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**SUGGESTED RUNNING HEAD: SELECTIVE ATTENTION IN AUTISM**

**Effects of Perceptual Load and Socially Meaningful Stimuli on Crossmodal Selective Attention in Autism Spectrum Disorder and Neurotypical samples**

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# Abstract

The present study examined whether increasing visual perceptual load differentially affected both Socially Meaningful and Non-socially Meaningful auditory stimulus awareness in neurotypical (NT, *n* = 59) adults and Autism Spectrum Disorder (ASD, *n* = 57) adults. On a target trial, an unexpected critical auditory stimulus (CAS), either a Non-socially Meaningful (‘beep’ sound) or Socially Meaningful (‘hi’) stimulus, was played concurrently with the presentation of the visual task. Under conditions of low visual perceptual load both NT and ASD samples reliably noticed the CAS at similar rates (77%-81%), whether the CAS was Socially Meaningful or Non-socially Meaningful. However, during high visual perceptual load NT and ASD participants reliably noticed the meaningful CAS (NT = 71%, ASD = 67%), but NT participants were unlikely to notice the Non-meaningful CAS (20%), whereas ASD participants reliably noticed it (80%), suggesting an inability to engage selective attention to ignore non-salient irrelevant distractor stimuli in ASD.

*Keywords:* Autism Spectrum Disorder, selective attention, inattentional deafness, perceptual load, load theory, crossmodal attention

* 1. **Selective Attention**

Selective attention is the process of focusing on, and reacting to certain stimuli when several occur simultaneously (Broadbent, 1958; Peterson & Posner, 2012; Treisman & Riley, 1969). The ability to ignore certain stimuli, whilst attending to other aspects of the environment is important to prevent overloading our sensory and perceptual systems. Research on selective attention in Autism Spectrum Disorder (ASD) is a large, complex, and expanding literature (see Fein, 2011; Just & Pelphrey, 2013; Marco, Hinkley, Hill, & Nagarajan, 2011, for example). ASD is a lifelong neurodevelopmental condition, defined in the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (DSM-5 American Psychiatric Association, 2013) by impaired communication, impaired social interactions, and repetitive behaviors (see also Landa, Holman, & Garrett-Mayer, 2007). Attentional deficits have been noted in the condition since Kanner’s (1943) and Asperger’s (cf. Frith, 1991) original definitions. Much literature suggests that people with ASD often have difficulties processing everyday sensory information and in focusing attentional resources which can be detrimental to social functioning (e.g., Baron-Cohen, 2008; Frith & Mira, 1992; Laurie, 2014). There have been a number of recent advances in the field of selective attention in ASD.

## 1.2 Selective Attention in Autism Spectrum Disorder

Much of the research on selective attention in ASD has provided contradictory findings. On one hand, for example, Burack (1994) suggested that children with ASD have a deficit in their selective attentional lens insofar as ASD participants were more distracted by peripheral visual stimuli, therefore, suggesting an inability to narrow their focus on a target stimulus. Participants in this study were asked to state whether they saw an ‘O’ or a ‘+’ in the centre of the screen, and their reaction time was recorded. Variables manipulated included the presence/absence of a window only showing the central target stimulus, the amount of non-target distractor stimuli, and the distance between the target and distractor stimuli. The results demonstrated that the presence of distractor stimuli negative impacted performance in the ASD group compared to the control group. These findings led to the conclusion that children with ASD had an overly broad attentional lens that they were unable to narrow efficiently (Burack, 1994; see also Adams & Jarrold, 2012; Christ, Kester, Bodner, & Miles, 2011; Ciesielski, Courchesne, & Elmasian, 1990; Kanakri, Shepley, Varni, & Tassinary, 2017; Smith & Milne, 2009).

O’Riordan (2004) used visual search tasks to show that ASD participants had a superior ability to detect target stimuli compared to neurotypical (NT) participants. Furthermore, when distractor stimuli were more similar to target stimuli NT participants showed significantly reduced detection of target stimuli compared to ASD participants. This suggests that adults with ASD have enhanced selective attention abilities or a superior visual discrimination ability more specifically. While it could be argued that performance on the visual search task may be affected by memory for rejected distractors in search abilities, Joseph, Keehn, Connolly, Wolfe, and Horowitz (2009) accounted for the potential confounding influence of memory by using both a standard static and a dynamic search task, with target and distractor stimuli randomly changing position every 500ms. Their findings showed that ASD participants had quicker reaction times and their performance accuracy was greater in the dynamic search task than that of NT participants. This suggests ASD participants have an enhanced ability to discriminate between targets and distractors at the locus of attention.

Both O’Riordan (2004) and Joseph et al. (2009) have argued that such performances observed in ASD samples is characterized by a superior selective attention coupled with an overly narrow attentional lens. The findings from these studies are supported by ASD individuals outperforming NT individuals in Stroop tests (Adams & Jarrold, 2009), and the weak central coherence theory of ASD (Frith, 1989; Happé, 1996; Happé & Frith, 2006). The weak central coherence theory suggests that individuals with ASD overly focus on the smaller parts of an overall picture, and are therefore more able to pick out finer detail due to selectivity in attention leading to enhanced focus and fixation on minor details. However, it could feasibly be argued that O’Riordan’s (2004) and Joseph et al.’s (2009) data could be accounted for by enhanced awareness of an overall visual scene (e.g., Kanakri et al., 2017).

**1.3 Load Theory**

Thus, it is apparent that there exists ambiguity in the literature on how selective attention functions in ASD. The discrepancies noted in previous selective attention research in ASD (e.g., for an impaired selective attention and an overly broad attentional lens; Burack, 1994; Smith & Milne, 2009; versus an overly narrow lens and superior selective attention; Joseph et al., 2009; O’Riordan, 2004) has recently been addressed by one particularly intriguing line of research that incorporates Lavie’s (1995) *Load theory* of attention and cognitive control (e.g., Remington, Swettenham, Campbell, & Coleman, 2009; Remington, Swettenham, & Lavie, 2012; Swettenham et al., 2014; Tillmann, Olguin, Tuomainen, & Swettenham, 2015; Tillmann & Swettenham, 2017). Load theory suggests that task-irrelevant distractor stimuli will only be processed if there are enough cognitive resources left over after the primary target stimuli have been processed. In other words, the bigger the perceptual load of the main task, the less the ability to process additional stimuli. If the perceptual load is low, a ‘spill-over’ of attentional resources will occur and additional stimuli will be processed automatically. For example, perceptual load can be manipulated by altering the number of task-relevant stimuli in a display (e.g., number of items in a search task; Tillmann & Swettenham, 2017), or the perceptual processing requirement of a task (e.g., the subtlety of a line discrimination; Lavie, 2005; Tillmann et al., 2015).

 Remington et al. (2009) hypothesized that individuals with ASD would have an enhanced visual perceptual load capacity as past research had shown that they performed better than control groups in visual search tasks when there were a large number of visual stimuli (e.g., O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001). They explored perceptual load capacity in an ASD and a NT control group, by using a mix of both a visual search task (Treisman & Gelade, 1980) and a flanker task (Eriksen & Eriksen, 1974). Wherein both NT and ASD groups showed they were still processing distractor (flanker) stimuli at a low perceptual load search task (i.e., finding two target items amongst distractor stimuli) the NT group showed signs of distractor stimuli interference at a higher perceptual load (four target items), whereas the ASD group did not. At the highest perceptual load (i.e., six target items) both groups showed distractor stimuli interference. This suggests that there might be a higher perceptual load capacity in ASD individuals as it took six target items to exhaust their perceptual capacity, whereas NT individual’s perceptual capacity was exhausted after just four target items. These findings were further supported in a study of visual detection sensitivity (Remington et al., 2012) and the detection of an unexpected task-irrelevant visual stimulus in an inattentional blindness task (Swettenham et al., 2014).

**1.4 Crossmodal Attention**

Such studies reviewed above, however, only tested the effects of perceptual load on selective attention in ASD in the visual domain. Therefore, it was not possible to generalise these findings across sensory modalities. Cross-modality research needs to be further explored as sensory input is not usually limited to one sense (e.g., vision; see Stein, 2012), and ASD individuals often present signs of overstimulation in all senses (Laurie, 2014). Harrison and Davies (2013) acknowledged the complexity of unpacking crossmodal attention research (see also, Klapatek, Ngo, & Spence, 2012; Liu, Wu, & Meng, 2012; Peterson & Posner, 2012), and noted that previous research had shown that visual spatial attention can be modulated by emotional prosody cues but that it was unclear whether this “crossmodal modulation of visual attention is associated with the engagement or disengagement of attentional resources” (p. 247). The debate tends to center around the relative importance of bottom-up versus top-down processes (e.g., Mast & Frings, 2014; Mast, Frings, & Spence, 2017) in determining attentional focus or attentional capture in crossmodal attention paradigms. For example, Mast et al. (2017) argued for the role of top-down ‘attentional control sets’ between vision audition but also acknowledged that “other studies have suggested that the detection of simultaneity across the senses and its influence on brain and cognitive processes is independent of the particular task, population or state of the individual (e.g., conscious awareness)” (p. 46). In other words, there is some support for bottom-up processes in selective attention, independent of task environment or top-down expectancies or attentional control sets.

**1.5 Inattentional Deafness paradigm**

 Research has shown that NT individuals show an increased inattentional deafness of unexpected audio stimuli when the visual perceptual load is increased (Macdonald & Lavie, 2011; Molloy, Griffiths, Chait, & Lavie, 2015). Tillmann et al. (2015) examined the effects of perceptual load on crossmodal (i.e., visual and audio) selective attention in ASD. They explored inattentional deafness, and hypothesized that unlike NT individuals, ASD individuals would be able to detect the unexpected audio stimulus in higher visual load tasks as past research (e.g., Remington et al., 2009; Remington et al., 2012; Swettenham et al., 2014) suggests that ASD individuals may have an enhanced perceptual capacity. In a similar procedure to Swettenham et al. (2014), Tillmann et al. (2015) manipulated the lengths of lines on a cross to create a low visual perceptual load condition (i.e., the lines were very clearly a different length and easy to discriminate), and a high visual perceptual load condition (i.e., the lines were much closer in length and more difficult to discriminate) (see Lavie, 2005). However, instead of using an unexpected visual stimulus (Swettenham et al., 2014), they used an unexpected auditory ‘beep’ presented simultaneously with the target cross. Tillmann et al. found that while both NT and ASD groups had similarly high detection rates in the low visual perceptual load condition, NT participants had significantly reduced detection rates of the unexpected audio stimulus in the high visual perceptual load condition. Importantly, detection rates remained high in the ASD group (supporting Macdonald & Lavie, 2011; Molloy et al., 2015). These findings further supported the proposition that there is an enhanced perceptual capacity in ASD (e.g., Remington et al., 2009; Remington et al., 2012; Swettenham et al., 2014), and moreover, that this perceptual capacity is shared across sensory modalities.

## 1.5 Socially Relevant Stimuli

As described in the DSM-5**,** two of the main impairments of ASD are diminished communication and social interaction abilities. As suggested by Tillman et al. (2015) there is a clear need to explore whether stimuli that convey biological and socially relevant information (e.g., a person greeting another person, or a person’s face) would produce different results. For example, in the visual and spatial attention literature there is considerable debate concerning whether socially (or biologically) relevant cues “are special when it comes to triggering reflexive shifts in attention….[as] it is not clear whether all cues belong to the same category or whether social information has a distinct functional role in cueing attention” (Wilson, Soranzo, & Bertamini, 2017, p. 56; see also Birmingham & Kingstone, 2009; Langton, Watt, & Bruce, 2000; Ristic & Kingstone, 2012). There is some ambiguity in the literature in terms of operational definitions of what constitutes a socially relevant cue. For instance, Wilson et al. (2017) critiqued a visual perspective taking attentional interference study by Nielsen, Lance, Levy, and Holmes (2015) who employed a human avatar, an arrow, or a dual-colored block as distractor stimuli. Nielsen et al. argued that the magnitude of attentional interference effects caused by irrelevant distractor cues in cognitive tasks depends on the level or amount of social characteristics that the cue has or conveys. Furthermore, they explained their attentional interference or intrusion findings, according to different levels of attributed social-relevance to each of the three cues, designating the avatar as social, the arrow as semi-social, and the dual-colored block as non-social. Nielsen et al. suggested that the more social the distractor cue, the stronger observed intrusion effects will be in attention-based paradigms. However, it could reasonably be argued that the levels of attributed social ‘quality’ to the three cues was quite arbitrary.

Of interest to the present study, Remington, Campbell, and Swettenham (2012) employed socially relevant distractors (i.e., faces) in a visual search task. They found that NT individuals processed these distractors across all visual perceptual load levels, whereas ASD individuals only processed them at low loads. These findings are contradictory to past research (Remington et al., 2009) where non-socially meaningful visual stimuli (i.e., shapes) were used, suggesting that NT individuals give a *special status* to socially meaningful stimuli, and process them in an automatic fashion regardless of the perceptual load of a relevant task (see Lavie, Ro, & Russell, 2003). These findings fit in with Cherry’s (1953) ‘cocktail party phenomenon’, wherein people (NT) show a shift of attention when they hear socially meaningful auditory stimuli (e.g., their name) (cf. Wood & Cowan, 1995).

 What remains to be examined is whether socially meaningful auditory stimuli would elicit greater detection rates in NT individuals across visual perceptual loads compared to ASD individuals. Exploring this area further will provide a clearer understanding of how selective attention functions in ASD, and shed some more light on how socially relevant stimuli are processed in ASD. This may have real world implications as it could help provide better understanding of how to support and care for ASD individuals. Furthermore, much of the research on attention in ASD has been conducted with child or adolescent populations (e.g., Tillmann & Swettenham, 2017). The present study employed an adult sample, and therefore, may help elucidate whether the findings with youthful populations to date also generalise across older age groups.

 **1.6 The Present Study**

The present study used a line discrimination task to manipulate visual perceptual load (Lavie, 2005; Tillmann et al., 2015). Based on previous findings of enhanced perceptual capacity in ASD (Remington et al., 2009; Remington et al., 2012; Swettenham et al., 2014), that attentional resources are allocated across sensory modalities in ASD (Tillmann et al., 2015), and that socially meaningful visual stimuli produce greater attentional demand in NT individuals (Remington et al., 2012), the present study explored the rates of detection of unexpected Non-socially Meaningful (‘beep’), and Socially Meaningful (a voice saying ‘hi’) auditory stimuli across visual perceptual loads in NT and ASD groups. Based on the literature reviewed (e.g., MacDonald & Lavie, 2011; Remington et al., 2012; Swettenham et al., 2014) we hypothesized that the ASD group would show an enhanced perceptual capacity that functions across sensory modalities, by having similarly high detection rates of an unexpected Non-socially Meaningful auditory stimulus across visual perceptual loads, whereas the NT group would show significantly reduced detection rates in the high visual perceptual load. Furthermore, we hypothesized that NT individuals would show similarly high detection rates of an unexpected Socially Meaningful auditory stimulus across both visual perceptual loads. As noted above, this research could help elucidate whether bottom-up or top-down processes have the greater influence on attentional capture (Mast et al., 2017). Moreover, this study could help explicate whether ASD persons have a genuinely enhanced perceptual capacity compared to NT individuals (Bayliss & Kritikos, 2011; Mayer, 2017). More specifically, if NT samples show significantly higher detection rates of an unexpected Socially Meaning auditory stimulus than to an unexpected Non-socially Meaningful auditory stimulus while engaged in a separate primary visual attention task (i.e., line discrimination), then it suggests, rather, that the central issue is likely one of disengagement of attention to irrelevant environmental stimuli (Harrison & Davies, 2013) in NT persons, and a failure to disengage in ASD samples.

# 2. Method

## 2.1 Participants

One-hundred and twenty-one participants completed the present study. Of these, 59 were neurotypical (NT) adults (31 male, 28 female, *M* age = 32.46 yrs., *SD* = 3.68, age range: 18 – 65 yrs.), recruited from the University of Chichester’s participation pool for psychology students and advertisement via university email network, and snowball sampling. Sixty-two adults with a diagnosis of autism spectrum disorder (ASD) took part (44 male, 18 female, *M* age = 26.15 yrs., *SD* = 1.98, age range: 18 – 61 yrs.). Once exclusion criterion (see Procedure section) was taken into consideration, this left 57 ASD participants in the final analysis (40 male, 17 female, *M* age = 26.30 yrs, *SD* = 2.05, age range: 18 – 61 yrs.) They were recruited from local charities and organisations (across the south east of England) that provide support to people with ASD. Prior to testing, all participants with ASD had received a clinical diagnosis of ASD from a trained, independent clinician as per the *Diagnostic and Statistical Manual of Mental Disorders,* *Fourth Edition* (American Psychiatric Association, 2000). None of the participants had any other known neurological disorders. There was no compensation of monetary value to any of the participants for their participation, though participants from the University of Chichester’s psychology research participation pool were allocated course credit. All participants gave informed consent prior to the experiment.

**2.2 Design**

A 2 x 2 x 2 between groups factorial experimental design was employed with three independent variables, each with two levels (‘Group’: ASD vs. NT; ‘Perceptual load’: High vs. Low; and ‘Auditory stimulus’: Socially Meaningful vs. Non-socially Meaningful), with all participants being randomly distributed across the two ‘Perceptual Load’ conditions and the two ‘Auditory Stimulus’ conditions. Thus, participants from each of the ASD and NT groups were randomly allocated to one of four conditions (see Procedure section for exclusion criteria): 1. Low Perceptual Load + Non-socially Meaningful Auditory Stimulus; 2. Low Perceptual Load + Socially Meaningful Auditory Stimulus; 3. High Perceptual Load + Non-socially Meaningful Auditory Stimulus; 4. High Perceptual Load + Socially Meaningful Auditory Stimulus). The final distribution of participants across conditions was as follows: 13 ASD and 14 NT in the Low Perceptual Load + Non-socially Meaningful Auditory Stimulus condition; 14 ASD and 16 NT in the Low Perceptual load + Socially Meaningful Auditory Stimulus condition; 15 ASD and 15 NT in the High Perceptual Load + Non-socially Meaningful Auditory Stimulus condition; and 15 ASD and 14 NT in the High Perceptual Load + Socially Meaningful Auditory Stimulus condition, respectively. In other words, there were eight between-subjects groups in total. There was one dependent variable, that was binary in nature, with participants either noticing the unexpected auditory stimulus or not, on the critical line discrimination trial.

## 2.3 Materials

Cedrus SuperLab (version 5) was used to create and present computer-based stimuli that were presented on an HP Envy A10-8700P 15.6” laptop (1366 x 768-pixel resolution). The visual stimuli consisted of a black fixation dot, a black cross, and a black visual mask (RGB: 0, 0, 0), centred at fixation and appearing on a white background (RGB: 255, 255, 255). The black cross was the primary target stimulus, 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 six trials, and counterbalanced across participants on trial seven and eight).

 Perceptual load of the primary visual cross-task was manipulated by increasing the complexity of perceptual operations involved in discriminating the length of the line 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 2.4º and a longer arm subtending 3.9º appeared, whereas in the Low Perceptual Load Condition, a cross with a shorter arm subtending .9º and a longer arm subtending 3.9º appeared. In total, four crosses were used; two in each of the High and Low Perceptual Load groups (see Figure 1). This manipulation of perceptual load has previously been successfully applied to neurotypical adults in an inattentional blindness (Cartwright-Finch & Lavie, 2007) and inattentional deafness paradigms (Macdonald & Lavie, 2011), and with ASD children in an inattentional deafness paradigm (Tillmann et al., 2015).

The auditory stimuli consisted of a recording of a male voice saying the word ‘hi’ in the Socially Meaningful Sound Condition, and an 180-Hz pure tone ‘beep’ in the Non-Socially Meaningful Sound Condition. Both stimuli were played through a pair of BOSE Companion 2 Series III 2.0 PC speakers placed either side of the laptop. Both auditory stimuli were presented 170ms in duration and 69.5dB in volume (around the average speaking volume) as measured by a TestSafe TSSL1 Sound Level Meter placed 60cm away, directly in front of the laptop.

A pen and paper was used to record participant’s responses as to whether they noticed the auditory stimulus or not. A piece of paper with a horizontal line next to the letter ‘H’ and a vertical line next to the letter ‘V’ was used to demonstrate what key to press. The laptop and speakers were set up on a table, with a chair positioned directly in front of it.

## 2.4 Procedure

Firstly, participants sat in a quiet room with no distractions. The room did vary between some of the participants as the researcher had to travel to a number of different support and treatment centres for those with ASD to collect data, although care was taken to equate the set-up of each room and ensure minimal distractions. Participants from the ASD group had a support worker or a family member in the room with them. They read the study information sheet. In the ASD group, the participant could ask their support worker, family member or researcher to read it to them and have a verbal explanation of what the experiment involved if they wished. The participants then gave informed consent, answered some basic demographic questions, and could ask any questions. Next, participants positioned their chair directly in front of the laptop, and about 60cm away from the laptop screen.

 The experimenter loaded a new SuperLab file on the laptop and the participant was randomly allocated to one of the four conditions. The first screen presented to the participant was one of detailed instructions of exactly what the participant needed to do. The sheet of paper signalling vertical and horizontal lines was placed next to the laptop. Once they were satisfied and confirmed they fully understood the instructions, as checked by the researcher, the experiment began by pressing any key on the laptop.

 The black fixation dot appeared on the screen for 1500ms. This was to show the participant where to look on the screen. Next, a blank white screen for 96ms, followed by the black cross for 170ms, then a visual masking screen for 496ms, which resembled black and white ‘fuzzy’ static (see Fig. 2). Immediately following this, a screen appeared that said: “Press the letter ‘V’ on the keyboard if you think the vertical line was longer, or, press the letter ‘H’ on the keyboard if you think the horizontal line was longer.” The participants were permitted as much time as they needed to make their decision and then pressed the key that represented what they believed to be the correct response. The next trial began once they pressed the key. This trial was repeated six times. The presentation of each target cross was randomized, with either the vertical or horizontal line being longer on each of the six trials, and always remained in either the High or Low Perceptual Load Condition.

 On the seventh, and critical, trial the events remained the same, but upon presentation of the target cross the unexpected auditory stimulus, either the ‘hi’ or the ‘beep’ depending on assigned condition, played from the speakers simultaneously. After participants had selected which line they believed was longer, they were presented with a screen that asked: “Did you notice anything else?” The researcher then asked the same question to the participant. This is the standard way of assessing awareness on the critical trial in inattentional deafness paradigms (e.g., MacDonald & Lavie, 2011; Tillmann et al., 2015). Participants responded verbally, giving details of the critical stimulus (i.e. imitating the ‘beep’ sound, or saying ‘hi’) where possible. The researcher then noted their response. On the eighth, and final, trial the events remained the same as the critical seventh trial, but this time measured the detection of the auditory stimulus in the absence of attention to the visual task. Participants were told prior to this trial to ignore the cross stimulus and instead attend to any other stimulus they might notice. This was a control trial to ensure participants could hear the auditory stimulus. Lastly, participants were debriefed. In total, each participant was in the research room for about 10 minutes.

Participants were excluded if they failed to give at least five correct responses on the six non-critical line discrimination trials (see Tillmann et al., 2015), gave an incorrect response on the critical trial line discrimination, or were unable to hear the auditory stimulus on the control trial. These exclusion criteria were necessary to make sure that all participants were engaging with the primary (i.e., line discrimination) task on the critical trial that featured the additional auditory stimulus. Five participants from the ASD group made fewer than five correct discriminations in the non-critical line discrimination trials (two from the High Load + Non-socially Meaningful Condition, two from the High Load + Socially Meaningful Condition, and one from the Low Load + Socially Meaningful Condition) and were, therefore, removed from the sample.

# 3. Results

## 3.1 Controls

The proportion of male participants in the NT group (53%) was different from the proportion of males in the ASD group (70%), but not significantly so, χ²(1) = 3.09, *p* = .079 (R Core Team, 2017). This is in line with the higher population prevalence of ASD among males than females. We assessed whether gender affected detection of the CAS and it did not (OR, 1.680; 95% CI, 0.74-3.988; *p* = .224). Gender was not included in further analyses.

As mentioned in the method, we included participants who made 1 error in the visual task during a non-critical trial in our analyses. Ten participants made 1 error and these participants were balanced across NT (4) and ASD (6), and High (6) and Low (4) Perceptual Load, but were more than twice as common in the Socially Meaningful Condition (7) than the Non-socially Meaningful Condition (3). Discrimination error was found to affect detection of the CAS, (OR, 0.263; 95% CI, 0.063-0.985; *p* = .05), and was, thus, included as a covariate in further analyses. The CAS was detected by 40% of the participants who made an error on non-critical trials, compared to 71.7% of the rest of the sample.

## 3.2 Detection

 As can be seen in Figure 3, detection performance was similar across conditions by NT and ASD participants, except when NT participants were required to detect a non-meaningful CAS during high visual perceptual load. A logistic regression estimated a main effect of Discrimination Error and main effects of Perceptual Load, CAS Meaningfulness and Diagnostic Group and the interactions among these variables. The model significantly improved on the null model, χ²(8) = 22.41, *p* = .004. The three-way interaction among Perceptual Load, CAS Meaningfulness and Diagnostic Group approached significance (OR, 0.046; 95% CI, 0.001-1.577; *p* = .09; see Table 1). A significant main effect of Perceptual Load was observed (OR, 0.405; 95% CI, 0.163 -0.973; *p* = .046), indicating higher detection during Low Perceptual load. A main effect of Discrimination Error approached significance (OR, 0.252; 95% CI, 0.050 -1.150; *p* = .078) in the direction of fewer detections among those who made such errors. In light of the strong three-way interaction effect, two further regression analyses were conducted to investigate whether Perceptual Load moderated the effects of CAS Meaningfulness and Diagnostic Group.

## 3.2.1 Low Perceptual Load

Since the availability of attentional resources was determined by perceptual load, we examined the effects of CAS meaningfulness for NT and ASD participants at low and high perceptual load separately. The first logistic regression estimated a main effect of Discrimination Error and main and interaction effects of CAS Meaningfulness and Diagnostic Group under low perceptual load. The model did not significantly improve on the null model, χ²(4) = 0.114, *p* = .998 (see Table 2). Neither Discrimination Error, Diagnostic Group nor CAS Meaningfulness affected detection rates when Perceptual Load was low.

## 3.2.2 High Perceptual Load

 A second logistic regression replicated the previous analysis (i.e., a main effect of Discrimination Error and main and interaction effects of CAS Meaningfulness and Diagnostic Group) under conditions of high perceptual load. In this case, the model significantly improved on the null model, χ²(4) = 18.612, *p* = .001 (see Table 3). A significant interaction effect between CAS Meaningfulness and Diagnostic Group was observed (OR, 0.055; 95% CI, 0.004 -0.619; *p* = .022) indicating that the CAS Meaningfulness affect NT and ASD participants differently under conditions of high perceptual load. Significantly fewer NT participants (25%) than ASD participants (75%) detected a non-meaningful CAS during high visual perceptual load, χ²(1) = 8.533, *p* = .003.

 Main effects of Discrimination Error (OR, 0.0955; 95% CI, 0.004 -0.8; *p* = .054), CAS Meaningfulness (OR, 3.193; 95% CI, 0.924 -11.669; *p* = .068), and Diagnostic Group (OR, 2.994; 95% CI, 0.847-11.474; *p* = .094), all approached significance under high perceptual load. These effects suggest disadvantages in CAS detection in those who made discrimination errors and advantages for Meaningful CAS and ASD participants, but should be interpreted with care in light of the strong interaction effect.

# 4. Discussion

In line with the first hypothesis, the results show that both Diagnostic group (NT vs. ASD) and Perceptual Load (Low vs. High) had a significant impact and interaction on detection rates of the Non-socially Meaningful critical auditory stimulus (CAS). Specifically, whereas both Diagnostic groups had similarly high detection rates in the Low Load Condition, the NT group showed significantly reduced detection rates in the High Load compared to the Low Load, and the ASD group showed no difference in detection across Perceptual Load conditions. Furthermore, the results suggest that increased rates of detection of the Non-meaningful CAS in the ASD group, when the visual perceptual load was high, are not likely to be explained by a trade-off in line discrimination accuracy. The results show that there was no significant impact of the Diagnostic group or Perceptual Load on detection rates of the Socially Meaningful unexpected CAS. There were similarly high detection rates across the Diagnostic groups and Perceptual Loads, and the NT group did not show significantly higher detection rates in the High Load Condition compared to the ASD group. Further analysis showed that there was no statistically significant difference in detection rates between the Non-socially Meaningful and Socially Meaningful CAS in the Diagnostic groups and Perceptual Loads, except in the NT/High Load Condition where detection rates were significantly reduced in the Non-socially Meaningful CAS compared to the Socially Meaningful CAS.

**4.1 Enhanced Perceptual Capacity in ASD?**

 The results from the present study show some support the theory of an enhanced perceptual capacity in ASD (Remington et al., 2009; Remington et al., 2012; Swettenham et al., 2014). Lavie (1995) stated that if a central task does not exhaust perceptual capacity, additional information may be processed. Given that there were no significant differences between Diagnostic groups in the line discrimination task, yet the ASD group had significantly higher detection rates of the Non-socially Meaningful CAS in the High Load Condition, this could indicate that there is no selective attention deficit in ASD. The present data suggest that there may be an enhanced perceptual capacity in ASD individuals as they still had cognitive resources left over to process both the unexpected Socially Meaningful and Non-socially Meaningful CAS under the conditions of high visual perceptual load. In previous research, this effect has generally been found in the visual domain only. By replicating Tillmann et al.’s (2015) study with the Non-meaningful CAS, the present study further supported their findings that the enhanced perceptual capacity found in ASD functions across sensory modalities. This suggests that individuals with ASD may process more information and stimuli from their environment from multiple senses than NT populations. With the evidence that individuals with ASD often become overwhelmed by too much sensory stimulation (Baron-Cohen, 2008; Laurie, 2014), it may be suggested that although ASD individuals show an enhanced perceptual capacity, it may be the cause of some distress seen in ASD individuals as this potentially exhausts other necessary concurrent cognitive resources or capacities. This is unclear from the design of the present study, but future research could employ an added measure of stress levels and see if ASD individuals present higher levels of stress when detecting stimuli at a higher perceptual load. Furthermore, the present study provides an advance on Tillmann et al.’s (2015) findings by extending them to an adult ASD population for the first time.

 The results in the Socially Meaningful CAS Condition were quite intriguing. As shown, there was no impact or interaction of Diagnostic group or Perceptual Load on detection of the unexpected Socially Meaningful CAS. However, in the High Perceptual Load Condition the NT group showed significantly higher detection rates of the Socially Meaningful CAS than the Non-socially Meaningful CAS. Moreover, in the High Perceptual Load Condition the NT group did not demonstrate significantly higher detection rates for the Socially Meaningful CAS than the ASD group. Unlike in Remington et al.’s (2012) study, NT participants did not show higher awareness of socially meaningful stimuli under high perceptual load compared to ASD; in fact, they showed no difference. This is likely due to ASD participants still noticing the unexpected CAS regardless of its meaning, due to an enhanced perceptual capacity.

However, importantly, it did show that NT individuals detected Socially Meaningful stimuli at higher rates than Non-socially Meaningful stimuli without any decreases in performance accuracy on the line discrimination task. Therefore, in certain contexts at least, it would suggest the NT individuals could have an equally high perceptual capacity as ASD individuals. This conclusion is somewhat contradictory to past research (Lavie, 2005; Remington et al., 2009; Remington, Swettenham, & Lavie, 2012; Swettenham et al., 2014; Tillmann et al., 2015) and, therefore, further research is much needed in this area. For example, there could be utility in examining the effects of ‘richness’ of the socially meaningful stimuli (Birmingham & Kingstone, 2009; Wilson et al., 2017) and contextual factors in which they are experienced and perceived (e.g., visual faces in Remington et al.’s 2012 study versus the social greeting auditory word ‘hi’ in the present study). As noted above, Nielsen et al. (2015) demonstrated, with respect to visual perspective taking research at least, that level of social quality of distractor stimuli influences the likelihood of observing interference effects in selective attention tasks.

 The present study, therefore, proposes that NT individuals do give a *special status* to socially meaningful stimuli (Remington et al., 2012), and, moreover, that they have an enhanced attentional filter to filter out non-meaningful stimuli. This supports Wilson et al. (2017)’s proposition that stimulus salience, and not just sentience, is a key dimension to consider to attentional interference paradigms or selective attention preparations. From a different perspective, there may be an enhanced perceptual capacity in ASD, but NT individuals have enough remaining resources left-over to process meaningful stimuli or process them in an automatic fashion. This is supported by the seminal work in selective attention by Broadbent (1958), Cherry (1953), and Moray (1959). They found that whereas a non-meaningful background auditory stimulus was not noticed by a NT population in dichotic listening and shadowing tasks, a meaningful auditory stimulus, such as their name, was detected. Furthermore, Treisman and Riley (1969) suggest that people are permanently primed to detect personally significant words and theorise that they may require less perceptual information than other auditory stimuli to trigger identification. Therefore, applying these theories, along with Load theory (Lavie, 1995), may help to explain the findings in the present study.

 The finding of similar detection rates of an unexpected Socially Meaningful CAS across both ASD and NT groups at High Perceptual Load levels was unexpected based on Remington et al. (2009). What needs to be done in future research is to introduce higher levels of visual perceptual load (i.e., make the visual task even more difficult). By doing this, it would give a better understanding of where ASD perceptual capacity ends and they are no longer able to detect the unexpected Non-socially Meaningful or Socially Meaningful auditory stimulus. Furthermore, it would help elucidate the extent to which NT individuals allocate special status to Socially Meaningful stimuli. This would then create a clearer understanding of how perceptual capacity and the selective attention filter fit together in ASD. Future studies could also consider the use of reaction times within the present study’s procedure. This may help to produce more nuanced findings. Examining reaction times, along with accuracy of responses on the cross-task (line discrimination), would show if increased detection rates were to do with participants spending more time diverting attentional resources between sensory modalities. This methodology may further explain the filtering process and perceptual capacity functions in NT and ASD groups. Future research could also examine the effects of employing different sets of meaningful auditory stimuli such as the participant’s own name, danger words such as ‘fire’, or category members such as instances of fruits, vehicles, or colors, as the present study was somewhat constrained by attempts to carefully and systematically build upon previous work in this area (e.g., Tillmann et al., 2015) by minimising potential extraneous confounding variables, and hence the auditory stimulus utilised (i.e., ‘hi’) could be considered rather limited.

 **4.2 Limitations and Suggestions for Future Research**

 Limitations of the present study include the lack of matching NT and ASD groups for chronological age and nonverbal IQ using the matrix reasoning subscale from the Wechsler Abbreviated Scale for Intelligence (WASI). This is often done in research using ASD participants as it allows for findings to be attributed to ASD rather than intelligence, age, or other functions. This was not possible in the present research due to limited time imposed by institutional ethical considerations (i.e., ASD Support and Treatment Centres). While all ASD participants had been diagnosed with ASD by fully trained and qualified clinicians and all attended support and treatment centres for those with ASD, they could be considered to be in the high functioning end of the spectrum. Their clinicians reported each ASD participant had above average levels of awareness and verbal fluency that potentially reduces the impact of possible underlying differences in verbal intelligence in the present study. Future studies should consider the use of standardised tests of intelligence such as the WASI, verbal ability, working memory, and learning difficulties to exclude these as potential confounding variables. Furthermore, future studies could use an additional diagnostic group (e.g., individuals with specific learning difficulties) to give a deeper understanding of how selective attention functions among these groups. To date, limited research has been done in this area.

 Moreover, the present study did not include an administration of the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) self-report measure with the NT sample. In future studies, it would be advisable to assess whether NT persons who score highly on autism-like traits on the AQ, but who would not be classified on ASD spectrum, perform more similarly to other NT persons or to ASD individuals in selective attention or inattentional deafness studies (Mayer, 2017). For example, Bayliss and Kritikos (2011) found that individuals high on AQ rating but not on ASD spectrum were able to disengage from invalid cues in target trials. A further study could examine the effects of speech with nonsense syllables versus speech with real words in this inattentional deafness paradigm. For example, it would be interesting to expound whether ASD and NT samples would show similarly high rates of detection to a nonsense speech sound such as ‘hee’ or ‘haa’ as they would to the meaningful social greeting ‘hi’. In other words, this could examine whether all speech sounds are perceived and attended to equally, even if they have no apparent connotative or denotative meaning or association. A further limitation of this current study is that it was not possible, in this instance, for the experimenter to be blind as to the group assignment as the research took place in either an autism support service or a university laboratory setting. It should be acknowledged, at this point, that the computer programme randomly assigned participants (ASD and neurotypical) to one of the two perceptual load and one of the two auditory stimuli conditions. It could be argued, perhaps, that there is potential for bias in interpreting a participant’s response as to whether they perceived an auditory stimulus, and if so, what it was. However, there were no participant responses deemed ambiguous as all participants were verbally competent, and a follow-up query asked a participant to confirm their response. Future research, however, should seek to minimise any potential experimenter bias by building in a blind testing protocol. Lastly, the present study employed an inattentional deafness paradigm based on previous research (e.g., MacDonald & Lavie, 2011; Molloy et al., 2015; Tillman et al., 2015). Thus, a limitation of the presentation study could be that studies such as these administer just one ‘critical’ trial to assess attentional awareness, whereas future research should aim to develop designs that allow for a greater number of critical trials to be administered in order to examine the reliability and stability of the findings.

 The findings from the present study further support the evidence that processing sensory information functions somewhat differently in ASD compared to NT people (e.g., Baron-Cohen, 2008; Frith & Mira, 1992; Laurie, 2014). By showing that ASD individuals have an enhanced perceptual capacity, or are less able to filter out Non-socially Meaningful stimuli, it suggests that they may be under more cognitive strain processing such information. These findings could help inform support centres, schools, and other facilities in how to manage their environment to provide better experiences for people with ASD. For example, schools and support facilities increasingly provide ‘sensory rooms’ which have low-level stimulation and provide a comfortable environment for ASD individuals. Furthermore, some cinemas now show ‘autism friendly films’ which reduce background noise, lower the brightness, and provide a less overwhelming experience for those with ASD.

 **4.3 Conclusion**

 To conclude, the present study investigated the effects of Perceptual Load and Non-socially Meaningful/Socially Meaningful stimuli on crossmodal selective attention in ASD and NT samples. It has provided some support for a possible enhanced cross-modal perceptual capacity in ASD (Tillman et al., 2015), and, importantly, that this is also evident in an adult population. However, crucially, the findings suggest that this enhanced perceptual capacity as compared to NT populations is negated by socially meaningful unexpected stimuli. In other words, NT individuals process stimuli that hold a social meaning at a similar level to those with ASD under conditions of high perceptual load. Thus, the more cautious conclusion from the present study is that, rather than an overall enhanced perceptual capacity in ASD compared to NT samples, it is more likely that NT persons have a more finely tuned attentional filter (Bayliss & Kritikos, 2011) that helps prevent the conscious processing of non-salient or non-meaningful irrelevant distractor stimuli. This suggests that both stimulus content and contextual factors need to be considered in selective attention and inattentional deafness paradigms (Molloy et al., 2015; Tillman et al., 2015) insofar as NT individuals may allocate a *special status* to socially meaningful stimuli in that they have greater salience for them and not just sentience (Wilson et al., 2017), and thus may be able to process them with less cognitive effort.

**Compliance with Ethical Standards**:

There was no funding provided for the present study.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

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Table 1.

*Logistic regression analysis of CAS detection by Discrimination Error, Diagnostic Group, Perceptual Load and Meaningfulness of CAS*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *B* | *SE B* | *z* | *p* | *OR* | 95 % CI of OR |
| (Intercept)  | 0.306 | 0.384 | 0.797 | 0.425 | 1.358 | 0.619 -  | 2.883  |
| DiscriminationError | -1.378 | 0.783 | -1.760 | 0.078 | 0.252 | 0.050 -  | 1.150  |
| Diagnostic Group | 0.663 | 0.458 | 1.449 | 0.147 | 1.941 | 0.797 -  | 4.867  |
| Perceptual Load | -0.904 | 0.452 | -1.998 | 0.046 | 0.405 | 0.163 -  | 0.973  |
| CAS Meaningfulness | 0.608 | 0.463 | 1.314 | 0.189 | 1.837 | 0.745 -  | 4.645  |
| Group by Load  | 1.070 | 0.928 | 1.153 | 0.249 | 2.917 | 0.465 -  | 18.307  |
| Group by CAS  | -1.363 | 0.909 | -1.499 | 0.134 | 0.256 | 0.042 -  | 1.519  |
| Load by CAS  | 0.707 | 0.905 | 0.782 | 0.434 | 2.029 | 0.343 -  | 12.243  |
| Group by Load by CAS  | -3.076 | 1.816 | -1.694 | 0.090 | 0.046 | 0.001 -  | 1.577  |

Pseudo R squared = .156. All predictor variables were centred at 0 to avoid multicollinearity (Kappa = 5.233, Maximum VIF = 1.138). DiscriminationError was coded as +.5 if the participant erred on non-critical trials and -.5 if he/she did not. Diagnostic Group as coded as +.5 for ASD and -.5 for NT. Perceptual Load was coded as +.5 for High and -.5 for Low. CAS Meaningfulness was coded as +.5 for Meaningful CAS and -.5 for the Non-meaningful CAS.

Table 2.

*Logistic regression analysis of CAS detection by Discrimination Error, Diagnostic Group, and Meaningfulness of CAS under conditions of Low Perceptual Load*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *B* | *SE B* | *z* | *p* | *OR* | 95 % CI of OR |
| (Intercept)  | 1.225  | 0.631  | 1.941  | 0.052  | 3.405  | 1.088 -  | 16.316  |
| Discrimination Error | -0.217  | 1.288  | -0.169  | 0.866  | 0.805  | 0.074 -  | 18.820  |
| Diagnostic Group | -0.098  | 0.682  | -0.144  | 0.886  | 0.907  | 0.236 -  | 3.609  |
| CAS Meaningfulness | 0.147  | 0.658  | 0.223  | 0.823  | 1.158  | 0.313 -  | 4.315  |
| Group by CAS  | -0.041  | 1.315  | -0.031  | 0.975  | 0.960  | 0.070 -  | 13.311  |

Pseudo R squared = .002. For coding of predictor variables, see Table 1 (Kappa = 4.25, Maximum VIF = 1.145).

Table 3.

*Logistic regression analysis of CAS detection by Discrimination Error, Diagnostic Group, and Meaningfulness of CAS under conditions of High Perceptual Load*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *B* | *SE B* | *z* | *p* | *OR* | 95 % CI of OR |
| (Intercept)  | -0.549  | 0.609  | -0.903  | 0.367  | 0.577  | 0.124 -  | 1.682  |
| DiscriminationError | -2.354  | 1.222  | -1.926  | 0.054  | 0.095  | 0.004 -  | 0.800  |
| Diagnostic Group | 1.161  | 0.637  | 1.822  | 0.068  | 3.193  | 0.924 -  | 11.669  |
| CAS Meaningfulness | 1.097  | 0.655  | 1.675  | 0.094  | 2.994  | 0.847 -  | 11.474  |
| Group by CAS  | -2.906  | 1.272  | -2.285  | 0.022  | 0.055  | 0.004 -  | 0.619  |

Pseudo R squared = .233. For coding of predictor variables, see Table 1 (Kappa = 3.935, Maximum VIF = 1.065).

**Figure Captions**

*Figure 1.* Illustrations of cross (line discrimination) stimuli used.

*Figure 2.* Presentation order of stimuli in SuperLab 5 (Tillmann et al., 2015).

*Figure 3.* Percentage of participants who detected the Non-Meaningful and Meaningful CAS in each Diagnostic category at each level of Perceptual load. Plot developed using ggplot2 (Wickham, 2009).



 Low Load Horizontal Low Load Vertical



 High Load Horizontal High Load Vertical

Fig. 1



Fig. 2



Fig. 3