Journal of Abnormal Psychology
2012, Vol. 121, No. 2, 544–551

0021-843X/12/$12.00 DOI: 10.1037/a0027670

Lightening the Load: Perceptual Load Impairs Visual Detection in Typical Adults but Not in Autism

Anna M. Remington, John G. Swettenham, and Nilli Lavie
University College London

Autism spectrum disorder (ASD) research portrays a mixed picture of attentional abilities with demonstrations of enhancements (e.g., superior visual search) and deficits (e.g., higher distractibility). Here we test a potential resolution derived from the Load Theory of Attention (e.g., Lavie, 2005). In Load Theory, distractor processing depends on the perceptual load of the task and as such can only be eliminated under high load that engages full capacity. We hypothesize that ASD involves enhanced perceptual capacity, leading to the superior performance and increased distractor processing previously reported. Using a signal-detection paradigm, we test this directly and demonstrate that, under higher levels of load, perceptual sensitivity was reduced in typical adults but not in adults with ASD. These findings confirm our hypothesis and offer a promising solution to the previous discrepancies by suggesting that increased distractor processing in ASD results not from a filtering deficit but from enhanced perceptual capacity.

Keywords: autism, attention, perceptual load

The attentional and perceptual abnormalities seen in autism spectrum disorder (ASD) are well documented anecdotally and clinically (Ames & Fletcher-Watson, 2010; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006; Sanders, Johnson, Garavan, Gill, & Gallagher, 2008). As one of the earliest identifiable features of the condition (Elsabbagh et al., 2009; Merin, Young, Ozonoff, & Rogers, 2007; Zwaigenbaum et al., 2005), attention has become the focus of a growing body of research that highlights the numerous changes to such cognitive processes.

However, results in this area of research are diverse and often conflicting. Although some studies report an impairment in selective attention and demonstrate increased levels of distractibility (Burack, 1994; Christ, Holt, White, & Green, 2007; Ciesielski, Courchesne, & Elmasian, 1990), other studies point to an enhanced ability. Individuals with ASD are faster and more accurate than typical individuals at locating a figure hidden within a line drawing in studies using the Embedded Figures Task (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983), at segmenting and reproducing patterns in block design tasks (Shah & Frith, 1993), and at finding target stimuli presented among multiple other items in tasks of visual search (O'Riordan, 2004; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998). Thus, although some research suggests superior visual attention abilities, other studies suggest impairments that often lead to greater processing of irrelevant and potentially distracting information in ASD.

This discrepancy can be resolved by the Load Theory of Attention and Cognitive Control (Lavie, 2005). According to this theory, the extent to which irrelevant distractors are perceived depends on whether the task performed exhausts perceptual capacity or leaves some spare capacity that "spills over," resulting in irrelevant distractor processing. The extent to which a task is likely to fill perceptual capacity (and thus only task-relevant information is processed) or leaves spare capacity (and one becomes prone to distractor processing) depends on the level of load in the task. Tasks with high perceptual load will engage full capacity, thus resulting in no additional processing of irrelevant distractors. In contrast, tasks involving only low perceptual load will result in distractor processing because of the spillover of the remaining processing capacity.

What are the implications of applying this framework to ASD? The previous indications that individuals with ASD manifest superior performance on certain visual attention tasks suggest that ASD may involve enhancement of some perceptual capacities. This suggestion, when taken within the framework of Load Theory, leads to an important novel hypothesis that may explain the apparently discrepant findings of increased vulnerability to irrelevant distraction. If ASD involves enhancement of perceptual capacity, then, according to the Load Theory, tasks that use those perceptual capacities are less loading for such individuals and therefore more likely to result in remaining capacity that spills over to distractor processing in the ASD individuals compared with typical adults. Specifically, in visual attention tasks such as those described above, distractor processing is expected to be found under higher levels of load in the ASD group. This hypothesis received preliminary support in a recent study that assessed irrelevant distractor effects using a visual search task modified to include an irrelevant distractor presented in the periphery. The participants were required to search for one of two target letters (either

This article was published Online First March 19, 2012.

Anna M. Remington and Nilli Lavie, Institute of Cognitive Neuroscience, University College London; John G. Swettenham, Developmental Science, University College London.

Preparation of this article was supported by a Wellcome Trust Grant WT080568MA (N.L.), a Developmental Science, UCL Scholarship (A.M.R.), and an Economic and Social Research Council (United Kingdom) Postdoctoral Fellowship (A.M.R.).

Correspondence concerning this article should be addressed to Anna Remington, Institute of Cognitive Neuroscience, University College London, 17 Queens Square, London, WC1N 3AR. E-mail: A.remington@ucl.ac.uk

X or N) while attempting to ignore an irrelevant distractor that was either incongruent (the opposite target letter) or neutral (unrelated to both targets, e.g., the letter L). Longer reaction time (RT) in the incongruent (vs. neutral) condition indicated a failure to ignore the distractor. The level of perceptual load in the search task was varied by increasing the number of items in the central search array, and the results demonstrated that ASD adults required higher levels of perceptual load than the age and nonverbal IQ-matched typical group before the interference effect of irrelevant distractors was eliminated (Remington, Swettenham, Campbell, & Coleman, 2009).

These findings provide preliminary support for our hypothesis that ASD involves increased distractor perception because the higher perceptual capacity is not filled even at levels sufficient to exhaust the typical adult capacity. However, the measure of distractor perception via the interference effect of response congruency on RT is only indirect. Longer RT in the presence of response-incongruent distractors may not necessarily indicate their perception, but instead may reflect post-perceptual processes such as interference with response selection. Given that a critical tenet of our hypothesis is that ASD involves enhanced perceptual capacity rather than a deficit in preventing response interference by distractors, it is important to directly test our prediction by using a measure of perception that neither relies on RT nor compounds any component of distraction.

To that end, in the present study we assessed the effect of perceptual load on visual attention in ASD using a signal detection paradigm that assessed perceptual sensitivity and any potential effects on the response criterion. Our enhanced perceptual capacity hypothesis leads us to predict that individuals with ASD will show greater resilience to the effects of perceptual load on visual detection.

Method

Participants

Participants in this study were 16 adults with ASD and 16 typical adults. Adults with ASD were recruited via advertisements on the National Autistic Society website and by contacting people in online ASD communities and on social networking websites.

Typical participants were recruited from undergraduate and postgraduate courses at University College London and through social networking websites. All participants in the ASD group had received a clinical diagnosis of autism ($n = 3$) or Asperger syndrome ($n = 13$) 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. Two participants with ASD and two typical participants were excluded from the sample because of error rates that were greater than 2.5 *SD* above their group mean. The resulting 14 in each group remained matched for chronological age and nonverbal IQ using the matrix reasoning subscale from the Wechsler Abbreviated Scale for Intelligence (WASI) (see Table 1). Independent sample *t* tests indicated that the groups did not differ on any of these measures (all p values >0.30).

Apparatus and Stimuli

Microsoft Visual Basic (version 6) was used to create computer-based stimuli that were presented on a custom-built small-form desktop computer and displayed on a ProLite 15-in. flat LCD screen (1280 × 1024 pixel resolution, 2-ms response rate). Viewing distance was 60 cm.

The task involved a dual-task paradigm that was based on that of Macdonald and Lavie (2008) that required participants to identify a target letter (X or N) and then indicate the presence or absence of a meaningless small gray character (the Critical Stimulus [CS]) that was presented outside of the ring. Participants were presented with six letters that were placed, equally spaced, around the circumference of an imaginary ring with a radius of 1.7° visual angles. In each trial, one of the letters was the target letter (X or N) and, depending on the condition, the other ring positions were occupied by a nontarget letter that was perceptually similar to the target (Z, H, K, Y, or V) or a small letter *O* (easy to distinguish from the target-letter). Target and similar nontarget elements measured 0.6° × 0.6° visual angles. The dissimilar nontarget element (*O*) measured 0.2° × 0.2°.

The perceptual load of the task was manipulated by changing the number of similar nontarget letters and *O*s in the ring to create trials with set size 1 (the target letter and five *O*s in the ring), 2 (target, one similar nontarget and four *O*s in the ring), 4 (target, three similar nontarget elements and two *O*s), and 6 (target and five similar nontarget letters).

In 50% of the trials, the CS, a meaningless gray squiggle, measuring 0.3° × 0.3° visual angles was presented, outside of the ring of letters, in one of six positions that were arranged on the circumference of an imaginary ring with radius 5.4°. The six CS positions were such that each one lay on an imaginary line that passed through the center of the ring and bisected two adjacent letter locations. The location of the target, its proximity to the CS, and, in set size 4, the target letter's location within the group of similar nontarget elements (edge/middle) were counterbalanced across all of the trials.

Table 1
Descriptive Statistics for Each Group

	ASD (11 males, 3 females)			Typical (6 males, 8 females)		
	Mean	*SD*	Range	Mean	*SD*	Range
Age (years: months)	24:1	4:5	18:09–30:11	25:9	3:0	19:8–30:1
WASI vocabulary subtest	65.2	6.7	54–76	66.9	3.8	60–71
WASI matrix reasoning	55.9	9.6	39–67	56.0	8.4	41–65
WASI full-scale IQ (two subtests)	119	13.4	97–138	121	8.0	109–131

The letters in the ring were presented in black on a light gray background (red green blue [RGB] values: 204,204,204) and the CS was a darker gray (RGB: 153,153,153). After the presentation of the experimental stimulus, a black mesh pattern that covered the entire screen other than the central 9.5°- by 9.5°-square, was presented as a mask. The clear square in the center was to ensure that the ring of letters was not masked.

Seventy-two trials of each set size were created. These were presented as four blocks of each set size in which each block contained 18 trials of the same set size. Participants were permitted to take short breaks between each block. Blocks were presented such that all 72 trials of any one set size were performed before moving on to four blocks of a different set size. The first four blocks presented to each participant contained trials of set size 2, and the presentation order of the other set sizes was randomly determined by the computer program.

A control block of 72 trials was also created in which participants were told not to search for the target letter but only to indicate the presence or absence of the CS. Eighteen trials of each set size, 50% containing the CS, were used to create the control block.

Procedure

After a fixation cross that was presented for 1000 ms, the experimental display was presented for only 100 ms to preclude voluntary eye movement. The mask was then presented for 500 ms, followed by a blank screen for 1.4 s, a question mark for 100 ms, and a final blank screen for 1.9 s. The duration of the two blank screen phases was such that there was a 2-s response window for the letter identification and the CS detection tasks. Both of these 2-s windows elapsed regardless of the response time. If no response was given within the time limit, the trial was recorded as "time out" and classed as an error (see Figure 1). The entire experiment took approximately 20 min to complete.

Participants were told that they would see a ring made up of letters in the center of the screen and that one of those letters would be either an X or an N. They were told to press the Z key if an X was present and the X key if an N was present—and to respond as quickly as they could after they saw the ring of letters. Participants were also told that they should look for a little gray squiggle that would appear outside of the ring in some of the trials. They were instructed to wait until they saw the question mark and then indicate with a key-press (N for present, M for absent) whether the CS was present or absent in that trial. Stickers were placed over the Z, X, N, and M keys to clarify which key corresponded to which response. All participants were right-handed and used their right hand to press the N/M buttons and their left hand for the Z/X buttons.

After a set of practice trials, the participants completed the 16 experimental blocks and were able to take breaks between blocks if required. No difference was noted in the number or duration of breaks taken by each group. An incorrect response on the letter detection task elicited a brief computer tone, and participants were informed that this indicated that an error had been made. The accuracy and response times for each trial were recorded by the computer program and subsequent comparison of CS detection rates at the various levels' set sizes allow for the effect of perceptual load on dual-task performance to be ascertained. After completing the experimental trials, participants performed the control block to ensure that all of the participants were able to detect the CS. This was vital to confirm that any failures to detect the CS during the experimental trials were due to the perceptual load of the central letter search task and not an underlying inability to recognize or perceive the squiggle.

Results

Letter Search Task

The search results are shown in Table 2. Mixed-model analysis of variance (ANOVAs) were performed on the median correct RTs and on the percentage errors with group (ASD vs. typical) as the between-subject factor and set size (1, 2, 4, and 6) as the within-subject factor.

The RT ANOVA revealed a main effect of set size; RT was longer in higher set sizes, $F(3, 78) = 13.899$, $p < .001$, $\eta_p^2 = 1.00$, indicating that our manipulation of set size was effective in increasing the search load. There was no main effect of group, $F(1, 26) < 1$, $p = .933$, $\eta_p^2 = 0.051$, and no significant interaction

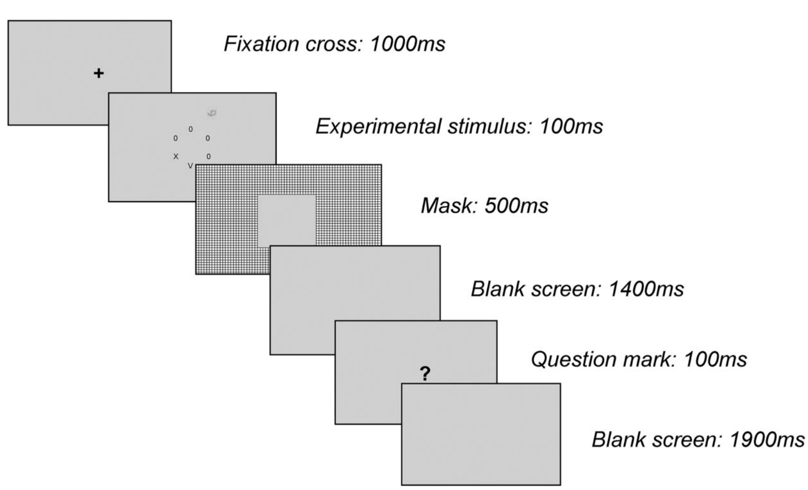

Figure 1. Example of an experimental trial with low perceptual load (set size 2) and critical stimulus present.

between set size and group, $F(3, 78) = 1.352$, $p = .264$, $\eta_p^2 = 0.347$. Thus, ASD was not associated with any generalized change in the processing speed or altered search task performance.

The error-rate ANOVA revealed a main effect of set size, $F(3, 78) = 60.877$, $p < .001$, $\eta_p^2 = 1.00$, a reflection of the increasing number of errors as perceptual load of the central task was increased. There was no main effect of group and no significant interaction between group and set size (F values <1). Neither group made significantly more errors or showed a different pattern of errors across the set sizes.

Detection Task

Trials with incorrect letter-search responses were excluded from the detection analyses. The percentage detection rates and detection sensitivity (d', which takes into account the detection hits and false alarms to give a true measure of detection sensitivity) for each participant at each set size were calculated and entered into mixed-model ANOVAs with set size as the within-subject factor and group as the between-subject factor.

Percentage Detection

The ANOVA of the percentage detection rates revealed no main effect of group, $F(1, 26) = 1.030$, $p = .319$, $\eta_p^2 = 0.165$. There was a main effect of set size, $F(3, 78) = 3.916$, $p = .012$, $\eta_p^2 = 0.811$, reflecting lower rates of detection with increased search set size. However, this effect was qualified by an interaction between group and set size, $F(3, 78) = 5.095$, $p = .003$, $\eta_p^2 = 0.908$. The pattern of interaction was as we predicted: Whereas the typical group showed a reduction in detection rate as set size was increased, $F(3, 39) = 6.413$, $p = .001$, $\eta_p^2 = 0.952$, the ASD group showed no effect of the search set size on detection rates ($F < 1$; see Figure 2A). Post hoc t tests indicated that there was a difference between the groups at the highest load condition ($p = .037$) but not at the other set sizes (all p values >0.19).

Detection Sensitivity

The ANOVA conducted on the d' measure of detection sensitivity revealed the same pattern (Figure 1b). There was no main effect of group ($F < 1$), but there was a significant main effect of set size, $F(3, 78) = 9.246$, $p < .001$, $\eta_p^2 = 0.995$, indicating that sensitivity was lower at the higher set sizes. Again, this was qualified by a significant interaction between group and set size, $F(3, 78) = 5.169$, $p = .003$, $\eta_p^2 = 0.912$. As shown in Figure 2b, the pattern of this interaction indicated that as with detection rates, whereas there was a significant drop in sensitivity as set size was increased in the typical adult group, $F(3, 39) = 10.796$, $p < .001$, $\eta_p^2 = 0.998$, there was no effect of set size on sensitivity in the ASD group, $F(3, 39) = 0.861$, $p = .470$, $\eta_p^2 = 0.220$. In addition, planned comparisons indicated that although there was no difference between the groups at the low load conditions (set size 1 and 2, p values >0.4), there was a significant difference in the d' of the two groups at set size 6, $t(26) = 2.141$ $p = .042$, and the difference at set size 4 was approaching significance, $t(26) = 1.983$ $p = .058$. As displayed in Figure 2b, with higher set sizes the ASD group showed improved detection sensitivity compared with the typical group. A further mixed-model ANOVA (load × group) on the β measure of response bias revealed no effects of set size (mean β: set size 1 = 2.1, set size 2 = 1.6, set size 4 = 1.7, set size 6 = 1.6), group (mean β: ASD = 1.9, typical group = 1.7), or their interaction (all F values <1).[1]

Table 2A
Mean RT and Error Rates, for the Letter-Search Task for Each Group at Each Set Size

Group		Set size 1	2	4	6
ASD	RT (ms)	794 (37)	845 (60)	928 (55)	990 (65)
	Percentage error	3.6	5.7	16.5	22.3
Typical	RT (ms)	864 (55)	823 (47)	935 (62)	966 (60)
	Percentage error	1.9	5.6	16.6	20.6

Note. *SE* in parentheses.

Table 2B
ANOVA Results for the Letter-Search Task for Each Group at Each Set Size

Source	ANOVA *df*	*F*	η_p^2	*p*
RT: group (G)	1,26	0.01	0.05	0.93
RT: set size (S)	3,78	13.89**	1.00	<0.01
RT: G × S	3,72	1.35	0.35	0.26
Error rate: group (G)	1,26	0.14	0.07	0.71
Error rate: set size (S)	3,78	60.89**	1.00	<0.01
Error rate: G × S	3,72	0.18	0.08	0.91

** $p < .01$.

Control Block

All of the participants achieved a correct response rate of over 84% on the control block, and there were no significant effects of set size on the detection rates and no group differences (all $F < 1.36$, all p values >0.2). This confirms that any differences seen in the pattern of detection under various levels of perceptual load are not due to an underlying inability to recognize or respond to the detection stimulus.

Discussion

The present findings demonstrate that ASD is associated with enhanced perceptual capacity in a visual detection task. In

[1] Because there were more males in the ASD group (11 of 14) compared with the control group (6 of 14), we reanalyzed the data with gender as a covariate. This did not change the pattern and significance of the results (all previously significant p values remained <0.015) except that the main effect of set size was no longer significant for percentage detection and detection sensitivity (both p values >0.05). Given the size of the sample, the loss of significance of this main effect may simply reflect the reduction in power once the groups were further split. Crucially, the critical results upon which our conclusions are based (i.e., the interaction between group and set size) remained significant for percentage detection, $F(3,78) = 3.983$, $p = 0.01$, and for detection sensitivity, $F(3,78) = 4.120$, $p = 0.009$.

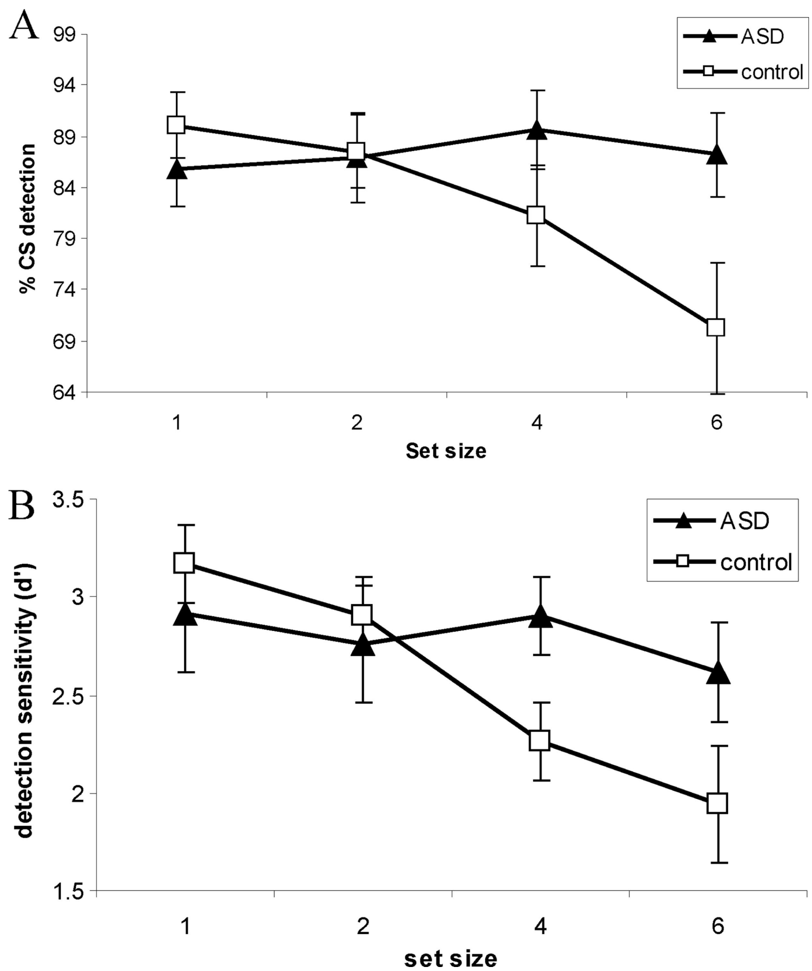

Figure 2. Percentage detection rates (A) and detection sensitivity (*d'*) (B) of each group at each level of perceptual load.

contrast to the significant reduction in visual detection performance as a function of increased perceptual load seen for the typical adult group, the participants with ASD showed no decrement associated with high load. Indeed, the high level of detection that the participants with ASD maintained even under higher levels of load clearly suggests a perceptual advantage. Furthermore, the signal detection analysis confirms that this advantage reflects superior perceptual sensitivity rather than a change in response criterion. It is important to note that this increased detection ability in ASD was not accompanied by any deterioration in the search task performance. Thus, these findings provide strong support for our claim that individuals with ASD show greater perceptual capacity than typical adults. Moreover, the ASD and typical adult group were matched on matrix-reasoning performance. This risks masking perceptual peaks because it means that the ASD-related advantage in the type of visual task used in our paradigm may already be taken into account (Dawson, Soulieres, Gernsbacher, & Mottron, 2007). That our group effect remains confirms the robustness of the findings.

Relation to Previous Research

The present conclusion regarding enhanced capacity may allow us to resolve previous discrepancies in autism research where there are reports of reduced resistance to distraction and superior performance on selective attention tasks such as visual search, embedded figures, and the like. A central tenet of Load Theory states that allocation of full perceptual capacity at any given time is mandatory; consequently, one cannot voluntarily withhold from processing stimuli in the visual field until the limits of capacity are reached. Enhanced perceptual capacity in ASD would therefore result in the indiscriminate processing of more information than for typical individuals. Although some of the information would be irrelevant and result in increased distractor processing (Burack, 1994; Remington et al., 2009), some would be relevant and therefore lead to a superior task performance (O'Riordan, 2004; O'Riordan & Plaisted, 2001; Plaisted et al., 1998; Shah & Frith, 1983, 1993). Thus, the seemingly contradictory reports of deficits and advantages may be reconciled by our proposed application of load framework to ASD.

With specific reference to the reports of superior performance in ASD, our account may allow for the drawing together of much of the previous data. The most intensively used paradigm in this area to date has been visual search, and the numerous studies with this paradigm point to an advantage that is primarily seen when the tasks place higher demands on perceptual capacity. This advantage is seen on conjunctive- versus feature-search tasks (O'Riordan, 2004; Plaisted et al., 1998), on more difficult feature-search versus easier feature-search tasks (Kemner, van Ewijk, van Engeland, & Hooge, 2008; O'Riordan, 2004 O'Riordan & Plaisted, 2001), on conjunctive tasks with higher target-distractor similarity versus those with greater distinction between target and distractors (O'Riordan & Plaisted, 2001), on tasks with heterogeneous distractors versus homogeneous distractors (Keehn, Brenner, Palmer, Lincoln, & Muller, 2008), and on dynamic- versus static-search tasks (Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009). In all of these comparison pairs, the latter of the two involves processing more information, and it is here that the superior behavior in ASD is evident. Furthermore, in all of these cases the advantage is most pronounced with many items in the display and for the target-absent trials, which require the scanning of more items compared with their target-present counterparts (on exhaustive search models this would correspond to twice the number). Given that larger search arrays are known to involve higher levels of perceptual load (e.g., Lavie, 1995; Lavie & Cox, 1997), our analysis of this literature suggests that individuals with ASD can accommodate a higher level of perceptual load. Indeed, that the advantage is seen in this variety of conditions rules out task-specific explanations and points again to an overall enhancement of perceptual capacity.

In our study, superior ASD performance was seen on the detection task whereas the visual search performance was equivalent between the ASD and typical individuals. This may be due to our overall task being more sensitive to reveal differences in detection performance rather than in the search performance component. For example, it is possible that our search task involved too few items to reveal an advantage (e.g., in our task the largest set size contained six items whereas in the previous visual search tasks we describe above that the higher set sizes involved over 15 items and typically extended to 25 items). Moreover, in our search task the target was always present (participants were required to discriminate one target from another) and so on average only half of the search items displayed had to be scanned.

However, the additional differences between our search task and those in which an advantage was found (e.g., the shorter presentation time in our study [100 ms] compared with the durations used in previous studies [ranging from 7 s to unlimited response time]) preclude a definitive conclusion. An interesting direction for future research into visual search abilities and ASD would be to address the critical conditions required to elicit superior performance. It is important to note that given that with equal visual search performance the ASD group showed an advantage in detection, the lack of visual search superiority does not detract from our conclusions regarding increased perceptual capacity in ASD.

The Nature of Increased Perceptual Capacity in ASD

Our account of increased capacity in ASD is consistent with previous suggestions that ASD involves enhanced low-level perceptual functioning (Mottron et al., 2006; Mottron & Burack, 2001), including lower thresholds for first-order luminance detection (Bertone, Mottron, Jelenic, & Faubert, 2005), better contour and texture processing (Pei et al., 2009), and superior spatial frequency processing (Jemel, Mimeault, Saint-Amour, Hosein, & Mottron, 2010; Milne, Griffiths, Buckley, & Scope, 2009; see Mottron et al., 2006 for a comprehensive review). In addition to accounting for performance on selective attention tasks (see also Remington et al., 2009), our hypothesis of increased perceptual capacity in ASD can also accommodate these perceptual advantages. We are therefore proposing an overarching account that may go some way to explain the various superiorities that are seen in ASD rather than focusing on a specific visual operation.

To further elucidate our hypothesis, it is important to consider the potential underlying neural mechanisms. Insights can be gained from the research concerning the neural basis of processing load in the typical population. It is presently known that in typical adults increases in the level of perceptual load of a task are associated with greater parietal cortex activity (e.g., Wojciulik & Kanwisher, 1999), a signal that is shown to track the number of objects attended to, thereby offering a marker of individual capacity (e.g., Jovicich et al., 2001; Mitchell & Cusack, 2008). This increase in parietal activity is also accompanied by reduced visual cortex response to task-irrelevant stimuli (Bahrami, Lavie, & Rees, 2007; Pinsk, Doniger, & Kastner, 2004; Schwartz et al., 2005; Yi, Woodman, Widders, Marois, & Chun, 2004) and reduced baseline level of visual cortex excitability in task-unrelated areas (Muggleton, Lamb, Walsh, & Lavie, 2008; Carmel, Thorne, Rees, & Lavie, 2011). These findings suggest that perceptual capacity is mediated by the availability of neural resources in a network of parietal and visual cortical areas.

What Are the Implications for Our Proposal of Increased Perceptual Capacity in ASD?

This putative neural mechanism in the typical population leads us to anticipate that ASD may involve greater availability of parietal and visual cortex resources, at least under some circumstances. Indeed, anatomical observations of increased gray matter volume in the parietal cortex of individuals with ASD (e.g., Ashtari et al., 2007; Brieber et al., 2007) and suggestions of overconnectivity in visuosensory areas (e.g., Bertone et al., 2005; Kéita, Mottron, & Bertone, 2010) may be plausible underlying substrates.

Functional findings of stronger activation of visual cortical areas in response to various perceptual tasks in ASD such as embedded figures (Manjaly et al., 2007; Ring et al., 1999), block design (Hubl et al., 2003), matrix reasoning (Soulieres et al., 2009), and visual search (Keehn et al., 2008) are in support of our hypothesis, and crucially these tasks are those for which behavioral superiorities are typically seen in the condition. Indeed, the superior performance on tasks of visual search has been seen to correlate with the increased level of occipital activation (Keehn et al., 2008).

Although potentially promising, our proposed mechanisms remain speculative until further testing. Empirical research linking the functional and structural changes in ASD with the effects of perceptual load on task performance would prove highly valuable in this respect.

The superior perceptual capacity we propose may, perhaps somewhat paradoxically, also relate to autistic symptomatology.

Enhanced capacity may lead to one of the core behavioral features of autism: preoccupation with object parts and scrutiny of fine object details (American Psychiatric Association, 1994), which in high-functioning adults may turn into high levels of visual expertise (e.g., artistic savants). On the other hand, it may be the case that such core behaviors will increase the tendency to scrutinize detail and therefore eventually, through "training," lead to better performance on tasks that involve this type of process. Subsequent research is warranted to distinguish between these alternative explanations.

Finally, the results should be considered with respect to the nature of the participant groups used here. The clinical group in this study was composed predominantly of those with Asperger syndrome ($n = 11$) rather than autism ($n = 3$), yet it has been suggested that perceptual abnormalities may be restricted to those with a strict diagnosis of autism. However, evidence for this claim appears to be mainly routed in studies of auditory perception (Bonnel et al., 2010), whereas in the visual domain there are many reports of visuospatial peaks in groups composed of those with Asperger syndrome and autism (e.g., Caron, Mottron, Rainville, & Chouinard, 2004; Jolliffe & Baron-Cohen, 1997; Joseph et al., 2009; Kemner et al., 2008; Smith & Milne, 2009). A close inspection of our data did not indicate any differences between those with Asperger syndrome and autism. However, to fully establish any relationship between diagnosis and visual superiority, one would clearly need to assess a much larger sample of individuals.

In addition, because the study presented here and the previous study of perceptual load effects on ASD performance (Remington et al., 2009) were performed with intellectually able young adults (IQ > 90), the findings may have limited generalizability with respect to other autistic subgroups. Because the autistic spectrum contains children and adults with a wide range of intellectual abilities and comorbid impairments, an important challenge for future research would be to clarify whether evidence of increased perceptual capacity is seen across the spectrum of IQ and symptom severity. The exploitation of such an enhancement may have beneficial implications for individuals with this condition, allowing them to capitalize on these abilities in the many situations in which increased visual detection is desirable.

References

American Psychiatric Association (1994). *DSM–IV Diagnostic and statistical manual of mental disorders* (4th ed.) Washington DC: American Psychiatric Association.

Ames, C., & Fletcher-Watson, S. (2010). A review of methods in the study of attention in autism. *Developmental Review, 30,* 52–73. doi:10.1016/j.dr.2009.12.003

Ashtari, M., Nichols, S., McIlree, C., Spritzer, L., Adesman, A., & Ardekani, B. (2007). Novel imaging technique shows gray matter increase in brains of autistic children. Paper presented at the annual meeting of the Radiological Society of North America, Chicago, IL.

Bahrami, B., Lavie, N., & Rees, G. (2007). Attentional load modulates responses of human primary visual cortex to invisible stimuli. *Current Biology, 17,* 509–513. doi:10.1016/j.cub.2007.01.070

Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2005). Enhanced and diminished visuo-spatial information processing in autism depends on stimulus complexity. *Brain: A Journal of Neurology, 128,* 2430–2441. doi:10.1093/brain/awh561

Bonnel, A., McAdams, S., Smith, B., Berthiaume, C., Bertone, A., Ciocca, V., . . . Mottron, L. (2010). Enhanced pure-tone pitch discrimination among persons with autism but not Asperger syndrome. *Neuropsychologia, 48,* 2465–2475. doi:10.1016/j.neuropsychologia.2010.04.020

Brieber, S., Neufang, S., Bruning, N., Kamp-Becker, I., Remschmidt, H., Herpertz-Dahlmann, B., . . . Konrad, K. (2007). Structural brain abnormalities in adolescents with autism spectrum disorder and patients with attention deficit/hyperactivity disorder. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 48,* 1251–1258. doi:10.1111/j.1469-7610.2007.01799.x

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

Carmel, D., Thorne, J. D., Rees, G., & Lavie, N. (2011). Perceptual load alters visual excitability. *Journal of Experimental Psychology: Human Perception and Performance, 37,* 1350–1360. doi:10.1037/a0024320

Caron, M. J., Mottron, L., Rainville, C., & Chouinard, S. (2004). Do high functioning persons with autism present superior spatial abilities? *Neuropsychologia, 42,* 467–481. doi:10.1016/j.neuropsychologia.2003.08.015

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

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

Dawson, M., Soulieres, I., Gernsbacher, M. A., & Mottron, L. (2007). The level and nature of autistic intelligence. *Psychological Science, 18,* 657–662. doi:10.1111/j.1467-9280.2007.01954.x

Elsabbagh, M., Volein, A., Csibra, G., Holmboe, K., Garwood, H., Tucker, L., . . . Johnson, M. H. (2009). Neural correlates of eye gaze processing in the infant broader autism phenotype. *Biological Psychiatry, 65,* 31–38. doi:10.1016/j.biopsych.2008.09.034

Hubl, D., Bölte, S., Feineis-Matthews, S., Lanfermann, H., Federspiel, A., Strik, W., . . . Dierks, T. (2003). Functional imbalance of visual pathways indicates alternative face processing strategies in autism. *Neurology, 61,* 1232–1237.

Jemel, B., Mimeault, D., Saint-Amour, D., Hosein, A., & Mottron, L. (2010). VEP contrast sensitivity responses reveal reduced functional segregation of mid and high filters of visual channels in autism. *Journal of Vision, 10.* doi:10.1167/10.6.13

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 and Allied Disciplines, 38,* 527–534. doi:10.1111/j.1469-7610.1997.tb01539.x

Joseph, R., Keehn, B., Connolly, C., Wolfe, J., & Horowitz, T. (2009). Why is visual search superior in autism spectrum disorder? *Developmental Science,12,* 1083–1096.

Jovicich, J., Peters, R. J., Koch, C., Braun, J., Chang, L., & Ernst, T. (2001). Brain areas specific for attentional load in a motion-tracking task. *Journal of Cognitive Neuroscience, 13,* 1048–1058. doi:10.1162/089892901753294347

Keehn, B., Brenner, L., Palmer, E., Lincoln, A. J., & Muller, R. A. (2008). Functional brain organization for visual search in ASD. *Journal of the International Neuropsychological Society, 14,* 990–1003. doi:10.1017/S1355617708081356

Kéita, L., Mottron, L., & Bertone, A. (2010). Far visual acuity is unremarkable in autism: Do we need to focus on crowding? *Autism Research, 3,* 333–341. doi:10.1002/aur.164

Kemner, C., van Ewijk, L., van Engeland, H., & Hooge, I. (2008). Brief report: Eye movements during visual search tasks indicate enhanced stimulus discriminability in subjects with PDD. *Journal of Autism and Developmental Disorders, 38,* 553–557. doi:10.1007/s10803-007-0406-0

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

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

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

Lord, C., Rutter, M., DiLavore, P. C., & Risi, S. (2002). *Autism Diagnostic Observational Schedule.* Los Angeles, CA: Western Psychological Services.

Macdonald, J. S., & Lavie, N. (2008). Load induced blindness. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 1078–1091. doi:10.1037/0096-1523.34.5.1078

Manjaly, Z. M., Bruning, N., Neufang, S., Stephand, K. E., Brieber, S., Marshall, J. C., . . . Fink, R. (2007). Neurophysiological correlates of relatively enhanced local visual search in autistic adolescents. *Neuroimage, 35,* 283–291.

Merin, N., Young, G. S., Ozonoff, S., & Rogers, S. J. (2007). Visual fixation patterns during reciprocal social interaction distinguish a subgroup of 6-month-old infants at-risk for autism from comparison infants. *Journal of Autism and Developmental Disorders, 37,* 108–121. doi:10.1007/s10803-006-0342-4

Milne, E., Griffiths, H., Buckley, D., & Scope, A. (2009). Vision in children and adolescents with autistic spectrum disorder: Evidence for reduced convergence. *Journal of Autism and Developmental Disorders, 39,* 965–975. doi:10.1007/s10803-009-0705-8

Mitchell, D. J., & Cusack, R. (2008). Flexible, capacity-limited activity of posterior parietal cortex in perceptual as well as visual short-term memory tasks. *Cerebral Cortex, 18,* 1788–1798. doi:10.1093/cercor/bhm205

Mottron, L., & Burack, J. (2001). Enhanced perceptual functioning in the development of autism. In J. Burack, T. Charman, N. Yirmiya, & P.D. Zelazo (Eds.), *The development of autism: Perspectives from theory and research* (pp. 131–148). Mahwah, NJ: Erlbaum.

Mottron, L., Dawson, M., Soulieres, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders, 36,* 27–43. doi:10.1007/s10803-005-0040-7

Muggleton, N., Lamb, R., Walsh, V., & Lavie, N. (2008). Perceptual load modulates visual cortex excitability to magnetic stimulation. *Journal of Neurophysiology, 100,* 516–519. doi:10.1152/jn.01287.2007

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

O'Riordan, M., & Plaisted, K. (2001). Enhanced discrimination in autism. *Quarterly Journal of Experimental Psychology: A. Human Experimental Psychology, 54,* 961–979.

O'Riordan, M. A., Plaisted, K. C., Driver, J., & Baron-Cohen, S. (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

Pei, F., Baldassi, S., Procida, G., Igliozzi, R., Tancredi, R., Muratori, F., & Cioni, G. (2009). Neural correlates of texture and contour integration in children with autism spectrum disorders. *Vision Research, 49,* 2140–2150. doi:10.1016/j.visres.2009.06.006

Pinsk, M. A., Doniger, G. M., & Kastner, S. (2004). Push-pull mechanism of selective attention in human extrastriate cortex. *Journal of Neurophysiology, 92,* 622–629. doi:10.1152/jn.00974.2003

Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998). Enhanced visual search for a conjunctive target in autism: A research note. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 39,* 777–783. doi:10.1017/S0021963098002613

Remington, A., Swettenham, J., Campbell, R., & Coleman, M. (2009). Selective attention and perceptual load in autism spectrum disorder. *Psychological Science, 20,* 1388–1393. doi:10.1111/j.1467-9280.2009.02454.x

Ring, H. A., Baron-Cohen, S., Wheelwright, S., Williams, S. C., Brammer, M., Andrew, C., & Bullmore, E. T. (1999). Cerebral correlates of preserved cognitive skills in autism: A functional MRI study of embedded figures task performance. *Brain, 122,* 1305–1315.

Sanders, J., Johnson, K. A., Garavan, H., Gill, M., & Gallagher, L. (2008). A review of neuropsychological and neuroimaging research in autistic spectrum disorders: Attention, inhibition and cognitive flexibility. *Research in Autism Spectrum Disorders, 2,* 1–16. doi:10.1016/j.rasd.2007.03.005

Schwartz, S., Vuilleumier, P., Hutton, C., Maravita, A., Dolan, R., & Driver, J. (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,* 770–786. doi:10.1093/cercor/bhh178

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 24,* 613–620. doi:10.1111/j.1469-7610.1983.tb00137.x

Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the block design task? *Journal of Child Psychology and Psychiatry and Allied Disciplines, 34,* 1351–1364. doi:10.1111/j.1469-7610.1993.tb02095.x

Smith, H., & Milne, E. (2009). Reduced change blindness suggests enhanced attention to detail in individuals with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 50,* 300–306. doi:10.1111/j.1469-7610.2008.01957.x

Soulieres, I., Dawson, M., Samson, F., Barbeau, E. B., Sahyoun, C. P., Strangman, G. E., . . . Mottron, L. (2009). Enhanced visual processing contributes to matrix reasoning in autism. *Human Brain Mapping, 30,* 4082–4107. doi:10.1002/hbm.20831

Wojciulik, E., & Kanwisher, N. (1999). The generality of parietal involvement in visual attention. *Neuron, 23,* 747–764. doi:10.1016/S0896-6273(01)80033-7

Yi, D. J., Woodman, G. F., Widders, D., Marois, R., & Chun, M. M. (2004). Neural fate of ignored stimuli: Dissociable effects of perceptual and working memory load. *Nature Neuroscience, 7,* 992–996. doi:10.1038/nn1294

Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience, 23,* 143–152. doi:10.1016/j.ijdevneu.2004.05.001

Received June 24, 2011
Revision received February 2, 2012
Accepted February 3, 2012 ■