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Superior Visual Search in Autism

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Children with a diagnosis of autism and normally developing children, matched for age and general ability, were tested on a series of visual search tasks in 2 separate experiments. The children with autism performed better than the normally developing children on difficult visual search tasks. This result occurred regardless of whether the target was uniquely defined by a single feature or a conjunction of features, as long as ceiling effects did not mask the difference. Superior visual search performance in autism can be seen as analogous to other reports of enhanced unique item detection in autism. Unique item detection in autism is discussed in the light of mechanisms proposed to be involved in normal visual search performance.

Autism is a psychiatric disorder that is characterized by three main features. The first feature encompasses gross social deficits, such as difficulties in forming and maintaining social relationships and deficits in engaging in reciprocal social interaction. The second defining characteristic of autism is a striking impairment in both verbal and nonverbal communication (Kanner, 1943; Rutter, 1983; Wing & Gould, 1979), and the third component of this diagnostic triad is the presence of repetitive behavior. Although the presence of this triad of impairments is sufficient for a diagnosis, there are other features that are also characteristic of autism, such as nonsocial perceptual and attentional deficits. Reports of perceptual disturbance in autism include acute attention to minor features of the environment and the ability to notice small changes in it, which often results in considerable distress (Hayes, 1987; Kanner, 1943; National Society for Autistic Children, 1978).

One nonsocial feature of autism that is particularly intriguing is superior performance on a conjunctive visual search task (Plaisted, O'Riordan, & Baron-Cohen, 1998b). In a visual search task, the participant is asked to indicate the presence or absence of a prespecified target that may be hidden among several simultaneously presented distractors. In a feature search task, the target is uniquely defined by one feature (e.g., a blue *X* target hidden among red *T* and green *X* distractors is unique in color). In such feature search tasks, the time taken to detect the target is typically largely independent of the number of distractor items presented, suggesting that it is found by an efficient parallel process, which can operate across all the items in the display at once (Treisman & Gelade, 1980). By contrast, in a conjunctive search task, the target shares each of its features with the distractors and is therefore unique only in terms of the specific combination of its feature (e.g., a red *X* target among red *T* and green *X* distractors is unique only in the combination of color and form). The classic profile of performance in such conjunctive search tasks is a linear increase in target detection time with increasing display size. That is, the more items presented to the participant, the longer it takes him or her to detect the target, as if attention has to be applied successively to each item in the display in turn (i.e., a serial search is required; Treisman & Gelade, 1980; but also see J. M. Wolfe, Cave, & Franzel, 1989). In practice, search rate is rarely completely independent of display size, and thus, the cutoff point between serial and parallel search strategies is difficult to define. Convention suggests that search rates lower than 10 ms per item reflect efficiently parallel search, whereas search rates higher than 10 ms per item may suggest the operation of serial (or inefficiently parallel) search (Davis & Driver, 1998; Treisman & Gelade, 1980). A further indication of serial search is an approximate 2:1 target-absent to target-present search rate ratio. This ratio derives from the notion that serial search will be terminated on detection of the target in target-present trials (which will occur after searching, on average, 50% of the display items) but will be exhaustive in target-absent trials. However, some argue that the serial–parallel distinction is an artificial one and that, in fact, there is a continuum of search behavior, with search rate rising as a function of increasing task difficulty (Duncan & Humphreys, 1989; Grossberg, Mingolla, & Ross, 1994; J. M. Wolfe, 1994; J. M. Wolfe et al., 1989).

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Plaisted et al. (1998b) investigated the performance of individuals with and without autism on visual search tasks. A group of high-functioning children with autism and a group of normally developing children, matched for chronological age and verbal mental age, using the British Picture Vocabulary Scale long form (Dunn, Dunn, Whetton, & Pintilie, 1982), were tested on two search tasks: one involving a conjunctive target and the other a feature target. In the feature task, the target was a red *S* hidden among red *T* and green *X* distractors, and in the conjunctive condition, the target was a red *X* hidden among red *T* and green *X* distractors. In each condition, the target was present on 50% of the trials, and the number of concurrent distractors in each display varied from trial to trial. In each condition, the participant knew what the target would be but did not know whether the target would be present or how many distractors would be presented.

In the control group, the time taken to detect the feature target was independent of the display size, whereas the time taken to detect a conjunctive target increased linearly with increasing display size. Thus, the results from the typically developing children replicated the results of many previous studies on normal adult samples (Duncan & Humphreys, 1989; Treisman & Gelade, 1980; J. M. Wolfe et al., 1989). In contrast, although the group with autism showed the same response time (RT) pattern as normal participants in the feature condition, they performed differently in the harder conjunctive condition. In that condition, the group with autism was significantly faster than the control group and showed less of an increase in RT with increasing display size than the control group.

Thus, Plaisted et al. (1998b) showed that individuals with autism were better than a matched control group at detecting a conjunctive target. However, before we can go on to examine the mechanisms underlying enhanced visual search in autism, there are two methodological issues regarding the findings of Plaisted et al.'s (1998b) experiment that must be resolved. First, it is well established that individuals with autism have poor language skills relative to their performance on other tasks (Rumsey & Hamberger, 1988; Szatmari, Tuff, Finlayson, & Bartolucci, 1990), whereas typically developing children tend to reach a level of performance on language tasks that is commensurate with their general level of functioning. Because the children with autism and the control group were matched on verbal ability in Plaisted et al.'s (1998b) study (using the British Picture Vocabulary Scale), it follows that the children with autism may have been of higher general ability than the normal children. Therefore, one possible explanation for the superior performance of the children with autism on the conjunctive search task is that it merely reflects an artifactual influence of their higher IQ. If so, a group of children with autism should not differ from a group of typically developing children in search performance, provided that the groups are appropriately matched for general ability.

Second, the results of Plaisted et al.'s (1998b) study showed that the children with autism were better than the normally developing children at searching for a conjunctive target but not for a feature target. This finding raises two possibilities: (a) that the superior visual search of the individuals with autism is confined to search for conjunctive targets or (b) that children with autism are especially good at visual search per se but this effect was masked by ceiling effects in the easy feature task of Plaisted et al.'s (1998b) study. The issue of whether superior search is confined to conjunctive target tasks or generalizes also to hard feature search tasks has implications regarding the mechanisms underlying the superiority in autism. If individuals with autism are superior at visual search regardless of whether the target is defined by a single feature or a conjunction of features, then the superiority results from some difference in a mechanism that is involved in both tasks. Conversely, if superiority is confined to search for conjunctive targets, then the reason for this effect must be a difference in a process involved in conjunctive but not feature search (presumably feature integration in particular).

To address these difficulties in interpreting Plaisted et al.'s (1998b) study, we investigated in Experiment 1 whether the apparently superior performance of individuals with autism on a conjunctive search task is an artifact of higher IQ by testing individuals with autism against controls who were matched for general nonverbal ability using Raven's Coloured Progressive Matrices (CPM; Raven, Court, & Raven, 1990). In Experiment 2, we examined whether the enhanced visual search by individuals with autism is restricted to search for conjunctive targets or applies instead to any difficult visual search task (including hard feature searches) by assessing the performance of children with autism against typically developing children on a feature task that has been found to be difficult in normal individuals. In this way, we hoped to avoid ceiling effects and thus allow any difference between individuals with and without autism to be observed even on feature tasks.

Experiment 1

Experiment 1 sought to replicate the results of enhanced conjunctive search in a group of children with autism versus a group of typically developing children who were matched using Raven's CPM (Raven, 1956; Raven et al., 1990). These matrices are a test of nonverbal reasoning ability and are considered to give an estimate of general intelligence that is unbiased by language skills. The children were tested on two search tasks: one for a feature target unique in terms of form and the other for a conjunctive target uniquely defined by the combination of color and form.

Method

Participants. Two groups of children participated: a group of 12 children with autism and a group of 12 developmentally normal children. All children in the group with autism had been diagnosed using the Autism Diagnostic Instrument—Revised (Lord, Rutter, & Le Couteur, 1994). The ages of the children in the control group ranged from 6 years 5 months to 10 years 9 months. The ages of the children with autism ranged from 6 years 11 months to 9 years 6 months.

The cognitive ability of the children was assessed using the CPM (Sets A, Ab, and B; Raven et al., 1990). Scores are shown in Table 1. Unpaired *t* tests revealed that the chronological ages and the CPM raw scores of the two groups did not differ significantly, $t(22) = 0.486$, $p = .632$, and $t(22) = 0.258$, $p = .799$, respectively. Chronological age is required together with CPM raw scores to determine a value of general IQ. Because our groups were well matched on both of these measures, it can be concluded that the groups were not significantly different in terms of general IQ.

Apparatus. The stimuli were generated by an Acorn Risc PC and displayed on a 14-in. (35.56-cm) color monitor. Participants responded by pressing one of two keys on the keyboard (the period key with the right hand for target-present responses or the *Z* key with the left hand for

Table 1
Chronological Ages (Years:Months) and Raven's Matrices Raw Scores for Children With Autism and Normally Developing Children in Experiment 1

Group	Age	Raven's matrices score
Control (n = 12)		
M	8:2	26
SD	1:6	4
Range	6:5–10:9	19–33
Autistic (n = 12)		
M	8:5	26
SD	0:11	4
Range	6:11–9:6	18–32

target-absent responses). To prevent irrelevant keys from being pressed, the keyboard was covered by a hard black plastic cover that had two openings to allow access to only the two response keys.

Stimuli. Each stimulus display consisted of 5, 15, or 25 elements (i.e., letters) arranged in an imaginary 16.8-cm by 16.8-cm square (approximately 33° visual angle) centered around a central fixation point (a hash mark). Each element measured 0.5 cm by 0.5 cm, subtending approximately 1.0° of visual angle horizontally and 1.0° vertically. The minimum distances between elements in any display were 0.7 cm between positions in a row and 0.7 cm between positions in a column, and items were positioned randomly across the screen rather than in positions in an imaginary grid. Hereinafter, the term *display size* refers to the number of elements in the display, not to the physical boundaries of the display, which remained fixed throughout. Display elements each had two dimensions: color (red or green) and form (*S, T,* or *X*). In the feature search task, nontargets differed from the target in the shape dimension (i.e., a red *S* target among green *X* and red *T* distractors). In the conjunction search task, each distractor shared one feature with the target (i.e., a red *X* target among red *T* and green *X* distractors).

Design. The experiment consisted of two different search tasks (feature or conjunction tasks). Each search task contained two fully crossed factors: display size (5, 15, or 25 items) and probe (target present or target absent), which yielded six possible display types. There were 10 trials for each of these display types, yielding 60 trials per session. Trials were randomized within blocks of 30 for each search task, with equal representation of all experimental factors in each block.

The order of positive and negative trials and of different display sizes was randomized within each session; thus, the participants knew what the target was but did not know whether a target would be present or what the display size would be on any trial. The participants performed a binary-choice RT task indicating present or absent for the single prespecified target by button presses on each trial.

Procedure. Each participant was tested on both the conjunctive and feature search tasks in separate sessions that were divided by a minimum interval of 24 hr. The order in which these tasks were presented was counterbalanced across participants within each group. The participants were informed of the target to search for in that session and that certain keys were to be pressed depending on whether the target was present or absent. Prior to each task, participants were given a block of 12 practice trials involving the stimuli for that task, with the experimenter's instruction and assistance. Following these practice trials (immediately prior to the test trials), participants were instructed to respond as quickly as possible and with as few errors as possible.

On each trial, the sequence of events was as follows: A fixation hash mark was presented on an otherwise blank screen for 500 ms. The search display was then presented, at which point the timing was initiated. The search display remained on for 10 s or until the participant responded, whichever occurred sooner. If the former occurred, the phrase "You were too slow" appeared in the center of the screen for 500 ms, followed by the presentation of the central hash mark for 500 ms, indicating the onset of the next trial. If the correct response was made, the next trial was initiated. If an incorrect response was made, a tone sounded as an indication of the error. An incorrect trial was followed by a dummy trial; the response to this trial was not recorded. This procedure allowed the participant to recover from an error. On the rare occasion that a button press occurred before the search display appeared on the screen, the phrase "You pressed too soon!" was displayed at the center of the screen for 500 ms. Then the task resumed as before, starting with the trial that had been interrupted by the premature response.

Results and Discussion

Before one can conclude that significantly faster RTs reflect superior task performance, one also has to show that this faster speed is not accompanied by reduced accuracy (Wickelgren, 1977). If speeded RT is accompanied by decreased accuracy, it may be that changes in search speed merely reflect differences in detection criteria. To show that there are no significant differences in accuracy, analysis of error rate is important. However, the absence of error rate differences does not completely eliminate the possibility that differences in detection criteria underlie speeded RTs, because error rate and RT are related by a rising S-shaped function such that small changes in error rate give rise to larger changes in RT. Thus, even if error rates are very low and there may not be enough power for these differences to reach significance, it is possible that such accuracy differences are giving rise to the observed changes in RT.

Because we were predicting superior performance by children with autism, it was essential for us to eliminate the possibility that differences in RTs between groups were merely reflecting differences in speed–accuracy criteria. Thus, we used several steps to minimize the plausibility of this account of RT differences. First, we filtered the data to ensure that the error rate for the group of children with autism was not higher than that for the group of typically developing children before we conducted analysis of variance (ANOVA) on the RT and the accuracy data.[1] Second, we analyzed both the RT and the error data so that differences between groups in either of these measures would be revealed. Finally, the graphs of both the error data and the RT data are presented here so that the reader might be assured that differences between the groups in RT measures were not mirrored by complementary opposite differences in accuracy measures.

Unless otherwise stated, a significance level of $p < .05$ was adopted for all statistical comparisons in this experiment and likewise for that which follows. Performance of the two groups of children was compared on the feature search task and the conjunctive search task. For each participant, RT data (for correct trials) and error data were averaged for the 10 trials for each particular combination of task, display size, and probe. The mean RT data and the error data were initially analyzed using a mixed ANOVA, with one between-subjects factor of group (control or autistic) and four within-subject factors of task (feature or conjunctive), probe

[1] Analysis of the RT data and the error data before filtering (i.e., with all participants) yielded identical results to analysis of the filtered data. This result was true for both experiments. These analyses are available from Michelle A. O'Riordan on request.

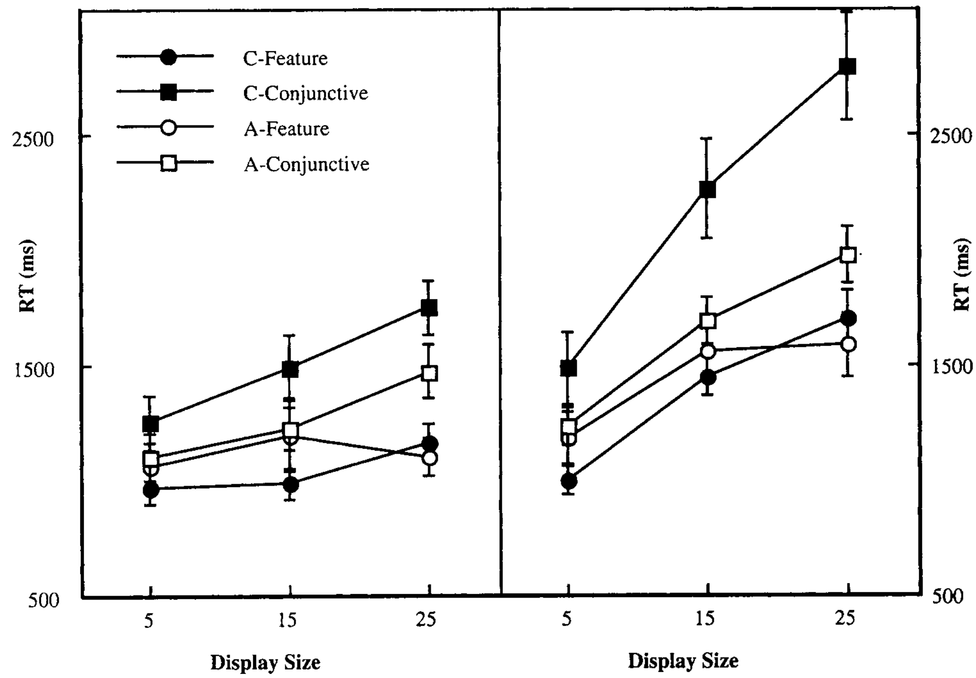

Figure 1. Response time (RT) data from Experiment 1. The left panel shows the data from target-present trials for the control group (C) and the group with autism (A) in the feature and conjunctive visual search tasks. The right panel shows the data from the target-absent trials for both groups and both tasks. Each data point shows mean RT ± *SEM*. There was no difference between the performance of the two groups in the feature search task, but the group with autism was significantly faster than the control group in the conjunctive search task.

(present or absent), display size (5, 15, or 25 items), and block (Session 1 or Session 2). Filtering the data resulted in the data from 1 child with autism being eliminated from the analysis so that the error rate would be not higher in the group with autism than in the control group.[2]

Figure 1 displays the mean RT data as a function of all the factors in the experimental design. The left panel shows the pattern of results for target-present trials on both search tasks for the normal participants and those with autism. This graph suggests that feature target detection in the normal participants was independent of display size, whereas conjunctive target detection time appears to have increased more substantially and linearly with display size; furthermore, RT also appears to have been much slower overall on the conjunctive task than on the feature task. This pattern of results in the normal group replicated the standard pattern for easy feature versus hard conjunctive search (e.g., Treisman & Gelade, 1980).

Although the participants with autism showed a similar tendency on the feature task, they seem to have performed better than the normal participants on the conjunctive task. In particular, the increase in RT with display size on the conjunctive task was not as dramatic for the participants with autism as it was for the control participants, and likewise the overall mean RT was not as high on this task for the group with autism.

The right panel in Figure 1 shows the pattern of results for target-absent trials on both search tasks for the normal participants and those with autism. The same pattern is apparent as for the target-present trials.

RT analysis. ANOVA critically revealed that the group by task interaction was significant, $F(1, 21) = 8.16$. Simple effects revealed that although there was no difference between the performance of the two groups on the feature task ($F < 1$), the control group was significantly slower than the group with autism on the conjunctive task, $F(1, 35) = 6.28$.

The group by probe interaction was also significant, $F(1, 21) = 4.39$. Simple effects revealed that the control group was significantly slower in target-absent trials relative to target-present trials, $F(1, 21) = 7.14$, but the effect of probe on the group with autism was not significant, $F(1, 21) = 2.96$, $p = .10$.

The group by display size interaction was also significant, $F(2, 42) = 7.72$. Simple effects revealed that the group with autism was significantly faster than the control group when searching the largest display of 25 items but not when searching 15-item or 5-item displays: $F(1, 25) = 5.20$, $F < 1$, and $F < 1$, for display sizes of 25 items, 15 items, and 5 items, respectively.

There were also important three-way interactions between group, task, and probe, $F(1, 21) = 6.80$, and between group, task, and display size, $F(2, 42) = 3.35$. To establish the source of these interactions, the data from each group were analyzed separately. Analysis of the data from the control group revealed interactions between task and probe, $F(1, 11) = 17.34$, and between task and display size, $F(2, 22) = 25.71$. Comparable analysis of the data from the group with autism also revealed a task by display size interaction, $F(2, 22) = 12.93$, but no interaction between task and

[2] After elimination of this participant's data, the chronological ages, $t(21) = 0.71$, $p = .49$, and the Raven's CPM raw scores, $t(21) = 0.32$, $p = .75$, of the two groups were still not significantly different.

probe ($F < 1$). Thus, the source of the interaction between group, task, and probe was revealed by the presence of a task by probe interaction in the data from the control group but not the group with autism. More specifically, typically developing children were slowed in target-absent trials relative to target-present trials to a greater extent on the conjunctive task than on the feature task. In contrast, the group with autism was slowed in target-absent relative to target-present trials comparably on both tasks.

The separate analyses of the data from each group did not reveal the source of the group by task by display size interaction in the overall analysis. However, Figure 1 suggests that this interaction occurred because, although both groups were slowed by increasing display size to a greater extent on the conjunctive task than on the feature task, the differential effect of display size on the tasks was greater in the control group than in the group with autism. Thus, several aspects of the results indicate that the group with autism performed better than normal controls in the harder search tasks (conjunction search, target-absent displays, and larger set sizes).

Further aspects of the results applied regardless of group. These main effects and interactions all replicated standard visual search results (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980). There were significant main effects of task, $F(1, 21) = 24.69$; probe, $F(1, 22) = 114.66$; display size, $F(2, 42) = 105.98$; and block, $F(1, 21) = 8.56$. There were also significant interactions between task and display size, $F(2, 42) = 34.17$; probe and display size, $F(2, 42) = 37.43$; task and probe, $F(1, 21) = 11.50$; and display size and block, $F(2, 42) = 3.24$.

Accuracy analysis. Figure 2 shows the pattern of accuracy as a function of the factors of the experimental design. Most importantly, there was no effect of group in the analysis of accuracy ($F < 1$); the control group made 3.0% errors, whereas the group with autism made 2.7% errors. There was only one interaction involving the group term. This was a three-way interaction between group, task, and block, $F(1, 21) = 5.18$. To establish the source of this interaction, the data from each group were analyzed separately. Analysis of the data from the control group revealed a task by block interaction, $F(1, 12) = 6.25$, reflecting that this group made significantly more errors on the conjunction task than the feature task in Block 2, $F(1, 11) = 19.56$, but there was no difference between the error rates on these tasks in Block 1 ($F < 1$). Analysis of the data from the group with autism revealed no such task by block interaction ($F < 1$). Thus, control participants but not individuals with autism showed a performance decrement on the harder task in the second block.

Taken together, the numerically lower error rate in the group with autism, the absence of effects involving the group term in the error analysis, and the pattern of accuracy of the two groups presented in Figure 2 suggest that there was no difference between the two groups in terms of accuracy. Thus, any differences in RT may be taken to indicate search differences rather than merely detection criterion differences. Once again in accordance with standard findings (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980), the ANOVA on accuracy also revealed significant main effects of task, $F(1, 21) = 9.18$, and probe, $F(1, 21) = 9.80$, and an interaction between task and probe, $F(1, 21) = 4.92$.

This experiment replicated the finding of Plaisted et al. (1998b) that children with autism were superior at conjunctive visual search. The more careful matching for general ability of the two groups of individuals in this experiment, using the nonverbal Raven's CPM measure, showed that the previous result cannot be explained by group differences in general ability. Therefore, some reason other than general ability underlies the superior perfor-

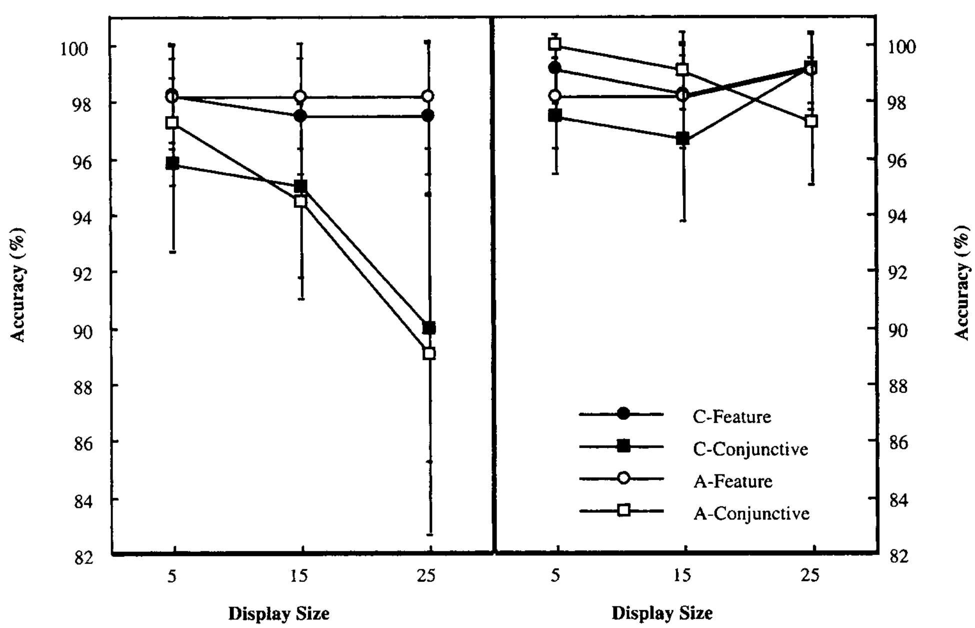

Figure 2. Accuracy data from Experiment 1. The left panel shows the data from target-present trials for the control group (C) and the group with autism (A) in the feature and conjunctive visual search tasks. The right panel shows the data from the target-absent trials for both groups and both tasks. Each data point shows mean percentage correct ± *SEM.* There was no difference between the performance of the two groups in either task.

mance of the autistic group at conjunction search. It is interesting to note that although the group with autism performed better than the control group on the conjunctive search task, both groups showed apparently serial search in this condition (see the Appendix for average search rates for each group in each condition).

Experiment 2

The first experiment demonstrated that superior conjunctive search in autism was observed even when general ability was controlled for with nonverbal IQ tests. However, that experiment did not address the question of whether superior visual search in autism is strictly confined to conjunctive tasks. In Experiment 1, as in Plaisted et al.'s (1998b) study, there was no systematic difference between the groups with and without autism on the feature task, only on the conjunction task. However, in the studies conducted so far, the feature task was much easier than the conjunction task for both groups. Performance may, therefore, have been at ceiling on the feature task, thus preventing the possibility of observing any group differences. In Experiment 2, we investigated whether there would be a difference in performance between individuals with and without autism on a feature task, which has previously been shown to be difficult for normal adults (Treisman & Gormican, 1988; Treisman & Souther, 1985). This task should prevent ceiling effects and thus reveal any possible difference between individuals with and without autism that may exist on visual search for features, provided the feature task is sufficiently hard.

Whether superior visual search in autism generalizes from conjunctive targets to hard feature targets has implications regarding the mechanisms underlying this phenomenon. If superiority is confined to search for conjunctive targets, some process involved in conjunction, but not feature search (presumably feature integration), is operating differently in autism than in typical development. Conversely, superior search for a hard feature target in autism would imply that the mechanism underlying the enhanced performance is involved in search for both feature and conjunctive targets.

This experiment again involved two search tasks. In both tasks, the stimuli consisted of two possible items that were distinguished from one another by a featural difference along a single dimension. In one task, one of these items was designated as the target, and the other item was replicated as the distractor. In the other task, the items that constituted the target and distractor were reversed. Specifically, in one task, the target was a tilted line that was presented among vertical line distractors. In the other task, a vertical line was the target, and the distractors were tilted lines. Studies with normal adults have shown that search for the tilted line target among vertical distractors is efficient and parallel, being scarcely affected by the number of distractors presented with the target; by contrast, search is inefficient and apparently serial for a vertical target among tilted distractors, with RT increasing linearly with display size. This contrasting pattern for the two related tasks is known as a "search asymmetry" effect (Treisman & Gormican, 1988; Treisman & Souther, 1985). If this effect is replicated in normal children, the harder of the two feature tasks (i.e., searching for a vertical line target among tilted line distractors) should provide the opportunity to observe any possible difference between the groups on a difficult feature task.

Method

Participants. Two groups of children participated: a group of 12 children with autism and a group of 12 developmentally normal children. The same diagnostic criteria as before were used. The ages of the children in the comparison group ranged from 6 years 5 months to 10 years 5 months. The ages of the children with autism ranged from 7 years 1 month to 9 years 7 months.[3]

The children were assessed on their mental age using the CPM (Sets A, Ab, and B; Raven et al., 1990). These data are presented in Table 2. Unpaired t tests revealed that the chronological ages and the CPM raw scores of the two groups did not differ significantly, $t(22) = 1.014$, $p = .322$, and $t(22) = 0.791$, $p = .438$, respectively.

Apparatus and stimuli. The apparatus was the same as that used in Experiment 1. Stimulus displays consisted of 5, 15, or 25 elements (i.e., straight lines) arranged in an imaginary 17.5-cm by 17.5-cm square (approximately 34° visual angle) centered around a central fixation point (a hash mark). Each element measured 0.7 cm by 0.7 cm, subtending approximately 1.0° of visual angle horizontally and 1.0° vertically. The minimum distances between the centers of each element in any display were 1.4 cm between positions in a row and 1.4 cm between positions in a column, and the items were presented in random locations across the screen. The items used in this experiment were all straight lines with a length of 0.7 cm. One type of line was vertical, and the other was rotated 18° counterclockwise.

Design. Two tasks were tested in separate sessions for each participant, with order counterbalanced within participant groups, as in Experiment 1. The tasks differed only in which of the two line types was designated the target and which provided the multiple distractors.

As in Experiment 1, each search task contained two crossed factors: display size (5, 15, or 25 elements) and probe (target present or target absent). There were 20 trials at each unique combination of factors, yielding a session of 120 trials per task, organized into four blocks. The sequence of different tasks (i.e., the particular combination of display size and probe) was randomized within each session in the appropriate proportions.

In each session, the participant knew what the potential target was but did not know whether a target would be present or what the display size would be on any trial. As before, the participants performed a binary-choice RT task, in which search was conducted for the single prespecified target.

Procedure. The procedure was the same as that used in Experiment 1 except for the larger number of 120 trials in each task, which were divided into four blocks. The first of the four blocks in each session was discarded as practice.

Results and Discussion

The data were filtered as in Experiment 1, and the data from 1 child in the control group were eliminated to ensure that the error rates for the group with autism were no higher than those for the typically developing children.[4] Performance of both groups was compared on the tilted target and vertical target tasks. For each participant, RT data and error data were averaged for the 15 trials

[3] After we filtered the data from each experiment, of the remaining participants, 7 children with autism and 6 of the typically developing children were included in both experiments.

[4] As in Experiment 1, the chronological ages, $t(20) = 1.42$, $p = .17$, and the Raven's CPM raw scores, $t(20) = 1.17$, $p = .26$, of the two groups still did not differ significantly after the 1 participant's data had been eliminated.

Table 2
Chronological Ages (Years:Months) and Raven's Matrices Raw Scores for Children With Autism and Normally Developing Children in Experiment 2

Group	Age	Raven's matrices score
Control (n = 12)		
M	8:4	26
SD	1:4	5
Range	6:5–10:5	15–32
Autistic (n = 12)		
M	8:9	28
SD	10:0	3
Range	7:1–9:7	23–32

for each particular combination of task, display size, and probe, as in Experiment 1.[5]

Figure 3 displays the mean RT data as a function of the factors in the experimental design. The left panel shows the pattern of results for target-present trials on both search tasks for the normal participants and those with autism. The graph suggests that for the normal group, both overall RT and the increase in RT with larger display sizes were greater in the task of detecting a vertical line among tilted distractors than in the reverse case of detecting a tilted line among vertical distractors. This finding suggests that the standard search asymmetry effect that has previously been observed in normal adults (Treisman & Gormican, 1988) was replicated in normal children in this experiment.

The graph also indicates that although the participants with autism showed the same RT pattern as normal participants on the easy tilted target task, they performed very differently on the hard vertical target task. The participants with autism were not slowed overall to the same extent as the normal participants on the vertical target task and showed less of an effect of display size on this task.

The right panel of Figure 3 shows the pattern of results for target-absent trials on both search tasks for the normal participants and those with autism. These data reflect the same pattern of results as the target-present data.

RT analysis. The mean RT scores were analyzed using a mixed ANOVA with the same factors as in the previous experiment. The analysis revealed a main effect of group, $F(1, 21) = 8.02$, which reflected that the children with autism were significantly faster overall than the typically developing children. As in Experiment 1, there was a critical significant interaction between group and task, $F(1, 21) = 15.11$. Simple effects revealed once again that the two groups did not perform significantly differently from one another on the easy task ($F < 1$, for tilted targets) but that the group with autism was significantly faster than the control group on the hard task, $F(1, 39) = 21.05$, for vertical targets.

There was also a significant interaction between group and probe, $F(1, 21) = 24.31$. Simple effects revealed that although the group with autism was significantly better than the control group in target-absent trials, $F(1, 23) = 15.04$, the same was not true in target-present trials, $F(1, 23) = 2.69$, $p = .12$.

There was also a significant group by display size interaction, $F(2, 42) = 12.03$. Simple effects showed that although the control group was slowed with increasing display sizes, $F(1, 28) = 4.36$, the performance of individuals with autism was overall unaffected by this factor ($F < 1$).

There were also important significant three-way interactions of group by task by display size, $F(2, 42) = 7.48$; of group by task by probe, $F(1, 21) = 8.85$; and of group by probe by display size, $F(2, 42) = 3.53$. To establish the sources of these interactions, the data from each group were analyzed separately by using the same within-subject factors as before. The analysis of the control group revealed a significant interaction between task and probe, $F(1, 10) = 11.32$, reflecting a greater difference between target-present and target-absent trials in the (hard) vertical target than in the (easy) tilted target task for the normal participants. There was also a task by display size interaction, $F(2, 20) = 13.15$. RT increased with increasing display size more on the vertical target task than the tilted target task. The probe by display size interaction was also significant, $F(2, 20) = 23.70$. Here, RT increased with increasing display size to a greater extent in target-absent trials than in target-present trials. Comparable analysis of the data from the group with autism revealed that, unlike the normal participants, there was no task by probe interaction ($F < 1$). However, the group with autism did show a task by display size interaction, $F(2, 22) = 5.95$, with a greater increase in RT against increasing display size on the vertical target task than on the tilted target task, and a probe by display size interaction, $F(2, 22) = 6.26$, reflecting a greater increase in RT with display size in target-absent trials than in target-present trials.

The presence of a task by probe interaction in the control group but not in the group with autism established the source of the three-way (group by task by probe) interaction in the original analysis. Whereas typically developing children were affected by target presence versus absence to a greater extent on the hard vertical target task than the easier tilted target task, the children with autism were not affected differentially by this for the two tasks. The presence of a task by display size interaction in the data from both groups suggests that both groups were slowed by increasing display size to a greater extent on the vertical target task than the tilted target task. However, inspection of Figure 3 suggests that the source of the three-way interaction between group, task, and display size was that the difference between the effect of display size on each task was greater in the control group than in the group with autism. In a similar manner, the probe by display size interaction was present in the data from both groups, but Figure 3 suggests that the source of the three-way interaction between group, probe, and display size was that the greater effect of display size on target-absent relative to target-present trials was more dramatic for the control group than the group with autism.

Thus, several aspects of the data suggest that the individuals with autism performed better than normal controls on the harder search tasks (vertical target, target-absent displays, and larger set sizes). The overall analysis also revealed significant main effects and interactions that replicated standard findings (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980). More specifically, there were main effects of task, $F(1, 21) = 67.93$; probe, $F(1,$

[5] Because of a computer glitch, error data were not recorded for 15-item displays in Block 2 for Control Participants 5 and 6. Values for these four data points were generated by averaging the values from Blocks 1 and 3 for these trial types for these participants. The same was true for the RT data.

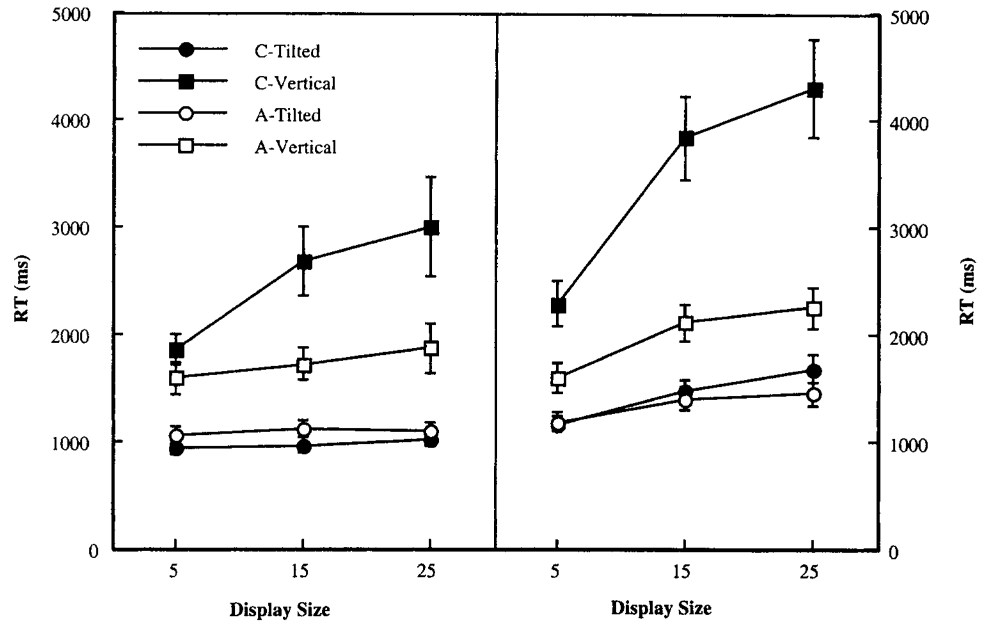

Figure 3. Response time (RT) data from Experiment 2. The left panel shows the data from target-present trials for the control group (C) and the group with autism (A) in the tilted target and vertical target visual search tasks. The right panel shows the data from the target-absent trials for both groups and both tasks. Each data point shows mean RT ± *SEM*. The group with autism was faster overall than the control group. Furthermore, there was a group by task interaction. The source of this interaction was that, although there was no difference between the performance of the two groups in the tilted target task, the group with autism was significantly faster than the control group in the vertical target task.

21) = 109.20; and display size, $F(2, 42) = 48.65$; and interactions between task and probe, $F(1, 21) = 8.54$; task and display size, $F(2, 42) = 19.02$; and probe and display size, $F(2, 42) = 27.64$. The three-way interaction of task by probe by display size was also significant, $F(2, 42) = 4.46$.

Accuracy analysis. The accuracy data are presented as a function of the factors of the experimental design in Figure 4. The mean accuracy scores were analyzed by ANOVA using the same factors as those used in Experiment 1. Most importantly, there was no effect of group in the accuracy analysis ($F < 1$); the control group made 7.3% errors, whereas the group with autism made 7.2% errors. Moreover, there were no interactions involving the group term in the accuracy analysis. The numerically higher error rate in the control group, the lack of significant effects involving the group term in the analysis of accuracy, and the pattern of accuracy of the two groups presented in Figure 4 suggest that there were no differences between the two groups in terms of accuracy. This result strongly suggests that any differences in RT can be taken to indicate search differences rather than simply differences in speed–accuracy trade-off. Significant main effects were obtained for task, $F(1, 21) = 20.35$; probe, $F(1, 21) = 12.63$; and display size $F(2, 42) = 4.95$. There were also significant interactions between task and probe, $F(1, 21) = 23.46$; between task, probe, and display size, $F(2, 42) = 3.78$; and between probe, display size, and block, $F(4, 84) = 4.84$. These results replicated typical findings for these visual search tasks (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980).

Experiment 2 demonstrated that the performance of individuals with autism was superior to that of a control group when a comparison was made using a difficult feature task (finding a vertical target among tilted distractors). This finding suggests that individuals with autism are better than typically developing individuals at hard visual searches per se and, hence, that the visual search superiority in autism is not confined specifically to conjunctive search tasks. The finding that superior visual search extends from conjunctive search to feature search is of theoretical importance. Specifically, this finding implies that the mechanism operating differently in autism and normal development is involved in both types of search task and is not a process exclusively required for conjunctive target detection, such as feature integration. However, superior visual search in autism has been seen only in tasks that reveal an apparently serial search strategy (see the Appendix for search rates for each group in each condition). This result may occur because performance on efficiently parallel search tasks is at ceiling and, thus, there is no room to see any possible difference between groups, or, alternatively, individuals with autism are efficient at a process that is selectively involved in serial but not parallel search.

General Discussion

Experiment 1 replicated the finding of Plaisted et al. (1998b) that children with autism were superior to typically developing children at hard conjunctive visual search, showing overall faster RTs and faster search rates. Unlike Plaisted et al.'s (1998b) study, the children in Experiment 1 were matched on a nonverbal measure of general ability, so the supernormal search performance of the group with autism cannot be an artifact of a higher level of

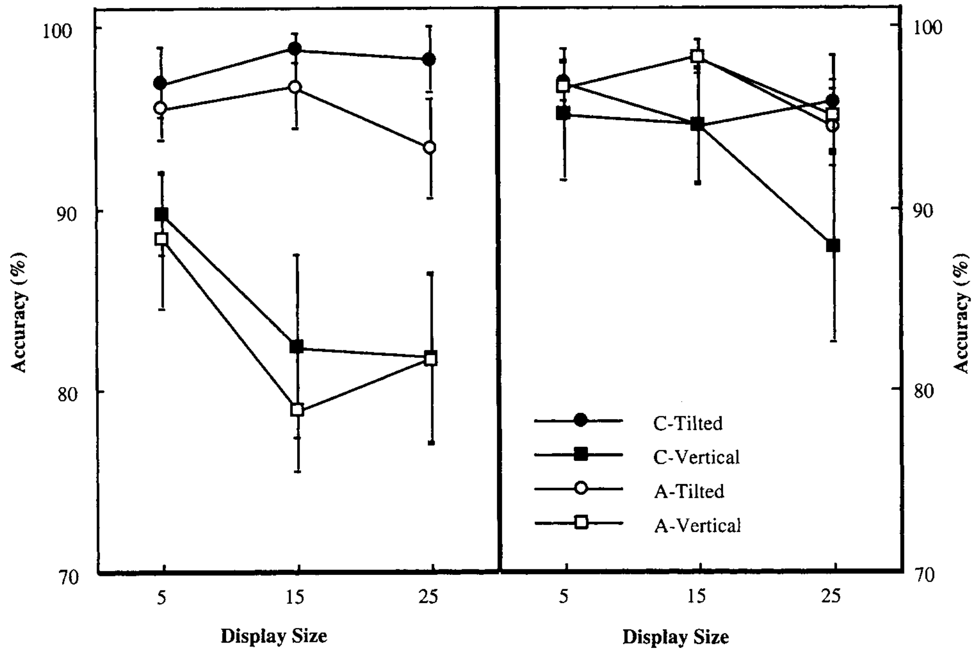

Figure 4. Accuracy data from Experiment 2. The left panel shows the data from target-present trials for the control group (C) and the group with autism (A) in the tilted target and vertical target visual search tasks. The right panel shows the data from the target-absent trials for both groups and both tasks. Each data point shows mean percentage correct ± *SEM.* There were no significant differences between the groups across tasks and conditions.

general functioning than the control group. Experiment 2 showed that, when performance was lowered from ceiling by using a difficult feature search task, individuals with autism were better than a matched control group even on feature tasks. Thus, in two separate experiments, we have found that children with autism are better than normally developing children, matched for age and general ability, at difficult visual search tasks.

One intriguing feature of the results is that the superiority of individuals with autism seemed to be more prominent in target-absent trials than in target-present trials. In fact, sometimes the superiority of individuals with autism seemed confined to target-absent trials (see the RT analyses in Experiments 1 and 2), but this was not always the case (see the analysis of the slope data in the Appendix). The increased superiority of individuals with autism in target-absent trials may simply have resulted from the fact that searching for the absence of something was more difficult than searching for its presence (Treisman & Gormican, 1988). Therefore, in target-absent trials, ceiling effects were avoided, allowing any possible differences between groups to be seen. Alternatively, it may be that, if the presence of a target is more salient to individuals with autism, then its absence might also be more obvious, and they may be more confident to indicate target absence. In other words, they may not engage in the checking procedure that most individuals use. Future research is required to determine the reasons for the magnification of the superiority of the group with autism in target-absent trials.

The finding of superior visual search in autism is interesting for several reasons. First, the finding of superior performance by individuals with autism on a conjunctive visual search task, which explicitly requires integration of the component parts of an object, challenges the lowest version of the weak central coherence hypothesis (Frith, 1989), which suggests that individuals with autism have a deficit in perceptual integration. A second interesting feature of the results presented here is that they seem to be inconsistent with the findings of impaired shifting of spatial attention in autism (Courchesne et al., 1994; Townsend, Courchesne, & Egaas, 1996; Wainwright-Sharpe & Bryson, 1993). In Experiments 1 and 2, we demonstrated superior performance in serial visual search tasks for individuals with autism relative to matched controls. Serial search involves shifting attention between successive locations in the visual display; therefore, this finding appears to challenge the notion of impaired attention shifting in autism. However, it is possible to reconcile these two findings because there are several types of attention shifting, and the type involved in visual search and that impaired in autism may be different. Attentional orienting to a stimulus can be overt (which includes orienting of the head and body) or covert (orienting of the mind's eye), and attention may be directed exogenously (by stimuli that automatically "drag" attention) or endogenously (e.g., when the participant must interpret a signal as indirectly indicating a likely target location and then voluntarily move attention). The type of orienting response and the type of cue may be combined orthogonally such that four types of orienting are possible. Many studies have investigated attention shifting in autism, but few have exhaustively assessed all kinds of attention shifting in the same group of children. One exception is a recent study by Swettenham, Milne, Plaisted, Campbell, and Coleman (2000), which demonstrated, within the same group of children, that endogenous shifts of attention were impaired in autism whereas exogenous shifting of attention was intact. Thus, superior visual search and endogenous attention-shifting impairments in autism can be reconciled if visual search emphasizes exogenous shifts of attention. However, it is not clear which type of attentional orienting is involved in visual search (O'Riordan, 1998). It may involve overt responding because participants are allowed several seconds to respond and the dimensions of the display size are sufficiently large that attention shifting may be overt. However, the average RT in conjunctive tasks has an order of magnitude that lies between the typical cue–target interval for orienting of overt attention. Thus, it seems that the type of attention shifting involved in visual search is likely to be overt but could also involve covert shifts. Furthermore, the items in the display that are most similar to the target template could be argued to capture attention and, as such, may be seen to act as an exogenous cue. Alternatively, it could be argued that the searcher compares items in the display with their template of the target and therefore directs their attention around the visual scene voluntarily (i.e., endogenously directed attention). This discussion suggests that exogenous overt attention is the most likely to be involved in visual search, but this remains to be explicitly determined. Thus, superior visual search and endogenous attention-shifting impairments in autism can be reconciled if visual search primarily involves exogenous shifts of attention.

Although the present finding may thus appear to challenge some existing accounts of perceptual and attentional disturbance in autism, the data presented here certainly support the notion of bizarre attentional and perceptual processing in autism. In fact, superior visual search performance could be seen as analogous to other reports of perceptual and attentional disturbance in autism, such as superior Embedded Figures Task performance[6] (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983) and the unusual ability to notice minor features and changes in the environment (Hayes, 1987; Kanner, 1943; NSAC, 1978). These phenomena might be collectively described as demonstrations of superior unique item detection in autism (Plaisted et al., 1998b), and thus similar mechanisms may underlie these phenomena. The mechanisms underlying unique item detection remain to be determined, and the visual search task may prove a useful tool in the investigation of these mechanisms because considerable research has been conducted on the processes involved in normal visual search (Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Treisman, 1988; Treisman & Gelade, 1980; Treisman & Sato, 1990; J. M. Wolfe, 1993, 1994; J. M. Wolfe et al., 1989; S. E. Wolfe & Durgin, 1997). Models of normal visual search suggest that several processes are involved in successful performance, and thus a difference in any of these mechanisms may underlie superior visual search performance in autism.

One possible account of superior visual search in autism derives from the notion that discriminability of the display items is the principal determinant of search efficiency (Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Treisman, 1988; J. M. Wolfe et al., 1989). This idea raises the possibility that superior visual search in autism results from an enhanced ability to discriminate between display items. It follows from this hypothesis that manipulating target–distractor similarity should not affect the performance of children with autism to the same extent as that of typically developing children. In fact, there is evidence that individuals with autism are better than matched controls at discriminating between highly similar novel stimuli (Plaisted & O'Riordan, 2000; Plaisted, O'Riordan, & Baron-Cohen, 1998a), which supports this explanation of superior visual search.

Mechanisms of top-down target excitation (Cave & Wolfe, 1990; Driver, McLeod, & Dienes, 1992; Horowitz, 1995; J. M. Wolfe et al., 1989) and distractor inhibition (Driver et al., 1992; Horowitz, 1995; Treisman & Gormican, 1988) have also been argued to be essential components of successful visual search. It is possible that stronger inhibitory and/or excitatory processing underlies the superiority of individuals with autism on visual search tasks. This notion would predict that individuals with autism would show greater effects on positive and/or negative priming tasks.

Another possible explanation for the superior visual search in autism may be found in the phenomenon of inhibition of return, which is the bias against attending to a previously attended (searched) location when searching for a target (Posner & Cohen, 1984). It has been demonstrated that inhibition of return may operate during visual search (Klein, 1988), putatively to improve search efficiency by keeping track of previously inspected search locations. It is possible that children with autism have a superior inhibition-of-return mechanism and that is what enhances their search efficiency above normal levels.[7] At present, we do not have data that are relevant to this question, but such a hypothesis would predict that measures of inhibition of return would be greater in individuals with autism.

These possible explanations for superior visual search performance in autism should be considered as neither collectively exhaustive nor mutually exclusive. Future research will determine the mechanisms underlying the phenomena illustrated in this article, and this work may be an important step in the investigation of the nonsocial features of autism. However, elucidating the precise nature of the mechanisms underlying superior visual search in autism may also have implications for understanding normal visual search performance. It seems that individuals with autism show superior performance on tasks that produce difficult, apparently serial search but not those that produce efficiently parallel search behavior. It may simply be that ceiling effects in the parallel performance tasks prevent any possible differences between groups from being detected. However, it remains a possibility that the superior performance of individuals with autism is confined to tasks that require serial search. This possibility would support the notion of a distinction between serial and parallel search and indeed may help define the distinction between tasks that produce serial versus parallel search. Knowledge of the neural mechanisms underlying normal visual search may also be facilitated by investigation of visual search in autism. More specifically, the identification of neural pathology in autism may highlight pathways that are involved in normal visual search performance.

Understanding the role of the characteristic nonsocial impairments in autism might also facilitate understanding the development of social cognition in the normally developing child. As already discussed, it is clear that there are disturbances in perceptual and attentional processing in autism, and it seems unlikely that

[6] Brian and Bryson (1996) have argued that this is not a universal finding.

[7] We thank Raymond Klein for this suggestion.

differences in such basic processes, which are intrinsic to all cognition and behavior, do not at least contribute to the social features of autism. Elucidating the nature of the nonsocial impairment will hopefully facilitate understanding of the role that these processes play in the manifestation of social impairments in autism (Jarrold, Butler, Cottington, & Jimenez, 2000) and thus also speak to the issue of distributed versus modular systems in the normally developing brain (O'Riordan, 2000).

In conclusion, this study has demonstrated that children with autism are better than normally developing children, matched for age and general ability, at detecting a prespecified target hidden among simultaneously presented distractors in standard visual search tasks, provided these are sufficiently hard. The performance of individuals with autism was superior to matched controls regardless of whether the target was uniquely defined by a feature or a conjunction of features, unless ceiling effects masked the difference. Possible explanations for this differential performance include an enhanced ability of individuals with autism to discriminate between items, a superior ability to excite target items and/or inhibit distractor items in autism, or superior inhibition-of-return mechanisms. These mechanisms need not be mutually exclusive, and future research should determine which mechanism underlies the superior visual search in autism. Following this path of research may not only facilitate understanding of autism but also have implications for issues surrounding normal visual search and social cognition.

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Appendix

Table A1 shows the mean search rates (in milliseconds per item) for each group for each combination of task and probe. For each experiment, for each participant, slope parameters for each combination of task and probe were generated by computing a linear regression of display size onto RT. The slope parameters from each experiment were analyzed using ANOVA with one between-subjects factor of group and two within-subject factors of task and probe.

Experiment 1

It is interesting that the analysis of slope data from Experiment 1 revealed a main effect of group, $F(1, 21) = 12.37$, and an interaction between group and probe, $F(1, 21) = 5.31$. Simple effects analysis revealed that the source of the group by probe interaction was that although the groups performed significantly differently in target-absent trials, $F(1, 40) = 17.49$, there was no difference in target-present trials, $F(1, 40) = 1.61$, $p = .21$. This analysis also revealed standard effects of task and probe.

Experiment 2

The analysis of the slope data from Experiment 2 revealed a critical main effect of group, $F(1, 21) = 13.81$. There was also an interaction between group and condition, $F(1, 21) = 8.44$. Simple-effects analysis revealed that the interaction between group and condition stemmed from there being an effect of condition on the performance of the typically developing individuals, $F(1, 21) = 14.28$, but no such effect in the data from the group with autism ($F < 1$). This analysis also showed a group by probe interaction, $F(1, 21) = 5.33$. Simple-effects analysis revealed that the individuals with autism were significantly better than the typically developing individuals in both target-present, $F(1, 21) = 5.81$, and target-absent, $F(1, 21) = 18.85$, trials. This analysis also revealed that the source of the interaction was that although the typically developing children were slowed in target-absent relative to target-present trials, $F(1, 21) = 17.16$, this was not significant in the data from the group with autism, $F(1, 21) = 3.87$, $p = .06$. This analysis also revealed the usual findings in visual search of main effects of task and probe and an interaction between task and probe.

Table A1
Search Rates (in Milliseconds per Item) for the Typically Developing Children and the Children with Autism in Each Task of Experiments 1 and 2

Experiment and group	Feature target		Conjunctive target	
	Present	Absent	Present	Absent
Experiment 1				
Control	9.52	38.13	25.10	65.41
Autistic	2.21	20.38	18.42	37.12
	Tilted target		Vertical target	
	Present	Absent	Present	Absent
Experiment 2				
Control	3.92	26.05	56.96	100.29
Autistic	2.29	13.08	14.00	32.93

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