Research Article

Selective Attention and Perceptual Load in Autism Spectrum Disorder

Anna Remington, John Swettenham, Ruth Campbell, and Mike Coleman

Department of Developmental Science, University College London

ABSTRACT—It has been suggested that the locus of selective attention (early vs. late in processing) is dependent on the perceptual load of the task. When perceptual load is low, irrelevant distractors are processed (late selection), whereas when perceptual load is high, distractor interference disappears (early selection). Attentional abnormalities have long been reported within autism spectrum disorder (ASD), and this study is the first to examine the effect of perceptual load on selective attention in this population. Fourteen adults with ASD and 23 adults without ASD performed a selective attention task with varying perceptual loads. Compared with the non-ASD group, the ASD group required higher levels of perceptual load to successfully ignore irrelevant distractors; moreover, the ASD group did not show any general reduction in performance speed or accuracy. These results suggest enhanced perceptual capacity in the ASD group and are consistent with previous observations regarding superior visual search abilities among individuals with ASD.

The ability to focus on particular aspects of the environment while ignoring others is crucial given that the brain has limited sensory and information-processing systems, which are constantly bombarded with an excess of information (Broadbent, 1958). “Without selective interest, experience is an utter chaos” (James, 1890, p. 402).

Anecdotally, this “chaos” is often observed in autistic spectrum disorder (ASD), in which individuals appear to fixate inappropriately on seemingly irrelevant information in the environment (Bryson, Wainwright-Sharp, & Smith, 1990). Although ASD is currently defined by impairments in social interaction, communication, and repetitive behaviors, the original definition of autism also made reference to attentional deficits associated with the condition (Kanner, 1943). Building on recent advances in the field of attention research, this study further investigated selective attention in ASD.

SELECTIVE ATTENTION

Over the past decades, conflicting reports about the locus of selection (early vs. late) have been put forward. Theories of early selection assert that perception requires selective attention in order to proceed; therefore, selection occurs after only basic physical properties of stimuli have been processed (Broadbent, 1958). Conversely, the argument for late selection states that selection takes place only after stimuli have been perceived fully in an automatic, parallel fashion (Deutsch & Deutsch, 1963). Experimental evidence in favor of each of these apparently conflicting theories has been presented (see Driver, 2001).

Lavie (1995) put forward a proposal that seems to resolve the dispute. She suggested that the locus of selection is dependent on the perceptual load (amount of potentially task-relevant information) of the task in question. When the perceptual load of a task is low, and does not exceed perceptual capacity, distractors are processed (late selection). However, when the perceptual load of a task is high, irrelevant distractors are not processed (early selection). It should be noted that perceptual load is not synonymous with task difficulty. For example, reducing target visibility may slow down performance, but it does not reduce distractor interference (Lavie & de Fockert, 2003).

Evidence for Lavie’s load theory has come from a number of behavioral studies in which participants detected a target in the presence of distractors or in which researchers measured priming effects in response to irrelevant distractors (for a review, see Lavie, 2005). Neuroimaging studies have demonstrated that neural activity related to irrelevant distractors is modulated by perceptual-load levels (Rees, Frith, & Lavie, 1997; Rees, Russell, Frith, ...
& Driver, 1999), and that visual cortex excitability to magnetic stimulation also appears to be affected by perceptual load (Muggleton, Lamb, Walsh, & Lavie, 2008). The perceptual-load effect has also been investigated within subsets of the population. Children and the elderly demonstrate early selection at lower set sizes than young adults, which suggests that children and the elderly have reduced perceptual capacity (Huang-Pollock, Carr, & Nigg, 2002; Maylor & Lavie, 1998). If this perceptual-load paradigm can be used to investigate selective attention and perceptual capacity, then it may have a valuable application within research into atypical populations, such as individuals with ASD, whose altered attentional abilities have often been highlighted (Burack, Enns, Stauder, Mottron, & Randolph, 1997).

**AUTISM AND ATTENTION**

The results of research concerning autism and attention have been diverse and contradictory. Dawson and Lewy (1989) suggested that a reduced ability to filter out irrelevant information could cause individuals with ASD to be bombarded with information, leading to overarousal. Indeed, Giesielski, Courchesne, and Elmasian (1990) showed that participants with autism had more difficulty filtering out distracting stimuli than a control group did. Giesielski et al. also showed that there was an altered pattern of event-related potentials (ERPs) in the autism group during selective attention tasks in both visual and auditory modalities. Selective attention ERPs that indicate interchannel- (Nd and N270) and intrachannel- (Nc and P3b) stimulus selection were observed in the control group. In contrast, the Nd, N270, and Nc ERPs were not seen in the autism group, and the P3b was significantly reduced. This pattern was seen even in individuals with autism whose task performance was as good as, or better than, the control participants’ performance, as measured by reaction time (RT) and accuracy data.

Similarly, Burack (1994) noted that there was an increased effect of distractors on the performance of participants with ASD compared with the performance of control participants, and concluded that individuals with ASD appeared to have an inefficient, overly broad attentional lens that failed to contract appropriately when attending to stimuli.

It is important to reexamine selective attention among individuals with ASD within the new frame of reference provided by the perceptual-load paradigm (Lavie, 1995). We designed the current study to address this need. We predicted that, compared with control participants, individuals with ASD would require a higher level of perceptual load to eliminate distractor processing. According to load theory, such a finding would indicate increased perceptual capacity in individuals with ASD.

**METHOD**

**Participants**

Participants in this study were 15 adults with ASD and 25 adults without ASD (control group). One individual with ASD and 2 control participants were removed from the sample because their error rates were more than 2.5 standard deviations above their group mean. All participants in the ASD group had received a clinical diagnosis of autism (n = 3) or Asperger’s syndrome (n = 11) from a trained, independent clinician who used the criteria listed in the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* (American Psychiatric Association, 1994). Diagnosis was then confirmed by assessment with Module 4 of the Autism Diagnostic Observational Schedule (Lord, Rutter, DiLavore, & Risi, 2002). None of the participants had any other mental or neurological disorder. Groups were matched for nonverbal IQ using a subscale from the Wechsler Abbreviated Scale for Intelligence (Wechsler, 1999; see Table 1).

**Stimuli and Procedure**

Stimuli were created using Microsoft Visual Basic (version 6), were run on a custom-built desktop computer, and were displayed on a ProLite 15-in. flat LCD screen (resolution of 1280 × 1024 pixels, 2-ms response rate). Viewing distance was 60 cm. The task was a response-competition paradigm based on a task developed by Eriksen and Eriksen (1974) and adapted by Maylor and Lavie (1998) in which participants were required to respond to a relevant target while ignoring irrelevant distractors.

Stimuli were presented in light gray against a black background. Following the presentation of a fixation cross in the center of the screen for 1,000 ms, a target letter (X or N) was presented in any of six positions that were located around the circumference of an imaginary circle with a radius of 2.1° of visual angle from the fixation point. The other positions in the ring were occupied by nontarget letters (Z, H, K, Y, or V) or by a combination of nontarget letters and small dots, so that all positions were filled. The number of letters and dots varied by condition. Target and nontarget elements measured 0.4° × 0.6°. A slightly larger distractor letter (0.5° × 0.9°) was presented on the right or left of the ring of letters, 4.3° from the center (see Fig. 1).

Participants were told that on each trial, they would see a ring made up of letters or of letters and dots in the center of the screen and that one letter would be either an X or an N. They were to

**TABLE 1**

*Descriptive Statistics for Each Group*

<table>
<thead>
<tr>
<th>Measure</th>
<th>ASD group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years:months)</td>
<td>23:6</td>
<td>4:4</td>
</tr>
<tr>
<td></td>
<td>18:10–30:0</td>
<td>26:7</td>
</tr>
<tr>
<td>WASI score: Vocabulary subtest</td>
<td>64:1</td>
<td>7:0</td>
</tr>
<tr>
<td></td>
<td>50–79</td>
<td>6:4</td>
</tr>
<tr>
<td>Matrix Reasoning</td>
<td>52:9</td>
<td>8:4</td>
</tr>
<tr>
<td></td>
<td>39–67</td>
<td>7:6</td>
</tr>
<tr>
<td>Full-scale IQ</td>
<td>115</td>
<td>12:3</td>
</tr>
<tr>
<td></td>
<td>97–136</td>
<td>11:1</td>
</tr>
</tbody>
</table>

Note. ASD = autism spectrum disorder; WASI = Wechsler Abbreviated Scale for Intelligence (Wechsler, 1999). The ASD group (n = 14) comprised 7 males and 7 females. The control group (n = 23) comprised 13 males and 10 females. Full-scale IQ comprises the Vocabulary and Matrix Reasoning subtests.
press the “X” key if an X was present and the “N” key if an N was present. It was emphasized that they should ignore the letters that were presented outside the ring. The accuracy and RT for each trial was recorded by the computer program.

The perceptual load of the task was manipulated by changing the number of nontarget letters in the ring to create trials with set sizes of 1 (only the target letter in the ring), 2 (target plus one nontarget), 4 (target plus three nontargets), and 6 (target plus five nontargets). The irrelevant distractors were either neutral (unrelated to the target letter, either T or L) or incompatible (an X distractor when the target was N, and vice versa). The experimental display was presented for only 100 ms in order to preclude voluntary eye movement.

Six blocks of 72 trials were created; within each block, each set size and distractor condition appeared equally often. Target and nontarget letters were equally likely to appear in each of the six ring positions, and the proximity of the target to the distractor letter was counterbalanced. For set sizes 2 and 4, the position of the group of letters and the position of the target within the group (edge vs. middle) was also counterbalanced.

RESULTS

Reaction Times

RTs above 3,000 ms were discarded. Median RTs for correct responses and error rates were calculated for each distractor condition at each set size (see Table 2). All trials with incorrect responses were excluded from further analyses. Median RTs were examined in an analysis of variance (ANOVA) with group (ASD or control) as a between-subjects factor, and distractor condition (neutral or incompatible) and set size (1, 2, 4, or 6) as within-subjects factors.

There was a significant main effect of set size, $F(3, 105) = 93.095, p < .001, \eta_p^2 = .747$, indicating that participants were slower to respond to trials with higher set sizes. There was also a main effect of distractor condition, $F(1, 35) = 18.092, p < .001, \eta_p^2 = .341$, reflecting the fact that RTs were faster for neutral trials than for incompatible trials. These two main effects suggest that perceptual load was effectively manipulated and that participants engaged in the task in the way that was intended.

There was no main effect of group, $F(1, 26) = 0.405, p = .539, \eta_p^2 = .095$; in other words, RTs were not significantly slower in one group than in the other. This indicates that any differences in RTs between the groups were not due to an overall reduction in processing speed in individuals with ASD.

The most important findings were a significant interaction between set size and distractor condition, $F(3, 105) = 4.285, p = .007, \eta_p^2 = .109$, and a significant three-way interaction of group, set size, and distractor condition, $F(3, 105) = 2.785, p = .044, \eta_p^2 = .074$. The two-way interaction implies that the effect of distractor condition varied with set size. The three-way interaction suggests that the two groups showed different patterns of distractor-condition effects across the set sizes. These patterns can be seen in Figure 2.

Using t tests to explore the interactions revealed that for the control group, there was a significant effect of distractor condition at set size 1, $t(22) = -3.470, p = .002$, and set size 2, $t(22) = -3.925, p = .001$, but no significant effect at set size 4, $t(22) = 1.191, p = .246$, or set size 6, $t(22) = -0.308, p = .761$ (Fig. 3a). For the ASD group, there was a significant effect of distractor condition at set size 1, $t(22) = -3.555, p = .005$; set size 2, $t(22) = -4.619, p < .001$; and set size 4, $t(22) = -2.751, p = .017$; there was no effect at set size 6, $t(22) = 0.499, p = .626$ (Fig. 3b). Thus, lingering interference by distractors was found at set size 4 in the ASD group, but the interference effect was eliminated at set size 4 in the control group. The lack of a

<table>
<thead>
<tr>
<th>Set size</th>
<th>Neutral distractors</th>
<th>Incompatible distractors</th>
<th>Neutral distractors</th>
<th>Incompatible distractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>561 (106)</td>
<td>582 (116)</td>
<td>538 (98)</td>
<td>563 (96)</td>
</tr>
<tr>
<td>2</td>
<td>608 (125)</td>
<td>642 (123)</td>
<td>584 (97)</td>
<td>611 (104)</td>
</tr>
<tr>
<td>4</td>
<td>651 (129)</td>
<td>679 (144)</td>
<td>651 (122)</td>
<td>636 (94)</td>
</tr>
<tr>
<td>6</td>
<td>733 (158)</td>
<td>726 (173)</td>
<td>701 (129)</td>
<td>704 (131)</td>
</tr>
</tbody>
</table>

Note. Reaction times are given in milliseconds. Standard deviations are given in parentheses. ASD = autism spectrum disorder.
significant effect of distractor condition at set size 4 in the control group appears to be the result of a reduction in RTs for trials with incompatible distractors (see Fig. 3a).

Accuracy Data
An ANOVA on the number of errors (see Table 3 for accuracy rates) revealed main effects of set size, $F(3, 105) = 151.824$, $p < .001, \eta^2_p = .813$, and distractor condition, $F(1, 35) = 8.287$, $p = .007, \eta^2_p = .191$; more errors were made on trials with higher set sizes, and more errors were made on trials within compatible, rather than neutral, distractors. Overall, there was no significant difference between the number of errors made by the two groups, $F(1, 35) = 0.478, p = .494, \eta^2_p = .013$. There were no significant interactions among distractor condition, set size, and group.

DISCUSSION
As predicted, individuals with ASD seemed to process distractors at higher levels of perceptual load than the control adults did. Given that there was no significant difference between the two groups in their RTs and error rates, it is not the case that the findings are a result of a general selective attention deficit in ASD. A general selective attention deficit would prevent individuals from effectively assigning their attention to the

TABLE 3
Accuracy for Each Set Size and Distractor Condition

<table>
<thead>
<tr>
<th>Set size</th>
<th>ASD group Neutral distractors</th>
<th>ASD group Incompatible distractors</th>
<th>Control group Neutral distractors</th>
<th>Control group Incompatible distractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.944 (.048)</td>
<td>.889 (.091)</td>
<td>.944 (.048)</td>
<td>.977 (.098)</td>
</tr>
<tr>
<td>2</td>
<td>.852 (.087)</td>
<td>.907 (.104)</td>
<td>.944 (.059)</td>
<td>.870 (.120)</td>
</tr>
<tr>
<td>4</td>
<td>.815 (.073)</td>
<td>.815 (.104)</td>
<td>.852 (.062)</td>
<td>.778 (.120)</td>
</tr>
<tr>
<td>6</td>
<td>.665 (.057)</td>
<td>.694 (.103)</td>
<td>.741 (.091)</td>
<td>.704 (.127)</td>
</tr>
</tbody>
</table>

Note. Accuracy was calculated as the proportion of trials with correct responses. Standard deviations are given in parentheses. ASD = autism spectrum disorder.
central task, regardless of perceptual load, and would be reflected in an overall drop in accuracy or speed.

The results presented here seem to suggest that the control and ASD groups had different perceptual capacities. According to Lavie (1995), if the central task does not exhaust perceptual capacity, then additional information within the visual field is also processed. If individuals with ASD have a larger perceptual capacity than individuals without ASD, this would result in the former engaging in more distractor processing at high levels of perceptual load, but without a reduction in task performance. This increased distractibility could be conceptualized as a reflection of an increased ability, rather than a deficit, even though distractibility has potentially detrimental effects in real-life situations.

The performance of the control group in this study differed slightly from the performance of control groups in previous studies. Maylor and Lavie (1998), Huang-Pollock et al. (2002), and Lavie and de Fockert (2003) reported that adults without ASD exhibited a reduction in interference effects between set sizes 4 and 6. The control group in the current study showed an earlier reduction in interference (between set sizes 2 and 4). The reason for this difference in performance is unclear given that similar procedures were used, and that participants in the various studies had similar ages and IQs. There may have been some differences in stimulus presentation (e.g., exact values for screen contrast, room lighting levels, and the exact color of the stimuli and background were not reported in previous studies), although it is unclear whether these factors could influence the perceptual-load effect (Lavie & de Fockert, 2003). It is important to note, however, that all participants in this study (both ASD and control individuals) performed the tasks under the same experimental conditions, and therefore the difference between the two groups is meaningful despite the shift in the absolute values seen in the control group.

These findings regarding increased perceptual capacity may also explain the superior visual search abilities that have consistently been found among individuals with ASD (O’Riordan & Plaisted, 2001; O’Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O’Riordan, & Baron-Cohen, 1998). In both feature- and conjunctive-search tasks, participants with ASD are more efficient than participants without ASD at detecting the location of a target within an array of nontarget elements. Increased perceptual capacity would allow more elements to be processed in a parallel fashion and would facilitate faster target location, and therefore may underlie these findings. In our study, inspection of the visual search slopes in the neutral distractor condition (the increase in RT resulting from the addition of extra elements to the central search task) indicated that the individuals with ASD were no more efficient at searching for the target (36.5 ms per item) than the control individuals (34.8 ms per item; see Fig. 3).

Last, we should emphasize that this study was performed with an adult population. It is currently not known whether the same pattern of increased distractor processing is seen in children with ASD or whether this develops later in life as a result of experience of a detail-focused cognitive style (Happe & Frith, 2006).

Acknowledgments—This research was supported by a departmental studentship awarded to Anna Remington. We thank Nilli Lavie for her invaluable comments, and we gratefully acknowledge the support of all the people who took part in the study.

REFERENCES


(Received 11/25/08; Revision accepted 3/8/09)