographic factors that influence the diagnosis of autistic spectrum disorders. *Social psychiatry and psychiatric epidemiology, 46*(12), 1283-1293.

Rutter, Michael, Bailey, Anthony, & Lord, Cathrine. (2003). *Social Communication Questionnaire*. Los Angeles, CA: Western Psychological Services.

Saemundsen, Evald, Magnússon, Páll, Georgsdóttir, Ingibjörg, Egilsson, Erlendur, & Rafnsson, Vilhjálmur. (2013). Prevalence of autism spectrum disorders in an Icelandic birth cohort. *BMJ open, 3*(6), e002748.

Salmond, CH, Ashburner, J, Connelly, A, Friston, KJ, Gadian, DG, & Vargha‐Khadem, F. (2005). The role of the medial temporal lobe in autistic spectrum disorders. *European Journal of Neuroscience, 22*(3), 764-772.

Santangelo, Valerio, Olivetti Belardinelli, Marta, & Spence, Charles. (2007). The suppression of reflexive visual and auditory orienting when attention is otherwise engaged. *Journal of Experimental Psychology: Human Perception and Performance, 33*(1), 137.

Scherer, Klaus R. (1995). Expression of emotion in voice and music. *Journal of voice, 9*(3), 235-248.

Scherer, S. W., Cheung, J., MacDonald, J. R., Osborne, L. R., Nakabayashi, K., Herbrick, J. A., . . . Tsui, L. C. (2003). Human chromosome 7: DNA sequence and biology. *Science, 300*(5620), 767-772.

Schreibman, Laura, & Lovaas, O Ivar. (1973). Overselective response to social stimuli by autistic children. *Journal of Abnormal Child Psychology, 1*(2), 152-168.

Schwartz, Sophie, Vuilleumier, Patrik, Hutton, Chloe, Maravita, Angelo, Dolan, Raymond J, & Driver, Jon. (2005). Attentional load and sensory competition in human vision: modulation of fMRI responses by load at fixation during task-irrelevant stimulation in the peripheral visual field. *Cerebral Cortex, 15*(6), 770-786. doi: 10.1093/cercor/bhh178

Schwarzkopf, D Samuel, Anderson, Elaine J, de Haas, Benjamin, White, Sarah J, & Rees, Geraint. (2014). Larger extrastriate population receptive fields in autism spectrum disorders. *The Journal of neuroscience : the official journal of the Society for Neuroscience, 34*, 2713-2724. doi: 10.1523/JNEUROSCI.4416-13.2014

Scott, Sophie K, Blank, C Catrin, Rosen, Stuart, & Wise, Richard JS. (2000). Identification of a pathway for intelligible speech in the left temporal lobe. *Brain, 123*(12), 2400-2406.

Shah, Amitta, & Frith, Uta. (1983). An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry, 24*(4), 613-620.

Shah, Amitta, & Frith, Uta. (1993). Why do autistic individuals show superior performance on the block design task? *Journal of Child Psychology and Psychiatry, 34*(8), 1351-1364.

Shepp, Bryan E, & Barrett, Susan E. (1991). The development of perceived structure and attention: Evidence from divided and selective attention tasks. *Journal of Experimental Child Psychology, 51*(3), 434-458.

Shoumaker, Robert D, Ajax, ET, & Schenkenberg, T. (1977). Pure word deafness (auditory verbal agnosia). *Diseases of the nervous system*.

Simons, Daniel J, & Chabris, Christopher F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception-London, 28*(9), 1059-1074.

Sinnett, Scott, Costa, Albert, & Soto-Faraco, Salvador. (2006). Manipulating inattentional blindness within and across sensory modalities. *The Quarterly Journal of Experimental Psychology, 59*, 1425-1442. doi: 10.1080/17470210500298948

Spence, Melanie J, & DeCasper, Anthony J. (1987). Prenatal experience with low-frequency maternal-voice sounds influence neonatal perception of maternal voice samples. *Infant Behavior and Development, 10*(2), 133-142.

Sperling, George. (1960). The information available in brief visual presentations. *Psychological monographs: General and applied, 74*(11), 1.

Stroop, J Ridley. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643.

Sutherland, Alexandra, & Crewther, David P. (2010). Magnocellular visual evoked potential delay with high autism spectrum quotient yields a neural mechanism for altered perception. *Brain*, awq122.

Swettenham, John, Baron-Cohen, S, Charman, T, Cox, A, Baird, G, Drew, A_, . . . Wheelwright, S. (1998). The frequency and distribution of spontaneous attention shifts between social and nonsocial stimuli in autistic, typically developing, and nonautistic developmentally delayed infants. *Journal of Child Psychology and Psychiatry, 39*(5), 747-753.

Swettenham, John, Remington, Anna, Murphy, Patrick, Feuerstein, Maike, Grim, Kelly, & Lavie, Nilli. (2014). Seeing the Unseen: Autism Involves Reduced Susceptibility to Inattentional Blindness. *Neuropsychology*. doi: 10.1037/neu0000042

Tager-Flusberg, Helen. (2007). Evaluating the theory-of-mind hypothesis of autism. *Current Directions in Psychological Science, 16*(6), 311-315.

Talay-Ongan, Ayshe, & Wood, Kara. (2000). Unusual sensory sensitivities in autism: A possible crossroads. *International Journal of Disability, Development and Education, 47*(2), 201-212.

Tallal, Paula. (2003). Language Learning Disabilities Integrating Research Approaches. *Current Directions in Psychological Science, 12*(6), 206-211.

Taylor, Brian, & Mueller, H Gustav. (2011). *Fitting and dispensing hearing aids*: Plural Publishing.

Teder-Sälejärvi, Wolfgang a, Pierce, Karen L, Courchesne, Eric, & Hillyard, Steven a. (2005). Auditory spatial localization and attention deficits in autistic adults. *Cognitive Brain Research, 23*, 221-234. doi: 10.1016/j.cogbrainres.2004.10.021

Tellinghuisen, Donald J, & Nowak, Erin J. (2003). The inability to ignore auditory distractors as a function of visual task perceptual load. *Perception & psychophysics, 65*, 817-828.

Theeuwes, Jan, Kramer, Arthur F, & Belopolsky, Artem V. (2004). Attentional set interacts with perceptual load in visual search. *Psychonomic Bulletin & Review, 11*(4), 697-702. doi: 10.3758/BF03196622

Tipper, Steven P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *The Quarterly Journal of Experimental Psychology, 37*(4), 571-590.

Townsend, J, Harris, N S, & Courchesne, E. (1996). Visual attention abnormalities in autism: delayed orienting to location. *Journal of the International Neuropsychological Society : JINS, 2*, 541-550.

Townsend, Jeanne, Courchesne, Eric, & Egaas, Brian. (1996). Slowed orienting of covert visual-spatial attention in autism: specific deficits associated with cerebellar and parietal abnormality. *Development and psychopathology, 8*(03), 563-584.

Treisman, Anne M. (1960). Contextual cues in selective listening. *The Quarterly Journal of Experimental Psychology, 12*(4), 242-248.

Treisman, Anne M. (1964). Selective attention in man. *British Medical Bulletin, 20*(1), 12-16.

Treisman, Anne M. (1969). Strategies and models of selective attention. *Psychological Review, 76*(3), 282.

Treisman, Anne M, & Gelade, Garry. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*(1), 97-136. doi: 10.1016/0010-0285(80)90005-5

Tsal, Yehoshua, & Benoni, Hanna. (2010a). Diluting the burden of load: perceptual load effects are simply dilution effects. *Journal of Experimental Psychology. Human Perception and Performance, 36*, 1645-1656. doi: 10.1037/a0018172

Tsal, Yehoshua, & Benoni, Hanna. (2010b). Much dilution little load in Lavie and Torralbo's (2010) response: A reply. *Journal of Experimental Psychology: Human Perception and Performance, 36,* 1665-1668. doi: 10.1037/a0021907

Uddin, Lucina Q, Supekar, Kaustubh, & Menon, Vinod. (2013). Reconceptualizing functional brain connectivity in autism from a developmental perspective. *Frontiers in Human Neuroscience, 7,* 458. doi: 10.3389/fnhum.2013.00458

Vargas, Diana L, Nascimbene, Caterina, Krishnan, Chitra, Zimmerman, Andrew W, & Pardo, Carlos A. (2005). Neuroglial activation and neuroinflammation in the brain of patients with autism. *Ann Neurol, 57*(1), 67-81.

Vissers, Marlies E, Cohen, Michael X, & Geurts, Hilde M. (2012). Brain connectivity and high functioning autism: a promising path of research that needs refined models, methodological convergence, and stronger behavioral links. *Neuroscience & Biobehavioral Reviews, 36*(1), 604-625.

Volkmar, Fred, Siegel, Matthew, Woodbury-Smith, Marc, King, Bryan, McCracken, James, & State, Matthew. (2014). Practice parameter for the assessment and treatment of children and adolescents with autism spectrum disorder. *Journal of the American Academy of Child & Adolescent Psychiatry, 53*(2), 237-257.

Von Wright, JM. (1970). On selection in visual immediate memory. *Acta Psychologica, 33*, 280-292.

Von Wright, JM, Anderson, K, Stenman, U, Rabbitt, PMA, & Dorric, S. (1975). Attention and performance: Academic Press Nueva York.

Vouloumanos, Athena, Hauser, Marc D, Werker, Janet F, & Martin, Alia. (2010). The tuning of human neonates' preference for speech. *Child Development, 81*(2), 517-527.

Vouloumanos, Athena, Kiehl, Kent A, Werker, Janet F, & Liddle, Peter F. (2001). Detection of sounds in the auditory stream: event-related fMRI evidence for differential activation to speech and nonspeech. *Journal of Cognitive Neuroscience, 13*(7), 994-1005.

Vouloumanos, Athena, & Werker, Janet F. (2004). Tuned to the signal: the privileged status of speech for young infants. *Developmental Science, 7*(3), 270-276.

Vouloumanos, Athena, & Werker, Janet F. (2007a). Listening to language at birth: Evidence for a bias for speech in neonates. *Developmental Science, 10*(2), 159-164.

Vouloumanos, Athena, & Werker, Janet F. (2007b). Why voice melody alone cannot explain neonates' preference for speech. *Developmental Science, 10*(2), 169.

Wainwright-Sharp, J Ann, & Bryson, Susan E. (1993). Visual orienting deficits in high-functioning people with autism. *Journal of Autism and Developmental Disorders, 23*(1), 1-13.

Webb, Sara Jane, Nalty, Theresa, Munson, Jeff, Brock, Catherine, Abbott, Robert, & Dawson, Geraldine. (2007). Rate of head circumference growth as a function of autism diagnosis and history of autistic regression. *J Child Neurol, 22*(10), 1182-1190.

Well, Arnold D, Lorch, Elizabeth Pugzles, & Anderson, Daniel R. (1980). Developmental trends in distractibility: Is absolute or proportional decrement the appropriate measure of interference? *Journal of Experimental Child Psychology, 30*(1), 109-124.

Werling, Donna M, & Geschwind, Daniel H. (2013). Sex differences in autism spectrum disorders. *Current opinion in neurology, 26*(2), 146.

Werner, Emily, & Dawson, Geraldine. (2005). Validation of the phenomenon of autistic regression using home videotapes. *Archives of General Psychiatry, 62*(8), 889-895.

Werner, Emily, Dawson, Geraldine, Osterling, Julie, & Dinno, Nuhad. (2000). Brief report: Recognition of autism spectrum disorder before one year of age: A retrospective study based on home videotapes. *Journal of Autism and Developmental Disorders, 30*(2), 157-162.

Wernicke, C. (1874). Der aphasische Symptomencomplex.

Whitehouse, Andrew J O, & Bishop, Dorothy V M. (2008). Do children with autism 'switch off' to speech sounds? An investigation using event-related potentials. *Developmental science, 11,* 516-524. doi: 10.1111/j.1467-7687.2008.00697.x

Wickens, Christopher D. (1974). Temporal limits of human information processing: A developmental study. *Psychological Bulletin, 81*(11), 739.

Wilson, Daryl E, Muroi, Miya, & MacLeod, Colin M. (2011). Dilution, not load, affects distractor processing. *Journal of Experimental Psychology: Human Perception and Performance, 37*(2), 319.

Wimmer, Heinz, & Perner, Josef. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition, 13*(1), 103-128.

Wimpory, Dawn C, Hobson, R Peter, Williams, J Mark G, & Nash, Susan. (2000). Are infants with autism socially engaged? A study of recent retrospective parental reports. *Journal of Autism and Developmental Disorders, 30*(6), 525-536.

Wing, L., & Gould, J. (1979). Severe Impairments of Social-Interaction and Associated Abnormalities in Children - Epidemiology and Classification. *Journal of Autism and Developmental Disorders, 9*(1), 11-29.

Wolfe, Jeremy M. (1998). Visual search. *Attention, 1*, 13-73.

Wolfe, Jeremy M. (1999). Inattentional amnesia. *Fleeting memories, 17*, 5.

Wolff, Jason J., Gu, Hongbin, Gerig, Guido, Elison, Jed T., Styner, Martin, Gouttard, Sylvain, . . . Network, the IBIS. (2012). Differences in White Matter Fiber Tract Development Present From 6 to 24 Months in Infants With Autism. *American Journal of Psychiatry, 169*(6), 589-600. doi: doi:10.1176/appi.ajp.2011.11091447

Yi, Do-Joon, Woodman, Geoffrey F, Widders, David, Marois, René, & Chun, Marvin M. (2004). Neural fate of ignored stimuli: dissociable effects of perceptual and working memory load. *Nature neuroscience, 7*(9), 992-996.

Zahn, Theodore P, Rumsey, Judith M, & Van Kammen, Daniel P. (1987). Autonomic nervous system activity in autistic, schizophrenic, and normal men: effects of stimulus significance. *Journal of abnormal psychology, 96*(2), 135.

Zatorre, Robert J, Belin, Pascal, & Penhune, Virginia B. (2002). Structure and function of auditory cortex: music and speech. *Trends in Cognitive Sciences, 6*(1), 37-46.

Zatorre, Robert J, Evans, Alan C, Meyer, Ernst, & Gjedde, Albert. (1992). Lateralization of phonetic and pitch discrimination in speech processing. *Science, 256*(5058), 846-849.