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Toddlers with Autism Spectrum Disorder are more successful at visual search than typically developing toddlers

Zsuzsa Kaldy, **Catherine Kraper**, **Alice S. Carter**, and **Erik Blaser**
Department of Psychology, University of Massachusetts Boston, USA

Abstract

Plaisted, O'Riordan and colleagues (Plaisted, O'Riordan & Baron-Cohen, 1998; O'Riordan, 2004) showed that school-age children and adults with Autism Spectrum Disorder (ASD) are faster at finding targets in certain types of visual search tasks than typical controls. Currently though, there is very little known about the visual search skills of very young children (1–3-year-olds) – both typically developing or with ASD. We used an eye-tracker to measure looking behavior, providing fine-grained measures of visual search in 2.5-year-old toddlers with and without ASD (this representing the age by which many children may first receive a diagnosis of ASD). Importantly, our paradigm required no verbal instructions or feedback, making the task appropriate for toddlers who are pre- or nonverbal. We found that toddlers with ASD were more successful at finding the target than typically developing, age-matched controls. Further, our paradigm allowed us to estimate the number of items scrutinized per trial, revealing that for large set size conjunctive search, toddlers with ASD scrutinized as many as twice the number of items as typically developing toddlers, in the same amount of time.

Introduction

Autism is a childhood onset developmental disorder characterized by three areas of symptoms: abnormal social skills, delayed and impaired language, and repetitive behaviors and/or restricted interests. Individuals with autism may also exhibit unique perceptual and attentional characteristics, such as biases to focus on visual details (for reviews, see Dakin & Frith, 2005; Simmons, Robertson, McKay, Toal, McAleer & Pollick, 2009). Differences in how visual information is processed can have broad effects, since it can influence the way individuals with autism learn language, approach novel surroundings, and navigate social situations.

In classic studies of visual search, two tasks have been contrasted extensively: so-called 'single feature' search (related concepts are referred to as 'efficient' (Wolfe, Cave & Franzel, 1989), 'pop out', 'parallel' or 'preattentive' (Julesz, 1981; Treisman & Gelade, 1980) search), versus 'feature conjunction' search (Treisman & Gelade, 1980) (with related concepts referred to as 'inefficient' (Wolfe, 2000) or 'serial' search). In a single feature search task an array of items is shown in which a 'target' item (the item that is to be searched for) has a unique feature that distinguishes it from a homogeneous set of distractors (e.g. a red disk target in a field of blue disk distractors). The classic signature of single feature search is that the amount of time it takes individuals to find the target is not affected by the size of the set of distractors (a red target in a field of 20 blue distractors is found as quickly as in a field of five); the target 'pops out'. However, to find an item that is unique among the distractors by virtue of having a conjunction of two different feature dimensions

Address for correspondence: Zsuzsa Kaldy, University of Massachusetts Boston, Department of Psychology, 100 Morrissey Blvd., Boston, MA 02125, USA; zsuzsa.kaldy@umb.edu.

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(e.g. a red disk among a distractor set containing both blue disks and red triangles) typically requires an effortful search of the items in the display in a more or less serial fashion; the target no longer pops out. Therefore, search times in feature conjunction search tasks typically vary linearly with the number of distractors. While research suggests that the mechanisms involved in single versus feature conjunction search may not be categorically different (see e.g. Duncan & Humphreys, 1989; Wolfe, 1998), and that target–distractor similarity and the perceptual characteristics of the target itself together determine the speed of search (Wolfe & Horowitz, 2004; see also Amso & Johnson, 2006, for how to vary target–distractor similarity in visual search in a developmental paradigm), experiments may be designed such that the pattern of results shows these characteristic differences.

For this study, we developed a version of the classic visual search paradigm that can contrast feature search and conjunction search with varying set sizes (using shape and color as features), but that does not require following verbal instructions, making it ideal for toddlers with weak receptive language skills.

Visual search in typically developing children

Infants as young as 3 months of age experience the pop-out effect of single feature search: 3-month-olds, but not 2-month-olds, will automatically, selectively orient to a unique patch of squares embedded in an array of horizontal lines (Salapatek, 1975). The effect has been studied systematically in various types of infant paradigm (e.g. looking time: Colombo, Ryther, Frick & Gifford 1995, and the reinforced-kicking paradigm: Rovee-Collier, Hankins & Bhatt, 1992). However, absolute reaction times are still slower (seconds or minutes) than those in adult visual search studies (a few hundred milliseconds). These longer reaction times leave room for other cognitive mechanisms, such as memory and motivation, to interfere with the more rapid, automatic processes of visual search. Adler and Orprecio (2006) used an eye-tracker to collect more immediate responses from infant participants. Infants' gaze latency patterns in pop-out displays were reported to be similar to that of adults, though they showed a greater delay in saccade initiation, possibly due to immature oculomotor pathways. Visual search studies with older children found a pattern of results that was similar to adults, and found that processing speed increased over the childhood years (Thompson & Massaro, 1989; Lobaugh, Cole & Rovet, 1998).

While there is a wealth of information about visual search in infants and older children, children between infant and preschooler age (1–3-year-olds) have been fairly neglected. Because basic perceptual and attentional skills change rapidly during these years, addressing this age group would help illuminate the developmental trajectory of these skills. Gerhardstein and Rovee-Collier (2002) presented the first study with this age group. They trained 1–3-year-olds to touch a screen when it displayed a unique target among distractors. Regardless of language ability, toddlers in this study were able to reliably locate the target item. Scerif, Cornish, Wilding, Driver and Karmiloff-Smith (2004) used a similar paradigm to study the effect of target–distractor similarity on visual search performance of typically developing toddlers and toddlers with Williams Syndrome and Fragile X Syndrome. In contrast to these previous studies, our paradigm does not require participants to follow verbal instructions or to have precise hand–eye coordination, making it even more suitable for testing young toddlers.

Visual search in older children and adults with Autism Spectrum Disorder

In a series of studies O'Riordan, Plaisted and their colleagues demonstrated that older children with autism demonstrated faster reaction times in difficult visual search tasks than nonverbal ability matched, general IQ matched and even age-matched typically developing

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children (Plaisted *et al*., 1998; O'Riordan, 2000; O'Riordan, Plaisted, Driver & Baron-Cohen, 2001). This finding was demonstrated with adults as well (O'Riordan, 2004).

But *how* do individuals with ASD achieve superior search performance in these tasks? O'Riordan and Plaisted (2001) proposed that individuals with ASD have enhanced 'perceptual discrimination' (better perceptual discrimination between targets and distractors). A few recent studies have provided further support for this hypothesis. Jarrold, Gilchrist and Bender (2005) found that adolescents with ASD were close to 1 second faster at detecting targets even in small (seven-item) visual search displays than nonverbal mental age matched controls. Kemner, van Ewijk, van Engeland & Hooge (2008) replicated the finding of O'Riordan (2004). They found that high-functioning adults with ASD were faster at finding the target and made fewer fixations in both easy and difficult search tasks. Joseph, Keehn, Connolly, Wolfe and Horowitz (2009) tested middle-school-aged children with and without ASD. They concluded that faster search in children with ASD was not a result of better memory for previously visited locations (as this in itself could speed up search by reducing time-consuming, but useless, 'revisits' to distractors), but was consistent with enhanced discrimination. Our design allowed us explore this process in greater detail.

The goals of our study

Our study seeks to fill an important gap in the literature. Our first aim was *theoretical*: to show whether basic attentional processing in ASD develops on a different path in 2-year-olds – the age by which many children will first receive a diagnosis of ASD. An early emergence of a difference may suggest that it is primary in nature and not a result of atypical social development. In addition to simply establishing that toddlers with ASD can outperform typically developing toddlers, our paradigm also allowed us to estimate the number of items scrutinized per trial (each trial had a fixed duration), thereby revealing differences in underlying processing.

Our second aim was *methodological*: to introduce a new, eye gaze based version of the classic visual search paradigm. Importantly, with this method, we did not need to ask participants to follow verbal instructions. Since even typically developing toddlers vary significantly in their receptive language skills at this young age (while toddlers with ASD are known to fall behind in this domain), a paradigm that eliminates the need for verbal instructions is useful. As well, gaze data collected with the eye-tracker is a rich source of information on search patterns. Research on infants and young toddlers has long relied on the measurement of different aspects of looking behavior (e.g. preferential looking and looking-time methods). These studies traditionally used human observers to code approximate gaze direction and duration. Using recent eye-tracking technology though eliminates the need for human interpretation and coding of gaze, and gives us moment-to-moment information regarding fixation location and duration.

Methods

Participants

We recruited typically developing toddlers from the Greater Boston area via mailings and we recruited toddlers with ASD through a local early intervention provider specializing in services for children with ASD. For detailed participant characteristics, please see Table 1. To verify the ASD diagnosis, toddlers in the ASD group were evaluated using the Autism Diagnostic Observation Schedule (ADOS: Lord, Risi, Lambrecht, Cook, Leventhal, Dilavore, Pickles & Rutter, 2000). Each participant met ADOS cutoff scores for ASD and 15 of the 17 participants met the criteria for autism. Diagnosis was confirmed by one of the co-authors, a clinical psychologist experienced in diagnosing young children with ASD

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(Alice S. Carter). Parents of each child completed a demographic questionnaire, which included information such as race and ethnicity, parent education, and household income, as well as the Parent Interview for Autism-Clinical Version (PIA-CV; see Stone, Coonrod, Pozdol & Turner, 2003), to verify that none of the toddlers in our typical sample were on the autism spectrum. Participants were evaluated for language and visual reception skills using the Receptive and Expressive Language (RL and EL) and the Visual Reception (VR) sub-scales from the Mullen Scales of Early Learning (MSEL; see Mullen, 1989). Typically developing children were matched by chronological age.1 The final sample included 17 typically developing toddlers (mean age: 29.5 ±2.6 months, 10 females) and 17 toddlers with ASD (mean age: 29.6 ±4.8 months, three females). Eight additional participants were tested, but excluded, due to fussiness or experimental error (five were typically developing, three were toddlers with ASD). None of the participants had first-degree relatives with known color blindness.

Stimuli, apparatus and procedure

We used a Tobii T120 eye-tracker to measure eye movement patterns. Participants sat on their caregivers' lap to view the displays, approximately 70 cm away from the monitor. Caregivers were asked to keep their eyes closed during testing. Following a 30-second calibration phase, participants saw one, two, or three blocks of trials (depending on time and motivation; mean number of blocks: 2.2 (ASD), 1.6 (TYP)).2 Each block consisted of four familiarization trials and 13 test trials and lasted for approximately 4 minutes. The test trials consisted of four single feature trials (set size 5 or 9) and nine feature conjunction trials (set size 5, 9 or 13). These trials were mixed in blocks and presented in random order, with the exception that the first three test trials were single feature trials to highlight the special status of the target through pop-out. To emphasize this further, and to grab participants' attention and fixation, before each trial began the target (a red apple) 'flew in' from the upper portion of the screen, stopped at the center of the screen for 1 second, then disappeared.

In familiarization trials, the three items that were used in the search displays (the red apple target, blue apple color distractor, and a red, elongated rectangle shape distractor) appeared on the screen for 3 seconds. In each trial, the three items were presented in a different spatial configuration. In test trials, participants were presented with a search display for 4 seconds (Figure 1). After the end of the trial, the target item spun clockwise 180 degrees, then counterclockwise 180 degrees (for a total of 3 seconds).

In sum then, we indicated, nonverbally, the special status of the target in four ways: by using a familiar object (red apple vs. blue apple-shapes and red rectangular-shape distractors), exploiting the pop-out effect of the first three single feature trials, using the target in pre-trial animations that directed children's gaze to the center of the screen, and ending each trial with the 'reward' spinning animation (an anticipated event interesting enough to help motivate active search).

[1]Since previous studies suggested superior performance in ASD even relative to age-matched controls, we did not think the weaker test of comparing to nonverbal IQ-matched controls was necessary. That said, an additional 10 typically developing younger toddlers were tested to confirm this assumption. These children were matched with the ASD group on the Visual Reception and Fine Motor sub-scales of the MSEL as a proxy for nonverbal IQ. Performance in this group was identical to or lower than the typical age-matched controls.

[2]We tested whether fatigue had an overall or a group-specific effect on our participants. We used a Generalized Estimating Equations method to conduct binary logistic regression analyses using the trial-by-trial success/failure measure as the dependent variable, Group (ASD, TYP) and Block (first, second, third) as the independent variables, and Participant as the subject variable. We analyzed feature conjunction trials (these are in mixed blocks with pop-out feature search trials). The main effects of Group and Block were not significant (Wald $\chi^2(1) = 3.38$, $p < .066$, Wald $\chi^2(2) = 3.8$, $p < .15$, respectively), nor was the interaction between them (Wald $\chi^2(2) = 2.15$, $p < .341$).

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With each event that occurred on the screen, there was an accompanying sound effect to make the experiment more engaging for toddlers. As the target item 'flew in' to the display before each trial, an airplane sound effect played; when the search items appeared, a 'bonk' sound played; while the items were displayed, a ticking clock played; and during the reward phase, when the target apple spun, cheering and clapping were played.

Results

First, we defined equal-sized areas of interest (AOIs) for all items within each test trial (see Figure 1). Trials in which the participant did not look at any items were excluded from further analysis (63 trials (7.34%) of the 858 trials collected).

To begin with, we want to make sure that participants noted the special status of the target, and that there was an equal level of engagement with the task for both the ASD and typically developing group (TYP). Then we will move on to the analyses of success rates.

The target is special

To test that the toddlers noted the preferential status of the target, we compared fixation length (FL) for the target to that of the distractors. We conducted a 2 × 2 repeated measures ANOVA to compare FL to the target with average FL to those distractors that the child looked at in any given trial (between-subjects factor: Group (ASD, TYP), within-subjects factor: Item Status (target, distractors)). To provide a fair comparison, we limited this analysis to successful trials (trials where there was at least one fixation at the target).

In children with ASD, the mean FL to the target was 1.10 s (SD = 0.78 s) and 0.54 s (0.39 s) to the distractors. In the typically developing group, the mean FL to the target was 0.92 s (0.59 s) and 0.67 s (0.42 s) to the distractors. There was a highly significant main effect of Item Status ($F(1, 474)$ =124.96, $p < .0001$, $\eta_p^2 = 0.208$), but no main effect of Group ($F(1, 474) < 1$, $p = ns$, $\eta_p^2 = 0.002$). The interaction between Item Status and Group was also highly significant ($F(1, 474) = 12.47$, $p < .0001$, $\eta_p^2 = 0.027$). In short, our participants in both groups looked significantly longer at the target than the average distractor, and this effect was stronger in children with ASD compared to typically developing controls.

Engagement with the task

We conducted some further analyses in order to test whether toddlers in the two groups were equally engaged in the task. The proportion of trials with no looks to any items in the display were not different ($\chi^2(1) = 0.037$, $p < .846$, two-tailed) between groups. In addition, we analyzed the time stamp of the last-fixated item for all trials combined, and for just feature conjunction trials. The time that this last item was fixated, on average, was 2.40 s (SD = 1.03 s) in the ASD group vs. 2.39 s (1.01 s) in the TYP group for all the trials combined, and 2.4 s (1.00 s) vs. 2.52 s (1.01 s), respectively, for the feature conjunction trials. There were no significant differences between the two groups (two-samples t-tests, respectively: $t(790) = 0.139$, $p < .89$, $d = 0.009$; $t(542) = 1.327$, $p < .185$, $d = 0.11$, two-tailed). This shows that typically developing children did not terminate search sooner than children with ASD, or vice versa; both groups stayed 'on task' equally.

Success at finding the target

Since we have established that both groups note the special status of the target and are equally engaged in the task, we can fairly compare their search performance. Instead of measuring reaction times, trials had a fixed 4-second length and our main measure of performance was the proportion of 'successful' trials, where a trial was considered successful if the participant fixated the target3 at least once. Figure 2 shows the success rates as a function of set size for each group. Since the dependent variable in these analyses is binary, we used a Generalized Estimating Equations method to conduct binary logistic regression analyses using the trial-by-trial success/failure measure as the dependent variable, Set Size and Group as the independent variables, and Participant as the subject variable. Single feature and feature conjunction trials were analyzed separately.

In single feature trials, the main effects of Set Size and Group were not significant (Wald $\chi^2(1) = 2.36$, $p < .124$, Wald $\chi^2(1) = 0.30$, $p < .583$, respectively), nor was the interaction between them (Wald $\chi^2(1) = 2.83$, $p < .093$).

In contrast, in feature conjunction trials, the main effects of Set Size and Group were highly significant (Wald $\chi^2(1) = 24.05$, $p < .00006$, Wald $\chi^2(1) = 18.63$, $p < .00001$, respectively). Set Size and Group again did not interact significantly (Wald $\chi^2(1) = 2.38$, $p < .303$). Thus, our key finding is that toddlers with ASD were more successful, able to find the target significantly more often in feature conjunction trials than age-matched typically developing controls.

Differences between the groups can be visualized using 'heat maps', where colors indicate how fixations were distributed in the display. Figure 3 shows group averages of these fixation distributions for the two groups in a set size 13 display. Children with ASD tended to spend the most time at the central fixation cross (where they were encouraged by the pre-trial animation to begin each trial) and the target itself. For this set size, the fixation pattern of typically developing children was much more evenly distributed among the items in the display: in terms of number of fixations; the target did not stand out among the distractors.

How did children with ASD achieve higher success rates?

To explain how toddlers with ASD achieved higher success rates in the feature conjunction task, we first examined the number of items that children looked at in any given trial. In the ASD group, the mean values were 2.57 ($SE = 0.166$) for set size 5, 3.30 (0.182) for set size 9, and 3.30 (0.349) for set size 13. In the TYP group, the corresponding values were 2.50 (0.132), 3.26 (0.151) and 3.76 (0.319), respectively. Since our dependent variable was count data that were negatively skewed, we conducted a Poisson regression analysis (a type of Generalized Linear Model). Group (ASD, TYP) and Set Size (5, 9, 13) were our two main factors. While the main effect of Set Size was highly significant (Wald $\chi^2(1) = 28.147$, $p < .0001$), the main effect of Group and the interaction between the two factors were not (Wald $\chi^2(1) = 0.270$, $p < .604$; Wald $\chi^2(2) = 1.070$, $p < .584$, respectively). That is, the number of items that were fixated on in any given trial was not different between the two groups. This result is in contrast with the results of Kemner *et al*. (2008) with adults, but consistent with the findings of Joseph *et al*. (2009) with middle-school-aged children.

We calculated what the predicted performance would be based on the number of items fixated per trial type for each group. This is a model of performance where participants scrutinize (that is, make a target/distractor determination), and only scrutinize, the items they have fixated (see Figure 4a and b). This model underestimates search performance, dramatically so for the ASD group. Of course, the implication is that participants scrutinize more items than just the ones which they have fixated (a well-established principle of visual search; see Wolfe, 2003). The number of items that were actually scrutinized for a given group and condition can be estimated from the success rate and set size (for example, a 33% success rate in set size 9 would mean that on average, 3 items were processed). Using that,

[3]Any (and only) fixations within the target AOI count. The 'Tobii fixation filter' looks for quick changes in the gaze point signal, checking if near-in-time candidate fixations are closer than a given spatial radius. We used the default radius (for the Tobii T120 controlled by Tobii Studio version 2.1.14) of 35 pixels, or about 1 degree of visual angle.

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typically developing toddlers scrutinized on average 3.49, 4.41, and 3.37 items per trial for set sizes 5, 9 and 13, respectively. Toddlers with ASD though were able to scrutinize 4.02, 6.25 and 8.08 items for set sizes 5, 9, and 13, respectively; notably more than twice as many for set size 13 (Figure 5). Casting the results in this way highlights the striking difference between groups in underlying processing.

Discussion

We adapted a classic visual search paradigm (Treisman & Gelade, 1980) for toddlers in an eye-tracking paradigm that did not require any verbal instructions. Using this paradigm, we showed that 2.5-year-old toddlers with ASD were more successful than typically developing toddlers of the same age (and higher cognitive functioning) at finding a target amidst distractors in a feature conjunction search. These results extend the developmental trend first identified by Plaisted and her colleagues (Plaisted *et al*., 1998) to the youngest age at which clinical diagnosis is typically made. Since diagnosis at this early age tends to be conservative, our sample likely included more participants from the low-functioning end of the spectrum than is typical in experimental studies of ASD (in fact, 15 out of 17 met the criteria for autism). Further, our paradigm allowed us to estimate the number of items scrutinized per (fixed duration) trial, revealing that in certain conditions toddlers with ASD scrutinized more than twice the number of items than typically developing toddlers.

Modifications versus standard visual search paradigms

We modified the classic visual search paradigm in two ways. First, instead of asking participants to press a button as soon as they found the target in the display, we instead presented them with the display, monitored their eye movements, and after the trial was over we presented them with a ‘reward’ associated with the target (a back-and-forth spinning animation). The fact that fixation length was longer for the target than for distractors in both single feature and feature conjunction trials demonstrates that participants appreciated the special status of the target. Because even typically developing children of this age have considerable variability in their language abilities, using a methodology that does not rely on receptive language skills meant that children’s performance was not hindered by a lack of understanding of the instructions. While others have got around this by using training sessions, the current method allows for greater practicality and ease in testing young children. Our method is also ideal for testing other groups with delayed or absent language abilities, such as toddlers and older children with Down Syndrome or Specific Language Impairment.

Second, we made another modification to the classic visual search paradigm. Instead of the typical reaction time design (where participants are allowed to conduct a self-terminating search, and time-to-target is taken as the performance measure) we used a success rate design (where trial length is fixed, and performance is measured by the proportion of trials on which the target is found). Using success rate allowed for straightforward estimates of the number of items that were scrutinized during search. This measure revealed three things. One is that the number of items processed exceeds the number of items fixated; both groups were processing more items than they looked at. The second, more interesting finding is that the number of items scrutinized by the toddlers with ASD dramatically exceeds that of typical toddlers. Third, beyond this absolute difference in performance, and perhaps most interestingly, toddlers with ASD scrutinize *more* items as set size increases while typical toddlers scrutinize a fixed, relatively smaller number independent of the set sizes we tested.

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Windowed search

Why would this be the case? We first assume that there is a global evaluation of the scene where candidate targets are identified and prioritized for scrutiny (determining whether an item is a target or distractor); i.e. a guided search (Wolfe *et al*., 1989). In the feature search trials, the true target should nearly always have the peak activation, so success rate should be maximal and independent of set size. In the conjunctive search case, the true target may not have peak activation. Because of this, a typically effortful, serial scrutiny now needs to be conducted of the (prioritized) set of candidate items to find the target.

If the ASD group were just better overall than the TYP group, this could be the end of the story: the ASD group has better guided search (i.e. the true target winds up with a higher ranking among candidate targets than it does with the TYP group). However, the ASD group does increasingly well as set size increases, scrutinizing more and more items (the better way to put this, perhaps, is that they are underperforming at small set sizes, creating a seeming paradox: If the ASD group can scrutinize 8 items in set size 13, why do they only manage to scrutinize 6 in set size 8 or 4 in set size 5?).

It is beyond the scope of this paper to definitely endorse a model of search, but we speculate that, in conjunctive search, participants scrutinize each item that they fixate along with a (sub)set of additional items that are outside fixation, but within an attentional ‘window’ (see the ‘parallel carwash’ metaphor in Wolfe, 2003) centered on fixation. As density increases with set size, more and more items fall within this window, and could potentially be scrutinized. We assume that this window is of a fixed size, and the same for both groups (this is both parsimonious and consistent with our data). Success rate, then, depends on how many of these these additional items can be scrutinized before the eyes move. Tellingly, the number of items that the TYP group scanned through was fixed and independent of set size: Even as more and more items fell within their search window as density increased, they still only managed to scrutinize roughly 3–4 unique4 items per trial; they were at asymptote. In contrast, toddlers with ASD apparently had the resources to scrutinize additional items. For the largest set size we measured (13 items), these toddlers scrutinized about 8 unique items per trial, more than twice as many as the typically developing toddlers (see Figure 5). And indeed, the linear nature of the increase in unique items scrutinized as a function of set size suggests that they could have scrutinized even more if tested with larger set sizes.

This begs the question of *why* toddlers with ASD can effectively search through more items per trial (even given the roughly equivalent number of items fixated). It could either be that toddlers with ASD simply *search faster*: conducting a faster-paced blind serial scrutiny of the items in this attentional window, or *search smarter*: leveraging enhanced discrimination between targets and distractors to allow for a more efficient guided search (Wolfe *et al*., 1989; O’Riordan & Plaisted, 2001) within the window. While our results cannot bear directly on this, the second hypothesis has better support in the literature on older children and adults with ASD (O’Riordan & Plaisted, 2001; Kemner *et al*., 2008, Joseph *et al*., 2009), and we favor it over the serial search pace hypothesis. (It is interesting to speculate too that certain unusual visual explorative behaviors, e.g. peering at objects from the corner of the eyes, could be associated with enhanced perceptual discrimination skills. This enhancement, after all, leads to more items scrutinized, over a greater spatial area, further into the periphery. Such behaviors emerge as early as 12 months of age in infants who are

[4]We measure ‘unique’ items because it is the number of unique items that are scrutinized that determines performance. However, it is important to keep in mind that – especially as density increases – there is an increasing likelihood of ‘re-processing’ items: the search window that surrounds a currently fixated item is very likely to capture already-processed items that fell within an earlier search window. This means that participants must actually scrutinize more and more items as set size increases in order to scrutinize enough unique items to achieve a certain level of performance.

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later diagnosed with ASD and correlate with the severity of the symptoms at 36 months (Ozonoff, Macari, Young, Goldring, Thompson & Rogers, 2008)).

In summary

In short then, as early as 2.5 years of age, toddlers with ASD are better at feature conjunction search than age-matched typically developing controls. It is likely that 'enhanced discrimination' (O'Riordan & Plaisted, 2001; Joseph *et al*., 2009) exaggerates the differences between the target and distractors, allowing toddlers with ASD to direct search toward the target more efficiently (put another way, the target was more *salient* (Treue, 2003; Kaldy & Blaser, 2009) for children with ASD, and this salience difference was exploited to aid search). The fact that we found this difference in visual search processes at the earliest age when diagnosis is typically made supports the view that differences in these processes in ASD are primary in nature.

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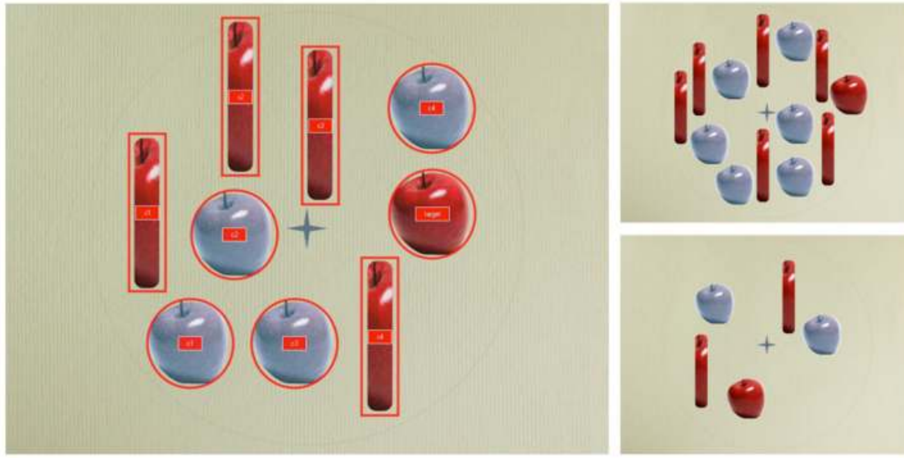

Figure 1.

Examples of conjunction search displays (for set size 9 with defined areas of interest (AOI's) relevant to calculating eye movement statistics; set sizes 13 and 5 are also inset). The red and blue apple-shaped items subtended 5×5 degrees of visual angle, the elongated apple items subtended 7.3×1.25 deg, and all items were constrained to appear within a virtual circle centered on fixation with a diameter of 20 deg. The positions of targets and distractors were randomized from trial to trial.

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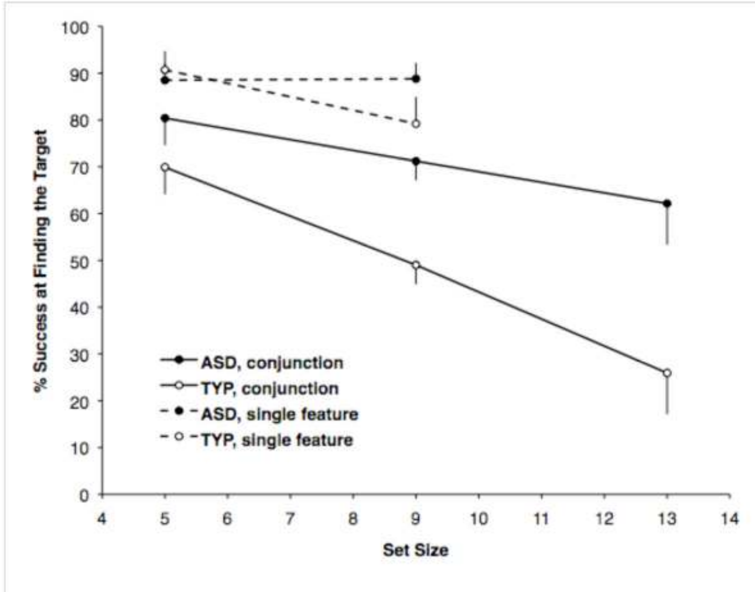

Figure 2.
Percent of successful trials in single feature and feature conjunction trials by group as a function of set size. Bars depict standard error.

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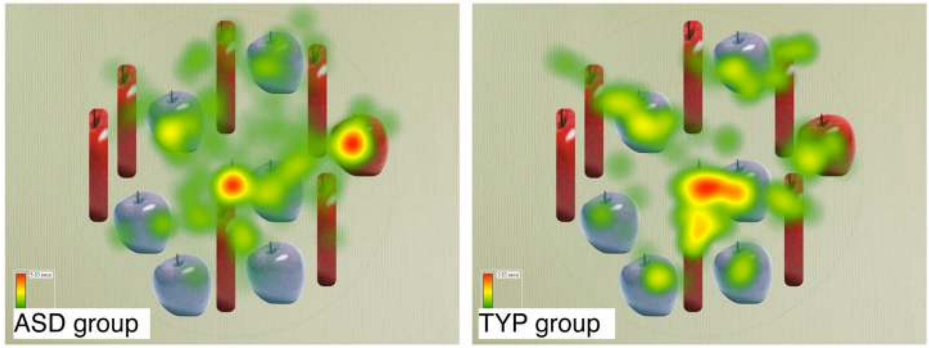

Figure 3.
Maps of fixation distribution in a 13-item feature conjunction trial (redder color means longer fixations) shown for both the ASD and the TYP group, respectively.

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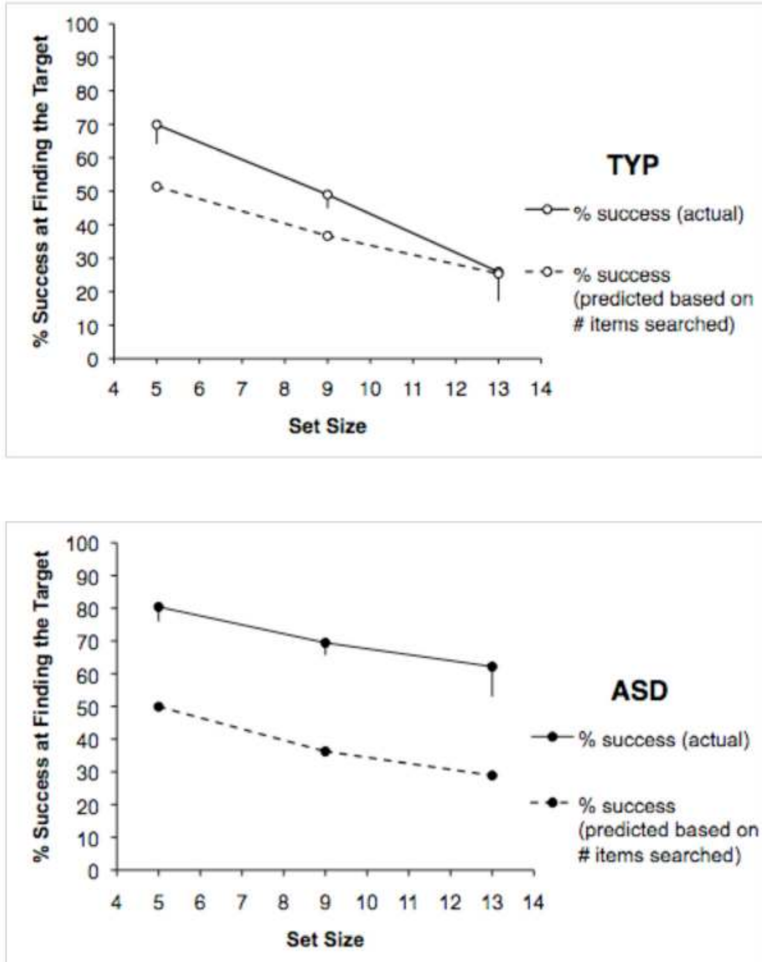

Figure 4.
Actual vs. predicted performance based on number of items fixated, shown for both TYP and ASD groups. Bars depict standard error.

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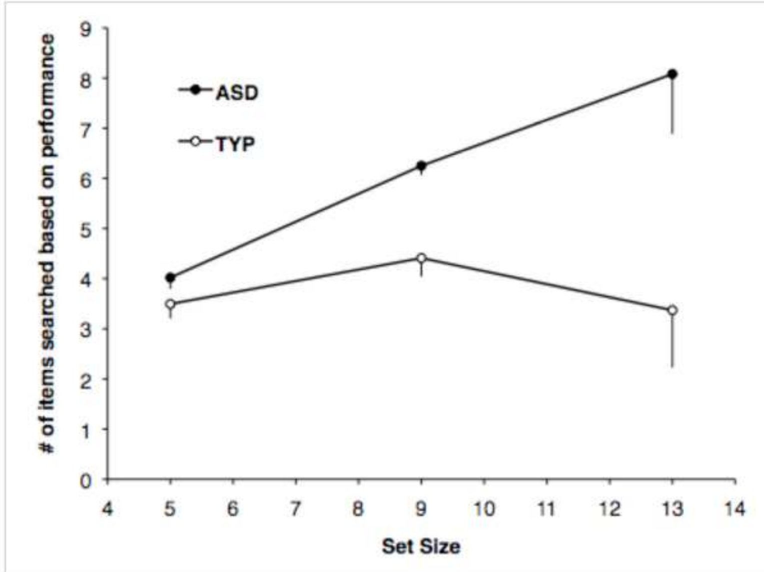

Figure 5.
Number of items scrutinized estimated from performance (success rate) by group. Bars depict standard error.

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Table 1

Participant characteristics (mean, SD)

	ASD	Age matched typically developing (TYP)	*p*	Effect size (*d*)
N	17	17		
Age (months)	29.6 (4.8)	29.5 (2.5)	*ns*	
Range (months)	21–35	25–34		
ADOS Communication	5.06 (2.0)	–		
ADOS Social Interactions	10.53 (3.1)	–		
ADOS Repetitive Actions	2.71 (1.5)	–		
Mullen Visual Reception Raw Score – age equivalent	23.4 (4.7) 20.9 (5.3)	34.7 (4.1) 35.3 (6.1)	< .001	1.57
Mullen Receptive Language Raw Score – age equivalent	18.7 (7.0) 18.1 (7.8)	30.8 (3.7) 33.8 (5.6)	< .001	1.50
Mullen Expressive Language Raw Score – age equivalent	16.2 (6.3) 16.5 (7.1)	28.2 (6.0) 31.1 (7.3)	< .001	1.41
Parent Interview for Autism— Clinical Version (PIA-CV) Score	121.1 (26.4)	169.4 (15.4)	< .001	2.31
Maternal education (years)	14.4 (2.4)	15.9 (2.8)	.097	
Household income (category)	9.5 (5.5)	12.4 (4.7)	.105	