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Children with autism are neither systematic nor optimal foragers

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Abstract

It is well established that children with autism often show outstanding visual search skills. To date, however, no study has tested whether these skills, usually assessed on a table-top or computer, translate to more true-to-life settings. One prominent account of autism, Baron-Cohen's "systemizing" theory, gives us good reason to suspect that they should. In this study, we tested whether autistic children's exceptional skills at small-scale search extend to a large-scale environment and, in so doing, tested key claims of the systemizing account. Twenty school-age children with autism and 20 age- and ability-matched typical children took part in a large-scale search task in the "foraging room": a purpose-built laboratory, with numerous possible search locations embedded into the floor. Children were instructed to search an array of 16 (green) locations to find the hidden (red) target as quickly as possible. The distribution of target locations was manipulated so that they appeared on one side of the midline for 80% of trials. Contrary to predictions of the systemizing account, autistic children's search behavior was much less efficient than that of typical children: they showed reduced sensitivity to the statistical properties of the search array and, furthermore, their search patterns were strikingly less optimal and less systematic. The nature of large-scale search behavior in autism cannot therefore be explained by a facility for systemizing. Rather, children with autism showed difficulties exploring and exploiting the large-scale space, which might instead be attributed to constraints (rather than benefits) in their cognitive repertoire.

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Autism is a common and often highly debilitating neurodevelopmental condition that is characterized by difficulties in social communication and repetitive and rigid patterns of behavior that are believed to be rooted in disrupted neurocognitive processes¹. Not all aspects of autistic cognition, however, are characterized by *impairments* in information processing. Rather, it is well established that people with autism show “islets of ability”². In particular, individuals with autism have been shown repeatedly to *outperform* typical children of similar age and ability on a range of visuospatial tasks. On classic visual search paradigms, children with autism are significantly faster than typical children at detecting a target (e.g., a red *S*) hidden amongst an array of distracters (e.g., a red *T* and a green *X*), particularly when search is more challenging, and requires multiple shifts of attention³⁻⁵.

One important yet hitherto unaddressed question is whether this talent is advantageous to the daily lives of people with autism. Experimental investigations of the visual search advantage in autism have almost exclusively relied on behavioral paradigms designed for the computer or table top, which are presumed to represent the state of neurocognitive processes beyond the controlled test situation (though see Caron et al.⁶). Such tasks nevertheless fail to model abilities in the larger-scale context that is typical of everyday life, including finding the carrots in the grocery store, looking for your keys in the kitchen, or finding your favorite animal in the zoo –functional behaviors that comprise a large-scale spatial navigation or search component *and* are critical to achieving independence in adulthood.

Here, we investigated whether the exceptional visual search skills of children with autism translate to behaviors in more true-to-life settings. One prominent theoretical account of autism gives us good reason to suspect that they should. Baron-Cohen et al. contend that the so-called “non-social” features of autism, including the remarkable talents in visual search together with the

defining restricted and repetitive behaviors, are manifestations of an exaggerated form of an evolutionarily adaptive, predominantly male style of processing known as *systemizing*⁷⁻¹⁰.

Systemizing is the strong preference to understand rule-based systems: to recognize the statistical regularities of stimuli within a system (e.g., prime numbers, computer programs, train timetables), to extract the “if-then” rules that govern the system, and to use these rules (repeatedly) to predict the system’s future behavior. Males, on average, show stronger systemizing than females, and people with autism – of all ages and ability – display an extreme form of this analytic information processing bias, or *hypersystemizing*⁷⁻¹⁰.

Furthermore, the systemizing account explicitly states that those tasks containing a spatial navigation or search component are precisely the situations, in evolutionary terms, in which systemizing should have conferred an advantage: strong systemizers “would have had greater success in both using and making tools for hunting, or *navigating space to explore far afield*”⁹ (p. 67, emphasis added). Accordingly, then, we hypothesized that the selective advantage for systemizing should be manifest in large-scale search or foraging, a fundamental spatial behavior, which not only relies on efficient navigational abilities but is one important context in which the human brain evolved¹¹.

In this study, we directly assessed this possibility using a more ecologically-valid search paradigm, which probes the kind of efficient navigational or foraging abilities at which individuals with autism – if hypersystemizers – should excel. Our large-scale search laboratory¹² (see Figure 1) allowed us to maintain a high degree of experimental control while approximating more closely the spatial scale that corresponds to a range of real-world tasks in which movements within the search space are required to find the target. Twenty children diagnosed with an autism spectrum condition (hereafter, “autism”) and 20 typically developing children of similar age, gender, and ability (see Table 1) took part in our “foraging game”. The child’s task was to search an array of 16 locations to

find the hidden target as quickly as possible (Figure 1A & B). They completed 40 experimental trials, divided into two blocks, separated by a short break.

Critically, and akin to search in everyday environments¹³, we probabilistically manipulated the distribution of target locations across trials so that they appeared on one side of the midline (left or right) for 80% of trials (the “rich” side; see Figure 1C). This particular probability cueing paradigm has been closely studied with adults¹³. Searching for a target in large-scale space poses a greater cost in terms of time and energy than searching in small-scale space; being able to exploit successfully the statistical distribution of target items is therefore critical to effective search. Importantly, this experimental manipulation enabled us to test directly whether children with autism, who purportedly are “expert in recognizing repeating patterns in stimuli”⁸ (p. 1377), should more readily infer the rule underlying this lawful, finite “system”. Furthermore, close analysis of *how* children carried out their search allowed us to assess whether individual children with autism were more repetitive or “systematic” in their search behavior, than typical children.

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Finally, we also examined the potential mechanisms underlying autistic children’s foraging behavior. Analysis of the component skills necessary for efficient large-scale search suggests that it depends on the abilities (a) to appraise perceptually the (global) spatial layout of the space, and (b) to remember constantly where one has searched previously (since forgetting can be costly)¹⁴. Individual differences in one – or both – of these skills might be predictive of autistic children’s search behavior. To assess this possibility, we also administered independent measures of children’s local-global processing (Children’s Embedded Figures Test^{2 15}; CEFT) and spatial memory (Corsi block task¹⁶).

Results

Our overarching aim was to test key claims of the systemizing account by examining the nature of large-scale search behavior in autism. We therefore examined whether (1) children with autism were sensitive to the statistical properties of a large-scale search environment, (2) children's search follows an optimal path, and (3) the search behavior of individual children was consistent or systematic across trials. The results below indicate that children with autism were not as sensitive to the probability manipulation as typical children and, further, that they were neither optimal nor systematic in their search – precisely the opposite to that predicted by the systemizing account. Our final analyses therefore examine the potential source(s) of autistic children's inefficiencies in foraging.

Sensitivity to the spatial probability rule

To test whether children with autism showed sensitivity to the statistical properties of the search array, a repeated-measures ANOVA with group (autism, typical) as a between-participants factor, and probability (sparse, rich) and block (Block 1, Block 2) as within-participants factors were carried out on the percentage of visits made to the rich side of space (i.e., 80% targets). This variable was derived by calculating the side of the array (left, right) showing the greatest density of button presses for each trial and indexes a child's search strategy independent of the speed with which they moved through the display (see Table 1).

There was no overall effect of group, $F(1, 38) > 1$, but there was a main effect of block, $F(1, 38) = 11.96$, $p = .001$, $\eta_p^2 = .24$, and significant block x group interaction, $F(1, 38) = 7.86$, $p = .008$, $\eta_p^2 = .17$. To explore this interaction we carried out a between group comparison for each block. Typical children were more likely to search in the rich side of space than children with autism in the first block of trials, $F(1, 39) = 7.13$, $p = .01$, Cohen's $d = .84$, but not in the second, $F(1, 39) < 1$, suggesting, in direct contrast to predictions, that children with autism took significantly *longer* to infer the rule.

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Search pattern comparison: optimal search

We further characterized children’s behavior by analyzing their search paths trial-by-trial. Each trial in our search task can be seen as a chain of inspections to finite spatial locations, and is therefore by nature very similar to eye movement sequences (or “scan paths”). A powerful way to analyze such data is to compare directly each search path against (a) an optimal way of performing the task and (b) a systematic (but not necessarily optimal) pattern of performance. We used the ScanMatch method¹⁷ to compare search paths, with the Euclidean distance between the buttons in the foraging room as the substitution matrix and a gap value of -200. A low gap value here minimizes the introduction of gaps to match the two foraging sequences¹⁷.

To establish the extent to which children’s paths were optimal, we defined optimality in terms of energy minimization, which approximates the shortest path to the target while ensuring that all intervening buttons are pressed. This description parallels the Euclidean-Travelling Salesman Problem¹⁸ (E-TSP) and in this context involves choosing a side on which to begin one’s search, and pressing the buttons along the optimal path until the target has been located. Humans have an inherent ability to find high-quality and reliable solutions to the E-TSP when confronted with problems with less than 60 locations¹⁸, which is true for children as well as adults¹⁹. We therefore computed this optimal path for any given trial using the open TSP genetic algorithm²⁰, and given the side chosen by the participant (with the greatest density of button presses, as described earlier), we truncated the path from the starting point to the target. This computation yielded an optimal path for a given trial (see Figure 2), which was directly compared with the participant’s path using the ScanMatch method. A high score on this Optimality Metric (approaching 1) is indicative of a near-optimal search path. Note that this comparison is independent of the probability manipulation as the participant’s side choice is explicitly taken into account.

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Inspection of both the individual (see Figure 2 for examples) and group (Table 1) Optimality Metric data clearly show that children with autism used a less optimal strategy than typical children for search in the foraging room. An ANOVA on the Optimality Metric data revealed significant main effects of block, $F(1, 38)=9.88$, $p=.003$, $\eta_p^2=.21$, and group, $F(1, 38)=6.24$, $p=.02$, $\eta_p^2=.14$, which were qualified by a marginally-significant block x group interaction, $F(1, 38)=3.46$, $p=.06$, $\eta_p^2=.09$. To explore this weak interaction we initially carried out a between group comparison for each block. Typical children followed an optimal search path to a significantly greater extent than children with autism during Block 1, $F(1, 39)=5.86$, $p=.02$, $d=.76$, and Block 2, $F(1, 39)=7.63$, $p=.009$, $d=.92$. Further post-hoc analyses (with Bonferroni correction) revealed that the source of the interaction lay with the degree to which children followed an optimal path from one block to the next: typical children's search paths became significantly more optimal over time, $t(19)=3.09$, $p=.009$, while autistic children's did not, $t(19)=1.16$, $p=.26$ (see Table 1).

Search pattern comparison: systematic search

It is possible that children with autism were using an alternative (less-optimal) strategy albeit in a systematic way. If children with autism are genuinely more “systematic” in their search⁷⁻¹⁰, then the pattern of button presses for individual autistic children should be more consistent than those for typical children. We once again used the ScanMatch method to derive a metric that indexed the consistent or repetitive nature of children's search. This method took into account both the side an individual visited and the length of his/her trial by truncating the longest path (since, if a child follow a systematic route, then his/her initial search patterns should be highly similar despite the target being in different locations). A high score of this Consistency Metric (approaching 1) reflects a consistency in the child's search behavior when faced with the same task on repeated trials (Table 1).

A repeated-measures ANOVA of the Consistency Metric showed no main effect of block or significant interaction involving block (both $p > .24$) but there was a significant effect of group, $F(1, 38) = 6.13$, $p = .02$, $\eta_p^2 = .14$. In striking contrast to the systemizing account, children with autism were significantly *less* consistent in their search overall ($M = .80$, $SD = .07$) than typical children ($M = .86$, $SD = .07$).

Together, these results strongly suggest that autistic children's search in large-scale space is less efficient and less systematic than typical children's search.

What, then, might account for the more chaotic search strategies of children with autism? One important measure of performance failure on our search task is the number of "revisits" children made during search (i.e., times that a location was inspected more than once in a trial; Table 1[†]). Revisits are costly and are rarely made by adults when searching in large-scale space¹⁴. A repeated-measures ANOVA on the total number of revisits revealed a significant effect of group, $F(1, 38) = 4.12$, $p = .04$, $\eta_p^2 = .10$, and a significant group x block interaction, $F(1, 38) = 8.15$, $p = .007$, $\eta_p^2 = .18$. To determine the source of this two-way interaction, we analyzed the group differences for each block separately. Autistic children made significantly more revisits than typical children in Block 2, $F(1, 39) = 7.13$, $p = .01$, $d = .44$, but not in Block 1, $F(1, 39) = 2.12$, $p = .15$.

To probe which component skills contribute to inefficiencies in autistic children's foraging performance, we examined the relationship between revisit frequency[‡] and children's scores on tests of local-global processing (the CEF^T²¹⁵) and spatial memory (the Corsi block task¹⁶) (see Table 1 for scores). In a hierarchical regression analysis, we first entered children's age, verbal ability, and nonverbal ability simultaneously as predictors of children's revisit frequency. These variables failed

[†] This variable was significantly positively skewed. A log transformation was applied to the data, which successfully normalized the data. Analyses are performed using the transformed scores although untransformed revisit data are reported in Table 1.

[‡] Preliminary data screening revealed one child who made an extreme number of revisits (+3 SD above the autism group mean). Following Wilcox²¹, this score was trimmed by replacing it with the value representing 3SD above the mean score, and subsequent correlational analyses were conducted using the trimmed score for this variable.

to contribute significantly to the model, $\Delta R^2=.27$, $\Delta F(3, 16)=1.96$, $p=.16$. Children's Corsi block task scores and CEFT scores were entered into the second and third steps of the analysis, respectively. Independent of age, verbal ability and nonverbal ability, both cognitive skills made unique (negative) contributions to predicting revisit frequency: children with autism who showed poorer spatial memory, $\beta=-.71$, $p<.01$, $\Delta R^2=.33$, $\Delta F(1, 14)=12.34$, $p=.003$, and better local processing (and hence, poorer global processing), $\beta=-.41$, $p<.01$, $\Delta R^2=.16$, $\Delta F(1, 15)=9.68$, $p=.008$, made *more* revisits during search [final model: $F(5, 19)=9.01$, $p=.001$, $R^2 = .76$].

Discussion

We assessed whether the previously reported *enhanced* visual search skills in autism translate to search in a more real-world environment. In so doing, we directly tested key claims of the systemizing account⁷⁻¹⁰ by analyzing the search patterns of children with and without autism within a large-scale space – a lawful, finite experimental structure, which was especially suited to revealing autistic children's propensity to systemize. Remarkably, children with autism showed reduced sensitivity to the probability rule governing the search array, and were both less optimal and less systematic in their search strategies, compared with typical children. These results cannot be accounted for by general and developmental differences in age, verbal ability, or nonverbal ability. Not only were the autism and typical groups matched on these variables but individual differences in these variables were unrelated to any of our experimental measures, especially the measure of performance failure (revisit frequency). Furthermore, all children found that foraging game enjoyable and were eager to find for the hidden target as quickly as they could, suggesting that the results cannot be attributable to general motivation or task-completion difficulties.

Together, these findings provide consistent evidence against the notion of systemizing in autism in two ways. First, they suggest that systemizing cannot depend on an enhanced drive to analyze systems “by observing the regularities in their behaviour and inferring the rules that govern

the system via the analysis of input-operation-output relationships”¹⁰ (p. 111). On this view, one should predict that children with autism would be just as sensitive to the probability manipulation – or perhaps even more so – than age- and ability-matched typical children. Instead, autistic children needed a greater number of trials to learn the rule and apply it to their search than their typical peers.

Second, our results speak against the notion that systemizing inherently involves “massive repetition in order to check and recheck the consistency of patterns”¹⁹ (p. 69). Rather than being significantly more systematic in their search, we found the *opposite* pattern: children with autism were significantly less repetitive in searching across trials than typical children. It is possible that autistic children’s strengths do not lie in *deducing* the rules that govern systems but, rather, in *applying* rules effectively once they become clearly known. Our data indicate, however, that despite having learned the rule by the second block of trials, children with autism showed no concomitant increase in the degree of consistency in their search. Our results therefore suggest not only that children with autism have difficulty inferring the rule that governs a (large-scale) system but also that they are less consistent in the way that they exploit the rule.

The pattern of findings reported here conflicts somewhat with previous investigations of implicit learning in autism. Several recent studies have shown that implicit learning, especially probabilistic implicit sequence learning, is unimpaired in autism²²⁻²³, despite initial reports suggesting that it was compromised²⁴. Brown et al.²² proposed that previous findings of poor implicit learning might be attributable to the use of (faulty) explicit strategies by children with autism. It is indeed possible that children in our study might have generated an explicit (albeit less efficient) strategy to find the hidden target during search. But if this were true, one might have expected individual children to verify the validity of their strategy by applying it in a consistent way across trials. Our analysis showed that this was not the case. Children with autism were less repetitive in their search patterns than typical children. We suggest instead that children with autism have specific difficulty

inferring a probabilistic rule within a large-scale environment, precisely because it requires continuous updating of egocentric and allocentric representations of space combined with the need to remember constantly where one has been in the environment¹⁴. An inability to coordinate one's behaviour in this way has far-reaching implications for navigating a local environment, and may be one important barrier to achieving functional independence in adulthood.

Our results demonstrate that children with autism do not show enhanced or systematic search during foraging. Differences in scale alone might be one reason for the discrepancy between the inefficiencies reported here and the previous reports of heightened performance on small-scale visual search tasks³⁻⁵, and future experiments will need to assess directly this possibility. We suggest, however, that the disadvantage for foraging is most likely directly attributable to the cognitive profile of autism²⁵⁻²⁶ (unrelated to systemizing), which now appears to be well-suited to table-top or computerized visual search but not to search in a wider context such as the foraging space. To forage successfully, participants must be able to orientate themselves effectively in space, and to remember where they searched previously within the space, neither of which skills are required in classic small-scale visual search paradigms¹⁴.

Close analysis of autistic children's large-scale search behavior revealed that inefficiencies as indexed by revisit frequency were in fact directly attributable to two limitations in exactly these areas. It was autistic participants' difficulties in forming a global, coherent representation and fundamental problems in spatial short-term memory that hindered their performance. Put simply, then, autistic children's search in a more true-to-life setting cannot be explained by a facility for systemizing but instead can be explained by their (limited) cognitive resources, which might otherwise permit them to show outstanding visual search in far more restricted contexts.

In summary, this is the first time large-scale search – or foraging – has been investigated in autism. Our findings clearly demonstrate the surprisingly *un*systematic nature of foraging behavior in

children with autism. In contrast to the view that the nonsocial features of autism confer an advantage to autistic children's real-world behavior⁷⁻¹⁰, we have shown that their everyday functional behavior – the ability to explore and exploit one's environment – instead may be limited by a specific pattern of constraints in their cognitive repertoire.

Method

Participants

Twenty children (18 males) with an autism spectrum condition, aged between 8 and 14 years (M=10 years, 7 months; SD=1 year, 4 months), were recruited via community contacts. All children had an independent clinical diagnosis of either autism (n=14) or Asperger Syndrome (n=6) made according to DSM-IV¹ criteria, and further scored above the threshold for autism spectrum disorder (ASD) on the Social Communication Questionnaire²⁷ (SCQ), and on the Autism Diagnostic Observation Schedules – Generic²⁸ (ADOS-G) (see Table 1). All children obtained standard scores of at least 80 on a test of receptive vocabulary, the British Picture Vocabulary Scale²⁹, and were free of medication.

Twenty typically developing children (18 boys; M=11 years, 0 months; SD=2 years 0 months) were recruited through local mainstream schools and community organizations, and served as comparison individuals. No typical child had a current or past medical or psychiatric diagnosis as reported by parents, or displayed clinically significant levels of autistic symptomatology, as indexed by the SCQ²⁷, a screening tool for autism (see Table 1).

There were no significant differences between the ASD and typical groups in terms of age, $F(1,39)=0.50$, $p=.48$, receptive vocabulary ability, $F(1,39)=.26$, $p=.61$, or nonverbal reasoning ability, $F(1,39)=.01$, $p=.96$, as assessed by Raven's Standard Progressive Matrices³⁰ (see Table 1).

Apparatus

The experiment was conducted in a large-scale search laboratory¹², which was an isolated room, measuring 4 x 4 meters, with a raised platform floor. Embedded in the floor were forty-nine search

locations arranged in a concentric structure (see Figure 1A). Each location was formed from a circular stainless steel switch (2.5 cm diameter) surrounded by an annulus (6 cm diameter) of light emitting diodes (LEDs). Each location could be individually illuminated green, red, or orange (see Figure 1B and C). The array was surrounded by dark, featureless ceiling-to-floor curtains, without apparent breaks. This ensured that the room was devoid of obvious landmarks other than the illuminated locations. The laboratory was evenly lit by dimmable units on the ceiling, all of which were obscured by white semi-opaque material. The experimenter sat in an adjoining room controlling stimulus presentation and observing the participant via a hidden camera mounted in the laboratory. The location and timing (with millisecond accuracy) of each button press was recorded.

Procedure

There were 16 (green) search locations illuminated on each trial, with 8 on either side of the array midline. The locations within the array were randomly assigned for each participant, and they remained fixed throughout the experiment (i.e., the array was not extinguished). The task was to find the hidden target, defined as the location that changed color from green to red when activated. This target appeared in each of the illuminated locations across the experiment and was always present in the array. There were 40 experimental trials, divided into two blocks of 20 trials[§]. Critically, the distribution of target locations was manipulated so that they appeared on one side of the midline (left or right) for 80% of trials (see Figure 1). Across the 40 trials, the target therefore appeared on one side (the “rich” side) for 32 trials. The likelihoods remained equal across blocks.

To begin, children were shown the laboratory and told that their task was to search the display of illuminated green locations to find the hidden target – the only light that changed from green to red when pressed. Children were instructed that a target was always present and they were to find it as quickly as they could. Importantly, they were never made aware of the probability

[§] Pilot testing with more experimental trials (60) resulted in children becoming more distractible between test trials.

manipulation. Children began each trial by pressing an orange location at a fixed point on the perimeter of the array, which was extinguished once activated. This starting location was fixed for each participant and appeared at either one end or the other of the midline (this was counterbalanced across participants). They then searched the array by activating the switch at each green location until they had located the target that illuminated red. Once children had found the target, the (orange) starting position was illuminated and the next trial began. To ensure that children understood fully the procedure, they first observed the experimenter search the display for the target, followed by two practice trials in which children themselves searched the display with the aid of the experimenter. Children then completed two blocks of trials, separated by a 5 min break (total = ~25 mins). The starting position (front or back of room, along the midline), the rich side of space (in room-based co-ordinates; left or right) and the side of the child's body that it appeared (egocentric left or right from the starting position) were fully counterbalanced across participants within each group.

In addition to background assessments (the ADOS-G, the BPVS, and Raven's Matrices), children also completed two measures thought to tap component processes of foraging: the Children's Embedded Figures Test¹⁵ (CEFT), a measure of local-global information-processing and the Corsi blocks¹⁶, a measure of spatial memory.

For the CEFT, participants completed Set A followed by Set B¹⁵, which together included 3 practice trials and 25 test trials. In each Set, children initially were shown a cardboard cut-out of a target shape (Set A: a triangle; Set B: house) and asked to find this shape hidden in a number of larger meaningful figures (e.g., a pram) as quickly as possible (Set A: 11 trials; Set B: 14 trials). Response latencies and accuracy were recorded for each trial. Children were given a maximum of 30 s to locate the target stimulus on each trial. One point was given for each trial on which they successfully located the hidden target. If the triangle was not located within 30 s, then an error was

recorded, and the maximum time (30 s) was given for that trial. The most sensitive dependent variable is time taken to find the hidden figure. Children with autism typically perform well on this task purportedly because they are not captured by the global image, which allows them to focus on the individual elements and find quickly the hidden target³. As such, fast times on the CEFT reflect good local processing (and hence, poorer global processing).

The Corsi blocks tapping task¹⁶ consists of a set of nine identical blocks positioned on a wooden board in a particular configuration. To begin, children were told: “Look at this board. It has 9 blocks on it. I am going to tap two blocks, one after the other. Watch carefully, because I want you to copy what I do. Try to tap the blocks in exactly the same order as I did.” The experimenter then pointed to the series of blocks at the rate of one block per second, and the child was instructed to point to the same blocks in the correct order. The experimenter recorded the sequence reproduced for each trial. There were a total of 8 problem sets, which progressively increased in complexity (i.e., the length of the sequences) with 5 trials per set. One point was given for each trial on which they successfully replicated the sequence. If a child failed four or more of the trials within a problem set, testing ceased. Scores on each trial were summed to yield a total score out of 40. A high score on the Corsi blocks task reflects better spatial memory. Previous work with children has reported that better spatial working memory is related to better foraging performance¹⁴.

Children completed the behavioral assessments followed by the “foraging game”. The procedures of this study were approved by the University’s Faculty of Science Human Research Ethics Committee, and informed written consent was granted by parents of all children prior to participation.

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References

1. *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV)* (2000) (American Psychiatric Association, Washington, D.C.). [4th edition]
2. Shah A, Frith U (1983) An islet of ability in autistic children: A research note. *J. Child Psychol. Psychiatr.* 24: 613–620.
3. Jarrold C, Gilchrist ID, Bender A (2005) Embedded figures detection in autism and typical development: Preliminary evidence of a double dissociation in relationships with visual search. *Dev. Sci.* 8: 344-351.
4. Joseph RM, Keehn B, Connolly C, Wolfe JM, Horowitz TS (2009) Why is visual search superior in autism spectrum disorder? *Dev. Sci.* 12: 1083–1096.
5. Plaisted K, O’Riordan M, Baron-Cohen S (1999) Enhanced visual search for a conjunctive target in autism: a research note. *J. Child Psychol. Psychiatr.* 39: 777–783.
6. Caron M-J, Mottron L, Rainville C, Chouinard S (2004) Do high-functioning persons with autism present superior spatial abilities? *Neuropsychologia* 42: 467-481.
7. Baron-Cohen S, Knickmeyer R, Belmonte MK (2005) Sex differences in the brain: implications for explaining autism. *Sci.* 310: 819–823.
8. Baron-Cohen S, Ashwin E, Ashwin C, Tavassoli T, Chakrabarti B (2009) Talent in autism: hyper-systemizing, hyper-attention to detail and sensory hypersensitivity, *Philos. Trans. R. Soc. London Ser. B* 364: 1377-1383.
9. Baron-Cohen S (2008) Autism, hypersystemizing, and truth. *Q. J. Exp. Psychol.* 61: 64-75.
10. Baron-Cohen S, Belmonte MK (2005) Autism: A window on to the development of the social and the analytic brain. *Annu. Rev. Neurosci.* 28: 109–26.
11. Kelly, R. L., *The foraging spectrum: Diversity in hunter-gatherer lifeways.* (London: Smithsonian Institution Press, 1995).

12. Smith AD, Hood BM, Gilchrist ID (2010) Probabilistic cuing in large-scale environmental search. *J. Exp. Psychol.: Learning, Memory, and Cognition* 36: 605-618.
13. Hollingworth A, Henderson JM (1998) Does consistent scene context facilitate object perception? *J. Exp. Psychol.: Gen.* 127: 398–415.
14. Gilchrist ID, North N, Hood B (2001) Is visual search really like foraging? *Percept.* 30: 1459–1464.
15. Witkin HA, Oltman PK, Raskin E, Karp S (1971) *A manual for the Embedded Figures Test.* (Palo Alto, CA: Consulting Psychologists Press).
16. Milner B (1971) Interhemispheric differences in the localization of psychological processes in man. *Brit. Med. Bull.* 27: 272-277.
17. Cristino F, Mathôt S, Theeuwes J, Gilchrist ID (2010) ScanMatch: A novel method for comparing fixation sequences. *Beh. Res. Methods* 42: 692-700; www.scanmatch.co.uk.
18. MacGregor JN, Ormerod T (1996) Human performance on the traveling salesman problem. *Percept. Psychophys.* 58: 527–539.
19. van Rooij I, Schactman A, Kadlec H, Stege U (2006) Perceptual or Analytical Processing? Evidence from children's and adults' performance on the Euclidean Traveling Salesperson Problem. *J. Prob. Solving* 1: 44 – 73.
20. Kirk J (2007) Traveling salesman problem - Genetic algorithm. URL (Accessed 5th May 2010): <http://www.mathworks.com/matlabcentral/fileexchange/13680-traveling-salesman-problem-genetic-algorithm>
21. Wilcox RR (2002) Understanding the practical advantages of modern ANOVA. *J. Clin. Child Adol. Psychol.* 31: 399–412.
22. Brown J, Aczel B, Jimenez L, Kaufman SB, Grant KP (2010) Intact implicit learning in autism spectrum conditions. *Quarterly J. of Exp. Psychol.* 63: 1–24.

23. Nemeth D, Janacsek K, Balogh V, Londe Z, Mingesz R, et al. (2010) Learning in Autism: Implicitly Superb. *PLoS ONE* 5: e11731.
24. Mostofsky SH, Goldberg MC, Landa RJ, Denckla MB (2000) Evidence for a deficit in procedural learning in children and adolescents with autism: implications for cerebellar contribution. *J. International Neuropsychological Society* 6: 752–759.
25. Happé F, Ronald A, Plomin R (2006) Time to give up on a single explanation for autism, *Nat. Neurosci.* 9: 1218-1220.
26. Pellicano E (2010) Individual differences in executive function and central coherence predict developmental changes in theory of mind in autism. *Dev. Psy.* 46: 530-544.
27. Rutter M, Bailey A, Lord C (2003) *SCQ: Social Communication Questionnaire* (Los Angeles, CA: Western Psychological Services).
28. Lord C, Rutter M, DiLavore PD, Risi S (1999) *Autism Diagnostic Observation Schedule—Generic* (Los Angeles, CA: Western Psychological Services).
29. Dunn LM, Dunn LM (1997) *Peabody Picture Vocabulary Test, Third Edition* (Circle Pines, Minnesota: American Guidance Service).
30. Raven JC, Court JH, Raven J (1991) *Standard Progressive Matrices* (Oxford: Oxford University Press).

Figure legends

Figure 1. The large-scale search laboratory. **A.** A plan layout of the 4 x 4 m room indicating an example set of locations (green dots) and the region of the room (yellow shading), which had a higher probability of containing the target. **B.** An example search location. The lights change from green (left) to red (right) to indicate the presence of the target. **C.** Illustrates a participant activating a (red) target location in the search laboratory.

Figure 2. Optimal search paths. This figure shows the search array and example search paths (blue line) for **A.** two typically developing children and **B.** two children with autism. The optimal search path on each trial is also shown (broad yellow line).

Table 1. *Descriptive statistics for chronological age, nonverbal ability, verbal ability, the Social Communication Questionnaire (SCQ) and experimental variables.*

Background Measures	Group		F	df	p
	ASD (n=20) M (SD) Range	Typical (n=20) M (SD) Range			
Chronological age (months)	127.70 (16.54) 102 – 172	132.35 (24.36) 98 – 177	.50	1,39	.48
Nonverbal ability ^a	36.30 (8.12) 25 – 48	36.20 (4.96) 24 – 45	.01	1,39	.96
Verbal ability ^b	103.35 (16.45) 80 – 137	105.80 (13.89) 82 – 132	.26	1,39	.61
SCQ score (out of 40) ^c	26.00 (5.56) 18 – 35	4.65 (3.22) 1 – 11	220.78	1,39	>.001
CEFT (ms) ^d	5.83 (3.85) 1.27 – 15.53	9.16 (4.22) 3.39 – 18.00	6.77	1,39	.01
Corsi block (out of 40) ^e	17.40 (4.38) 11 – 26	21.20 (4.72) 15 – 33	6.96	1,39	.01
Experimental Measures					
% of visits to rich side ^f					
Block 1	45.50 (16.77)	61.50 (20.91)			
Block 2	62.25 (17.43)	63.25 (25.30)			
Optimality Metric ^f					
Block 1	.63 (.11)	.70 (.07)			
Block 2	.65 (.12)	.74 (.07)			
Consistency Metric ^f					
Block 1	.79 (.08)	.85 (.08)			
Block 2	.80 (.08)	.87 (.08)			
Total number of revisits ^f					
Block 1	20.35 (23.68)	12.05 (12.00)			
Block 2	27.05 (29.70)	8.35 (8.56)			

Notes: ^a Raw scores on Raven's Standard Progressive Matrices³⁰; ^b Standard scores on the British Picture Vocabulary Scale²⁹ (BPVS); ^c Total scores on the Social Communication Questionnaire²⁷ (SCQ), where elevated scores reflect increased symptomatology; ^d Low times on the CEFT reflect good local processing; ^e High scores on the Corsi block task indicate good spatial memory; ^f See text for full details of these variables.

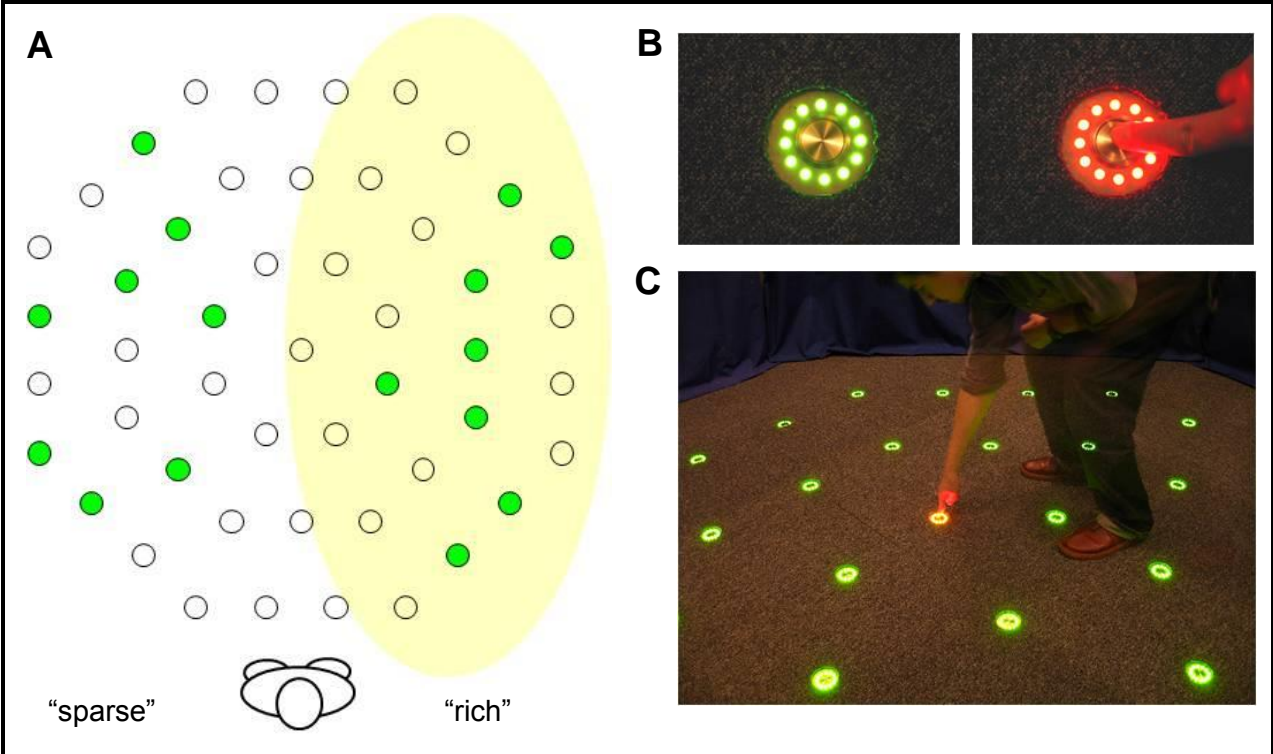


Figure 1.

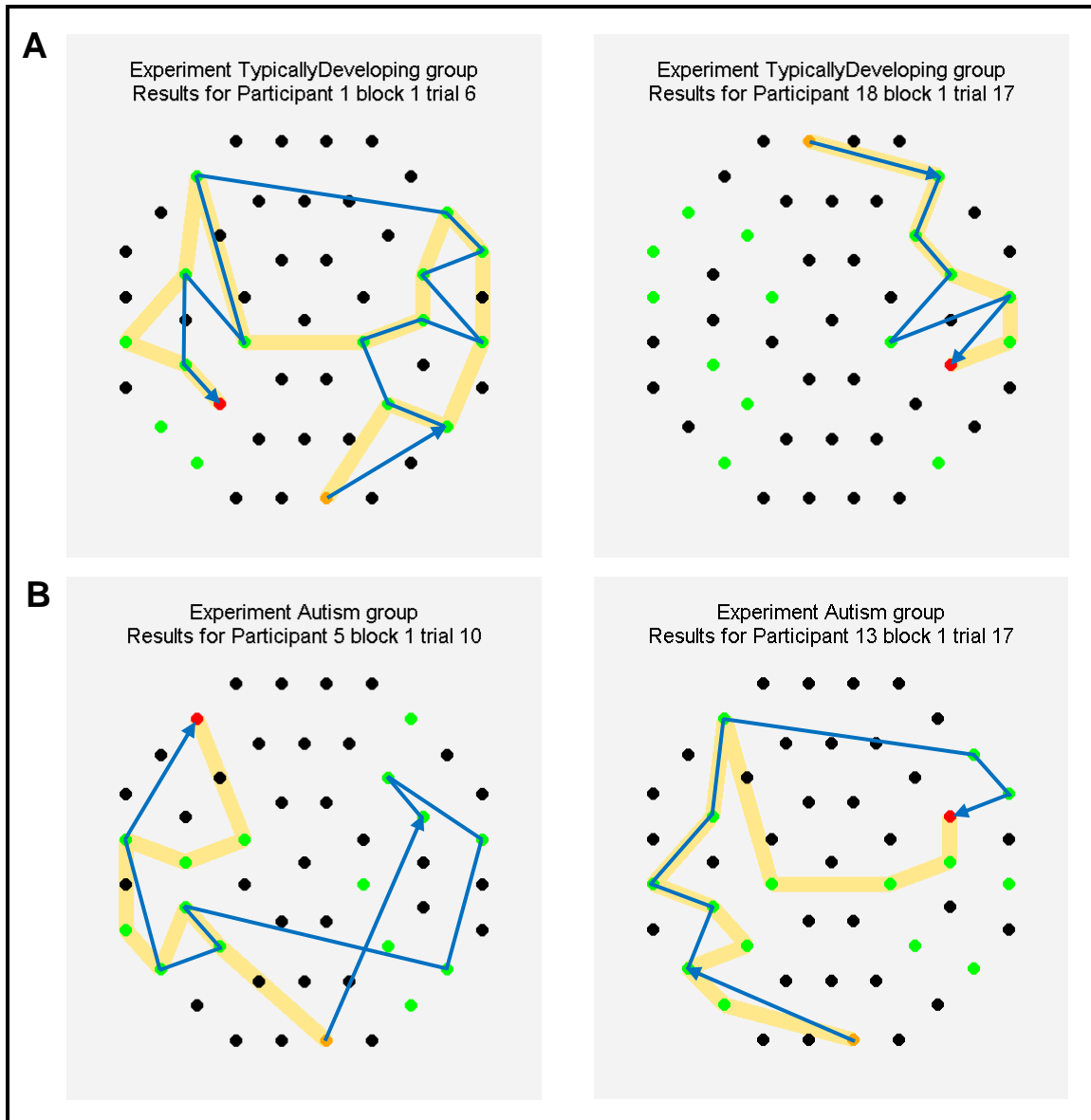


Figure 2.