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Do Adults Diagnosed with Autism Spectrum Disorders have an Advantage in Real-World Visual Search Tasks?

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Master of Science

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ABSTRACT

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Individuals with Autistic Spectrum Disorders (ASD) often perform better than typically developing (TD) individuals in simple, albeit difficult, visual search tasks. This ability is often attributed to a lack of drive for coherence or superior local processing. We compare thirty adults with ASD with forty-nine TD individuals and twenty-seven adults with anxiety (ANX) across two real-world visual search tasks. Individuals had to find either a number superimposed over a real-world scene ("no context" condition) or an object located in a contextually relevant location ("context" condition). Each participant completed forty-one trials in each condition, each with a unique scene. Eye movements were recorded using an SR Research EyeLink 1000 eyetracker. All groups performed better in the context condition. However, the ASD group was less accurate than both groups, across conditions. All groups were quicker to find the target in the context condition but the ASD group was slower than the TD group. Furthermore, the ASD group took longer to initiate their search, fixate on the target, and decide that they had found the target than the TD group. These results suggest that individuals with ASD are able to integrate contextual information to aid the search but that their previously seen visual search advantage may not transfer to visual searches of real-world scenes.

Keywords: autism spectrum disorder, visual search, real-world, eye tracking

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Do Adults Diagnosed with Autism Spectrum Disorders Have an Advantage in Real-World Visual Search Tasks?

Autism spectrum disorder (ASD) is a neurodevelopmental condition of childhood onset characterized by persistent deficits in social communication and social interaction, such as difficulty initiating and maintaining conversations and limited understanding of relationships; and by restricted, repetitive patterns of behavior, interests, and activities, such as stereotyped/repetitive movements, and inflexible routines (American Psychiatric Association, 2013). ASD is often accompanied by sensory hypo- or hyper-sensitivities (Glod, Riby, Honey, & Rodgers, 2015; Leekam, Nieto, Libby, Wing & Gould, 2007; Talay-Ongan & Wood, 2000), pronounced anxiety (Kerns & Kendall, 2012; Lugnegård, Hallerbäck, & Gillberg, 2011; Mannion & Leader, 2013), and perceptual abnormalities (Iarocci & McDonald, 2006; Meilleur, Berthiaume, Bertone, & Mottron 2014).

In contrast to the numerous difficulties faced by those with ASD, there are also reported advantages. For example, ASD samples have shown greater accuracy compared to a typically developing control sample on the block design task from the Wechsler Scales (Shah & Frith, 1993) when it required mentally segmenting the target image (i.e. reducing it into its constituent parts); ASD samples have also shown greater speed (Joliffe & Baron-Cohen, 1997; Pellicano et al., 2005) and better accuracy (Shah & Frith, 1983) when completing the embedded figures task—finding a simple target shape within a more complex design (see Muth, Hönekopp, & Falter, 2014, for a review). There is a growing body of literature suggesting that those with ASD also have advantages in more traditional visual search tasks (O'Riordan, Plaistead, Driver, & Baron-Cohen, 2001; Plaistead, O'Riordan, & Baron-Cohen, 1998; see Dakin & Frith, 2005 and Simmons et al., 2009, for reviews).

Visual Search in ASD

In visual search, a participant is tasked with identifying a specific item (the "target") which can be uniquely identified from among a group of other items (the "distractors"). There are two common visual search tasks (Duncan & Humphries, 1989; Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989). "Feature search" tasks require that the target can be differentiated from the distractors by a single feature, say, color, size, or shape (e.g., finding a red X among blue Xs). The target is said to "pop out" and the time taken to distinguish the target from the homogeneous distractors is independent of the set size (i.e. number of distractors in the array). In "conjunction search" tasks, the target is differentiated from the distractors by two or more features (e.g., finding a red X among red Ts and blue Xs). That is, the target differs from two sets of distractors by a single feature each and can only be identified via a combination of features. In contrast to the parallel search (i.e. all at once) involved in feature search, conjunction search requires the target and distractors to be searched serially (i.e. one after another) and, therefore, is generally more difficult and increases in difficulty as the number of distractors increases.

Kaldy, Kraper, Carter, and Blaser (2011) used both feature and conjunction searches with toddlers—with a mean age of two and a half years—who had a diagnosis of ASD and age-matched typically developing (TD) toddlers. In the feature search condition, there were no differences in accuracy between the ASD and TD groups. However, in the conjunction search condition, the ASD groups were more accurate than the TD group and, at the larger set size, they made discriminatory judgements between twice as many objects per trial, within the same length of time. Plaistead et al. (1998) also found advantages for children with ASD in conjunction search, compared to TD children. While both groups found the conjunction search harder, the ASD group made fewer errors and were not significantly slower compared to the feature search (unlike the TD children). To show that these differences were not due to variable ability between the ASD and TD groups, O'Riordan et al. (2001) replicated this study and ensured that the TD group were matched with the ASD group for general ability (non-verbal IQ test) and age. They, too, found that the ASD group was quicker than the TD group on the conjunction search but no less accurate. However, when they controlled for potential ceiling effects in the feature search, they also found that the ASD group performed the feature search task faster than the TD group. These characteristics have also been applied to the prediction of emerging ASD symptoms. Gilga, Bedford, Charman, Johnson, and The BASIS Team (2015) found that better performance on the visual search task (spontaneous orienting to letters) at nine months predicted greater severity of ASD symptoms at fifteen months and two years. In summary, children with ASD appear to be able to complete standard conjunction (and possibly feature) searches more quickly than TD children.

Adults with ASD have received less research attention than children but a similar advantage appears to be present. O'Riordan (2004), attempting to replicate findings from children, used feature and conjunction searches with adults diagnosed with ASD. They found that the ASD group was faster in the conjunction search and, once they controlled for ceiling effects in the feature search by adding a more difficult condition, the ASD group was also faster in the feature search. A similar result was found by Kemner, van Ewijk, van Engeland, & Hooge (2008) with age-, gender-, and IQ-matched adults with either autism or Asperger's syndrome (AS). Using an easy and more difficult feature search task, they found that the autism/AS group was faster on both tasks with the difference being more pronounced at the largest set size. As with children diagnosed with ASD, it is suggested that adults with ASD also have a speed advantage in standard feature and conjunction searches.

Possible Mechanisms for the ASD Visual Search Advantage

A number of potential mechanisms for the advantage that individuals with ASD appear to have in visual search have be postulated. In adults, it has been suggested that the factor which most determines the rate of success in conjunction searches is the discriminability of the target and distractors. That is, when target and distractor items are more similar, the search will become harder—requiring the active searching of more areas—and, therefore, become slower. O'Riordan and Plaistead (2001) applied this idea to visual search in children with ASD, using TD children matched for age and general ability. They found that the discriminability of target and distractors was the factor which most determined the rate of success for both ASD and TD children. Also, by manipulating the discriminability of the target and distractors in a number of conditions, they found that children with ASD had a greater ability than TD children—indicated by reduced reaction times—to discriminate between items. In addition, it has been shown in adults with high-functioning ASD (matched for IQ and age with TD adults) that a speed advantage in discriminating between items is present (O'Riordan, 2004). It has also been suggested that the ASD visual search advantage could be due to a heightened memory for previously searched distractor locations—thus, reducing the potential for double searching and improving efficiency (O'Riordan et al., 2001). This notion was investigated by Joseph, Keehn, Connolly, Wolfe, and Horowitz (2009) by adding a condition in which the search array changed every 500ms (ultimate item location was maintained within each trial but item orientation and which item location accommodated the target was changed). Both the ASD and the age- and nonverbal IQ-matched TD children showed similar changes between the static (single array per trial) and dynamic (array changing every 500ms) conditions. They concluded that superior search in ASD was not due to greater memory for distractor location but more likely due to non-search processes (e.g., being able to process basic stimulus feature information preattentively). Furthermore, the

ASD group were faster and made fewer fixations, and improved search was associated with increasing ASD symptoms. A central theme in many explanations of ASD search superiority involves integration—the ability to combine low level/local information (such as specific features of an object) with higher-level, global information (like a whole object or image)—which is suggested to be weaker in individuals with ASD (Behrmann, Thomas, and Humphreys, 2006; Dakin et al., 2005; Simmons et al., 2009; Smith, Ropar, & Allen, 2015). Furthermore, it has been suggested that higher-level features, such as goals and task expectations, can influence the performance of individuals with ASD, particularly in relation to whether the focus is on local or global information (Smith, Ropar, & Allen, 2015; White, 2013). Research has suggested that this disparity between local and global processing may not be due to difficulties in integration per se but differences in perception caused by factors such as the type of task used and the arrangement of the items (Kimchi, 1992; Lamb & Robertson, 1988; Mann & Walker, 2003). For example, an individual's functional field of view (FFoV) is the area of the visual field within which something can be perceived (Song, Hakoda, Sanefuji, & Cheng, 2015). By presenting stimuli at different distances from a central fixation, Song et al. (2015) showed that the FFoV in an ASD group was narrower that the FFoV in an age-matched TD group (6.62° compared to 8.57°). With greater distance from the fixation point (i.e. more peripheral), the ASD group made a correct identification on fewer trials, compared to the TD group. Song et al. (2015) suggest that this reduced FFoV may have the effect of reducing the impact of global information and imposing a bias towards local information.

Some of the proposed mechanisms not only offer potential independent insight into visual search in ASD but many also add understanding to current popular theories. Two theories that have emerged with the most fervent support are weak central coherence theory (WCC; Frith, 1989) and enhanced perceptual functioning (EPF; Mottron & Burack, 2001). In terms of local and global processing, WCC suggests that, while TD individuals have a drive to pull things together to form a more coherent whole—presumably to facilitate their understanding and experience—those with ASD seem to lack this drive towards global processing and, instead, favor local processing (see Happé & Booth, 2008 and Happé & Frith, 2006, for reviews). This extends beyond benefits in visual search and has positive and negative implications for interaction with, and understanding of, the world in general. In contrast to WCC, EPF suggests that individuals with ASD have superior local processing and that integrating global information is an optional stage (see Mottron, Dawson, Soulieres, Hubert, & Burack, 2006, for a review). Whether due to enhanced local processing or reduced global processing, it seems clear that the way individuals with ASD perceive the world is altered and, with it, the way in which they interact with it.

Everyday Implications of Visual Search

In understanding the abilities of individuals with ASD—whether with respect to visual search or beyond—there is an underlying intent to understand their experience in order to, ultimately, help improve it. Through published research, this often comes in the form of recommendations or inferences about what particular findings imply. However, caution should be exercised in the issuing of such inferences to ensure that they are appropriate and proportional with the research conducted (i.e. in a similar setting or with sufficient supporting literature). This is particularly important in light of the fact that visual search principles "discovered" under a largely lab-based focus are not always observed in tasks with a greater focus on a different context. For example, the traditional visual search paradigm involves searching for a target among distractors where the target is present on fifty percent of the trials. In general, people perform well on these tasks and commit few errors (Wolfe, 1998). However, there are certain "real-world" situations (e.g., baggage screening and cancer screening) in which target prevalence is far below fifty percent and can be closer to one percent. When these tasks are simulated in lab experiments, often with real-world images, errors (or, missed targets) can be considerably higher than expected under a traditional visual search paradigm and exceptionally more costly (Evans, Birdwell, & Wolfe, 2013; Fleck & Mitroff, 2007; Kunar, Rich, & Wolfe, 2010; Wolfe, Horowitz, & Kenner, 2005). Therefore, these real-world situations do not conform to previous traditional lab-based research—which suggested that people are good at searching for targets and that this "low prevalence effect" would not occur. Gonzalez, Martin, Minshew, & Behrmann, (2013) used computer-generated images of simulated luggage X-rays to investigate the visual search performance of adults with ASD. They used a traditional fifty percent target prevalence, as opposed to a prevalence more typical of baggage screening (e.g., one percent). Despite finding that the ASD group were more accurate at correctly identifying target-absent trials, this may not reflect their actual performance under more naturalistic conditions. However, Gonzalez et al. (2013) did acknowledge that they were not using a low prevalence paradigm and were sufficiently cautious in stating that, if individuals with ASD prove to have real-world advantages, "there is potential for this area of inquiry to uncover new ways of enhancing the self-efficacy and career prospects of adults with ASD". Similarly, sometimes real-world principles are embedded into lab experiments to create "quasi-lab-based" tasks. For example, traditional visual search items are static and infrequently change during a trial. However, when we search for things in the real-world, things can disappear from view, objects can move or grow, and shadows can cause altering luminance. Kunar and Watson (2011) sought to model these aspects simultaneously in the lab using controlled stimuli (Figure 1). This multi-element asynchronous dynamic (MAD) search yielded higher errors than traditional visual search and did not find the usually present detection advantage for moving objects and blinking (changing luminance) items. These examples illustrate the difference in conclusions that can be drawn from typical wholly lab-based visual search tasks and more naturalistic visual search tasks (Kingstone et al., 2003). Certainly, it is necessary and beneficial to study visual search in tightly controlled and simplified lab conditions to achieve experimental rigor but caution should be exercised when making inferences or recommendations from them that could have real-world implications.

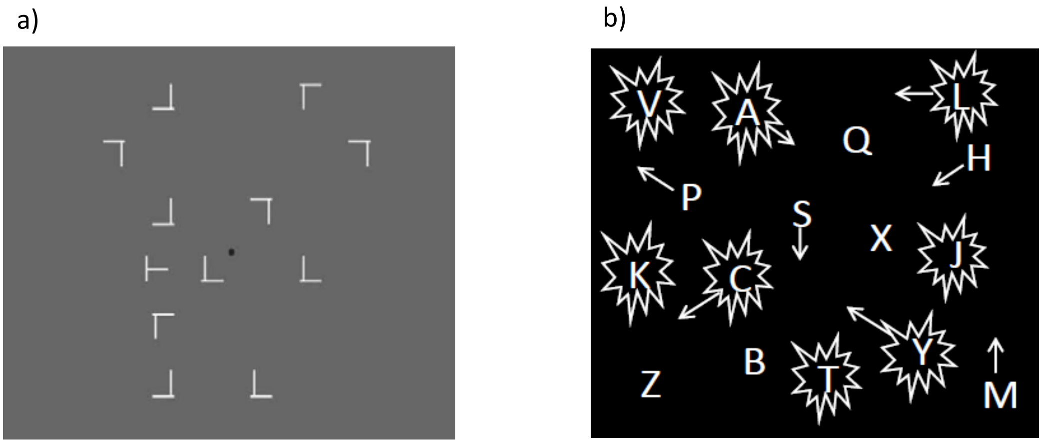

Figure 1. Example stimuli from visual search lab experiments. Image a) represents a traditional visual search display. Here, the target is the letter “T” and the distractors are offset “L”s (Russell & Kunar, 2012). Image b) represents a visual search task in which real-world elements (arrows indicate direction and explosions represent changing luminance) were incorporated to more closely represent real-world visual search (Kunar & Watson, 2011).

Visual Search in a Real-World Context

Visual search is often discussed in terms of bottom-up processing—where search is guided by salient features of the target—and top-down processing—where attention is "user-driven" and based upon information like specific target properties or probable location (Wolfe, 1998). In search using real-world scenes, top-down processing is believed to be more prominent than bottom-up processing (Chen & Zelinsky, 2006) and, when these scenes contain information that is congruent with expectations (objects appear where convention suggests they should), this can help guide search (Neider & Zelinsky, 2006; Võ and Henderson, 2009). While individuals with ASD attend to visually salient aspects of a visual scene—akin to bottom-up processing—in a similar way to TD individuals (Freeth, Foulsham, and Chapman, 2011), some research suggests that they do not apply top-down information—relative to context—as successfully as TD individuals (Benson, Piper, & Fletcher-Watson, 2009). In addition, relative to the performance of TD individuals, those with ASD have been seen to be slower at initiating the first saccade in search and make longer fixations, thus increasing search time (Kourkoulou, Kuhn, Findlay, & Leekham, 2013). Benson, Castelhano, Au-Yeung, and Rayner, (2012) investigated the ability of individuals with ASD to identify incongruent details in a real-world scene. Their first condition involved real-world scene pairs that were identical except for one object. In this condition, the ASD group and an IQ-matched TD group performed similarly, in terms of accuracy and reaction time, when identifying the difference. The second condition used the same real-world scenes but one image contained an object that was "incompatible" with the scene (e.g., an animal walking on a busy road). Participants were asked "which one's weird". In this condition, the ASD group were equally as accurate but responded slower—taking longer to scan the image before fixating on the "weird" target. In summary, while individuals with ASD demonstrate a visual search advantage in many lab-based visual search tasks—suggested to be due to a disparity between local and global processing levels—there seem to be complications with their processing of real-world images, particularly with relation to context.

Hypotheses

This study sought to understand the visual search abilities of adults with ASD, relative to TD individuals, using real-world scenes. As individuals with ASD have a high co-morbidity with anxiety (Lugnegård, Hallerbäck, & Gillberg, 2011; Mannion & Leader, 2013), groups of individuals with anxiety (ANX group) were included in order to attempt to separate the influence of ASD and anxiety. Given the use of real-world scenes, our hypotheses were as follows:

i. We expected that individuals with ASD would perform worse than TD and ANX individuals in both conditions. We believed that this would be manifest by reduced accuracy and slower reaction times.

ii. We expected that, when searching for targets located in a contextually-congruent location, all groups would improve, relative to the no context condition. We believed that this would be manifest by increased accuracy and faster reaction times.

Method

Participants

Three groups of adult participants were recruited: a group diagnosed with an autism spectrum disorder (ASD), a group with high levels of anxiety but not ASD (ANX), and a typically developing group (TD). Each group consisted of thirty, twenty-seven, and forty-nine participants respectively (see Table 1 for participant characteristics). A diagnosis of ASD was confirmed using Module 4 of the Autism Diagnostic Observation Schedule–Second Edition (ADOS-2; Lord et al., 2012; see "Measures" section for further details on this and other measures) using standard cut-offs. Level of anxiety was measured using the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) and was completed by all participants, using standard cut-offs. All groups completed the Wechsler Abbreviated Scale of Intelligence–Second Edition (WASI-II; Wechsler, 2011).

Table 1

Participant Characteristics

	ASD (n = 30)	ANX (n = 27)	TD (n = 49)
	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	25.38 (7.74)	21.59 (2.69)	20.88 (1.99)
Gender	25 Male	10 Male	31 Male
IQ (WASI-II)	110.67 (13.88)	112.42 (11.89)	112.02 (8.00)
Anxiety (PSWQ)	49.63 (14.48)	62.85 (8.83)	46.36 (12.89)

Note: WASI-II = Wechsler Abbreviated Scale of Intelligence—Second Edition; PSWQ = Penn State Worry Questionnaire.

The ASD group were recruited via community adverts and through a local private practice offering psychological services with a particular emphasis on ASD. The ANX group were recruited from students visiting the Brigham Young University counseling center for the first time, who specifically reported difficulty with anxiety. E-mail invitations were sent to those who scored above the 84th percentile for the anxiety scales—and below the 84th percentile on depression and the other scales—on the Counseling Center Assessment of Psychological Symptoms--62 (CCAPS-62; Locke et al., 2011). The TD group were recruited through a research participation program run by Brigham Young University. They were primarily undergraduate students and reported no significant psychological concerns or previous diagnosis.

Measures

Autism Diagnostic Observation Schedule—Second Edition (ADOS-2; Lord et al., 2012). The ADOS-2 is a semistructured, standardized measure assessing various aspects of ASD. Used in both clinical and research settings, it is part of the "gold Standard" of assessment for ASD (Kanne, Randolph, & Farmer, 2008). For this study, Module 4 (suitable for verbally fluent older adolescents and adults) was used with all participants.

In terms of internal consistency (Cronbach's α) for Module 4, McCrimmon and Rostad (2014) found that the social communication domain exceeded 0.75; the social interaction domain was 0.85, and the restricted and repetitive behaviors was 0.47 (values for this domain are lower for all modules). Correlations between items and domains ranged from 0.50 and 0.88. In another study, the ADOS-2 was able to classify 74.2% of the cases correctly as having ASD (Bastiaansen et al., 2011)

Counseling Center Assessment of Psychological Symptoms—Sixty-Two Item Version (CCAPS-62; Locke et al., 2011). The CCAPS-62 is a self-report measure of distress and adult mental health designed specifically for use with students in college counseling centers. An individual is asked to respond to questions in relation to the previous two weeks on a 5-point likert scale, ranging from "not at all like me" to "extremely like me". Separate scores can be obtained for each subscale (Depression, Generalized Anxiety, Social Anxiety, Academic Distress, Eating Concerns, Family Distress, Hostility, and Substance Use) and cut-off scores indicate level of severity from the ranges Low, Mild, and Elevated.

Concurrent validity, with relevant referent measures, has been established for each subscale in both a clinical (McAleavey et al., 2012) and a non-clinical (Locke et al., 2011) sample. For example, the depression subscale has a correlation of 0.821 ($p < 0.01$) with the Beck Depression Inventory (BDI) in a clinical sample and 0.721 ($p < 0.01$) in a non-clinical sample. This subscale also had an internal consistency (Cronbach's α) of 0.913 (Locke et al., 2011).

Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990). The 16-item PSWQ is a self-report questionnaire looking looks at the trait of worry. The questionnaire asks participants to indicate the extent to which statements are representative of them. It uses a five-point likert scale, ranging from “not at all typical of me” to “very typical of me.”

The PSWQ has a reported internal consistency (Cronbach’s α) of between .91 and .93; the test-retest reliability—from between two weeks and one month—has been ranges from .74 to.93 ($p < .001$) across samples (Meyer, Miller, Metzger, & Borkovec, 1990; Pallesen, Nordhus, Carlstedt, Thayer, & Johnsen, 2006); and Brown, Antony, & Barlow (1992) have shown convergent validity ($r = .35$, $p < .001$) with the Anxiety subscale of the Self-Analysis Questionnaire-Form 9 (Lovibond, 1983).

Wechsler Abbreviated Scale of Intelligence—Second Edition (WASI-II; Wechsler, 2011). The WASI-II is a short and reliable measure of intelligence that was designed to be used in both clinical and research settings. It can be used as a four-subtest version (Vocabulary, Similarities, Block Design, and Matrix Reasoning) and a two-subtest version (Vocabulary and Matrix Reasoning). In this study, the two-subtest version was administered. The scores on these subtests yield a Full-Scale IQ (FSIQ-2) and are intended to give an understanding of general cognitive abilities.

The FSIQ-2 score has an average reliability (Fisher's z-transformation) of 0.94 for the adult sample (Wechsler, 2011). In addition, it has established convergent validity with the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV), the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV), and the Kaufman Brief Intelligence Test, Second Edition (KBIT-2).

Stimuli

The stimuli used for both conditions (context and no-context) consisted of eighty-two images containing a variety of real-world scenes (see Figure 2). They ranged from images of household rooms to images of streets and were from diverse cultural settings. While the images represented a breadth of settings, each image had a depth of content so as to be consistent in their contextual richness. In the context condition, the target item was a real-world item located in its natural, expected position (e.g., a book on a bookshelf or a door-handle on a door). In the no-context condition, the target was a small digit (e.g., 2, 9) superimposed on the real-world scene in a random position. Digits were displayed in Arial 9pt font. The locations of these digits for each image were determined by taking the location of the targets in the context condition and randomly shuffling them across images. Thus, across all images, the natural in-scene targets and the superimposed digit targets appeared in the same sets of locations. Therefore, there was no benefit to understanding the context of the scene or the target in the no-context condition. However, in the context condition an understanding of the item-scene context (both the context of the scene as a whole and the likely context of the item within the scene) would allow the target search to be narrowed down. All images were displayed in full color, were of equivalent resolution, and were the same size relative to the visual display they were presented on. The area around the target that the participant had to fixate within to register a target as found was a circle with a diameter of 75 pixels, centered on the target.

Figure 2. Example real-world images. Image a) is an example of the “no-context” condition. The intended target (the number “8”) has been highlighted. Image b) is an example of the “context” condition. The intended target (a “Clock”) is locate on a mantelpiece and has been highlighted.

Eye Tracking

Eye movements were measured using an SR Research Eyelink 1000 eye-tracker (SR Research, Canada) with a resolution of 0.01° visual angle and a sampling rate of 1000Hz. Subjects were seated 60 cm away from a 24” LCD monitor with display resolution set to 1600 x 900. Scenes (800 x 600 pixel images) subtended 21 by 16 degrees of visual angle. Head movements were minimized with a chin and head rest. Although viewing was binocular, eye movements were recorded from the right eye. The experiment was controlled with SR Research Experiment Builder software.

Procedure

The visual search task was to indicate, via pressing a button on a button box, that a specified target had been located. Each trial involved the following sequence. Each trial began with a gaze trigger, which consisted of a black circle presented in the center of the screen. Once a stable fixation had been detected on the gaze trigger, a word (Times New Roman, 20pt font) was presented in the center of the screen for 1 second. This word identified the target for that trial, and was either an item name (e.g., "Candle"), for the context condition, or a number name (e.g., the printed word "Seven"), for the no-context condition. This word was followed by the presentation of the real-world scene. The next trial commenced once the participant had pressed the relevant button to indicate that they had found the target or after 12 seconds, whichever was sooner. Participants were instructed to press the button while looking at the target item. Following the completion of a trial, the gaze trigger reappeared and the process was repeated.

Each participant completed 41 trials, and a single practice trial, in both the context and no-context conditions, administered as separate blocks. The order of the context or no-context blocks was randomized, as was the order of the images within the blocks. No feedback was given for any of the trials. Reaction time (RT) was defined as the length of time between the scene onset and the button press. A successful trial was one in which the button was pressed while the target was fixated. Accuracy was defined as the proportion of successful trials.

Data Analysis

Prior to data analysis, some data was removed as part of data preparation. Trials with response times under 200ms were removed as outliers as well as those values that were greater than 2.5 SD from the mean of each participant. All data analysis was conducted using "R" (R Development Core Team, 2016). We employed mixed effects modeling for data analysis using the lme4 package (Bates, Mächler, Bolker, & Walker, 2014). This is a form of linear regression which allows for the inclusion of both fixed effects and random factors in the model that is also well-suited for analysing continuous and categorical predictors. In addition, continuous and categorical predictors can be included. Furthermore, ANOVA analyses are not appropriate for categorical data, such as the accuracy data obtained here, but logit mixed effects models can handle this type of data well (Jaeger, 2008). The accuracy data were subject to a logit transformation to satisfy normal distribution assumptions. RT data were similarly log transformed.

We also analyzed three variables that reflect different stages in the search processes: initiation time, scan time, and verification time (Malcolm & Henderson, 2009). Initiation time reflects how long it takes to begin the search and is defined as the elapsed time from the start of the search task (when the scene appears on screen) to the start of the first saccade. Scanning time is the time it takes to find the target and is timed from the start of the first saccade to the start of the first fixation on the target object. Verification time is the time required, once the target has been found, to identify it as the target. Finally, we analysed the number of distinct occasions per target that individuals in each group made a fixation (or series of fixations) within the target area. We refer to each occasion as a “run”.

Results

Central Hypotheses

Accuracy. The data from the fixed effects analysis of accuracy are shown in Table 2. The interaction of group (ASD/TD/ANX) and search condition (context [object]/no context [number]) was not significant and, therefore, was not included in the model. In all subsequent analyses, the interaction term was only included if it was significant. All groups were more accurate in the context (object search) condition, as expected. To look at the effect of group (in this and all subsequent analyses), the groups were dummy coded so that the TD and ANX groups could each be compared with the ASD group. Participants in the ASD group were less accurate than both the TD and ANX groups, while controlling for condition (see Figure 3), as per our hypothesis.

Table 2

Accuracy

	b	SE	*z*-value	*p*-value
(Intercept)	0.050	0.15	0.33	0.74
Context Search	1.23	0.088	14.01	< .001
Group: TD	0.88	0.15	5.70	< .001
Group: ANX	0.44	0.18	2.49	0.013

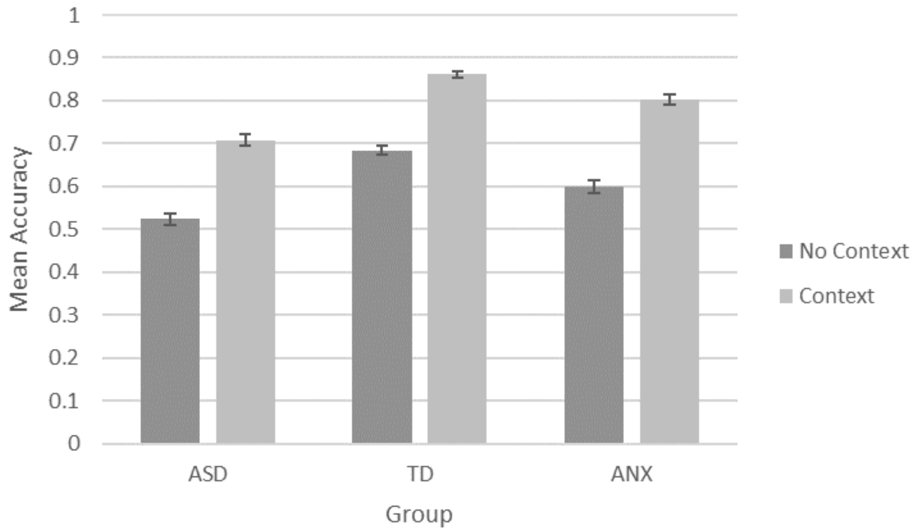

Figure 3. Mean accuracy for the autism (ASD), control (TD) and anxious (ANX) groups in both the context and no context conditions.

Reaction time. The fixed effects results for RT can be seen in Table 3. RT was defined as the time taken to identify the target image. Controlling for group, all participants were significantly faster in the context condition, as expected. The ASD group was significantly slower than the TD group, across conditions. However, the RT of the ASD and

ANX groups did not differ (Figure 4). We had expected, as per our hypothesis, the ASD group to be slower than both groups in the no context condition, but this was only the case for the TD group. They did, however, show an improvement (i.e. reduced reaction time) in the context condition. The interaction was not significant.

Table 3

Reaction Time

	b	SE	*t*-value	*p*-value
(Intercept)	8.08	0.042	192.98	< .001
Context Search	-0.17	0.020	-8.84	< .001
Group: TD	-0.19	0.036	-5.19	< .001
Group: ANX	-0.063	0.042	-1.50	0.14

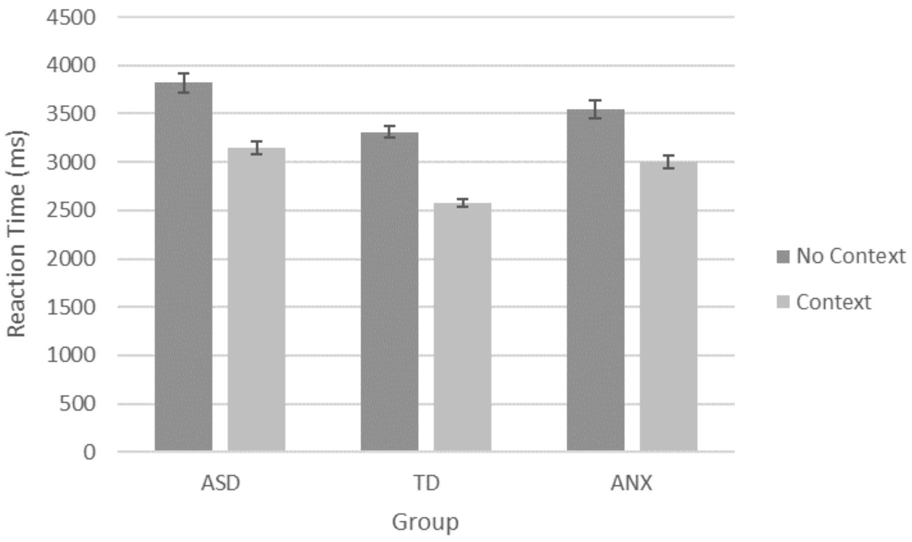

Figure 4. Reaction Time (ms) for the autism (ASD), control (TD) and anxious (ANX) groups in both the context and no context conditions.

Search Mechanics

Initiation time. The fixed effects results for search initiation can be seen in Table 4. There was no difference for all participants in the search initiation time across both search conditions. However, controlling for search condition, the ASD group took significantly longer to initiate their search than both the TD and the ANX groups (Figure 5). The interaction was not significant.

Table 4

Initiation Time

	b	SE	*t*-value	*p*-value
(Intercept)	5.71	0.020	281.76	< .001
Context Search	-0.011	0.0077	-1.39	0.17
Group: TD	-0.055	0.024	-2.30	0.023
Group: ANX	-0.062	0.027	-2.27	0.025

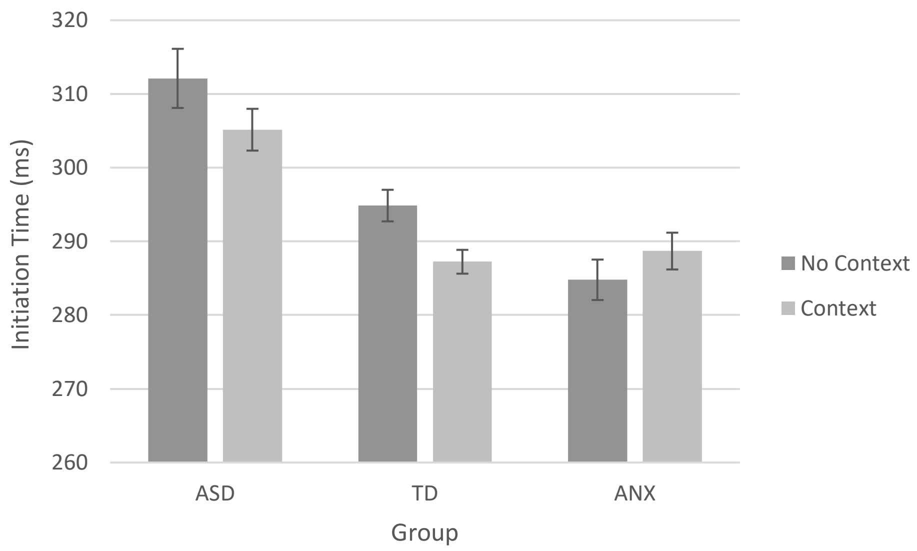

Figure 5. Initiation Time (ms) for the autism (ASD), control (TD) and anxious (ANX) groups in both the context and no context conditions.

Scanning time. The fixed effects for the scanning time are in Table 5. All participants took longer to make their first fixation on the target in the context condition than in the no context condition. The ASD group required a significantly longer scanning time than the TD group but there was no difference between the ASD and ANX groups (Figure 6). The interaction was not significant.

Table 5

Scanning Time

	b	SE	*t*-value	*p*-value
(Intercept)	6.18	0.081	76.13	< .001
Context Search	0.32	0.031	10.24	< .001
Group: ANX	0.021	0.11	0.20	0.84
Group: TD	-0.23	0.093	-2.50	0.014

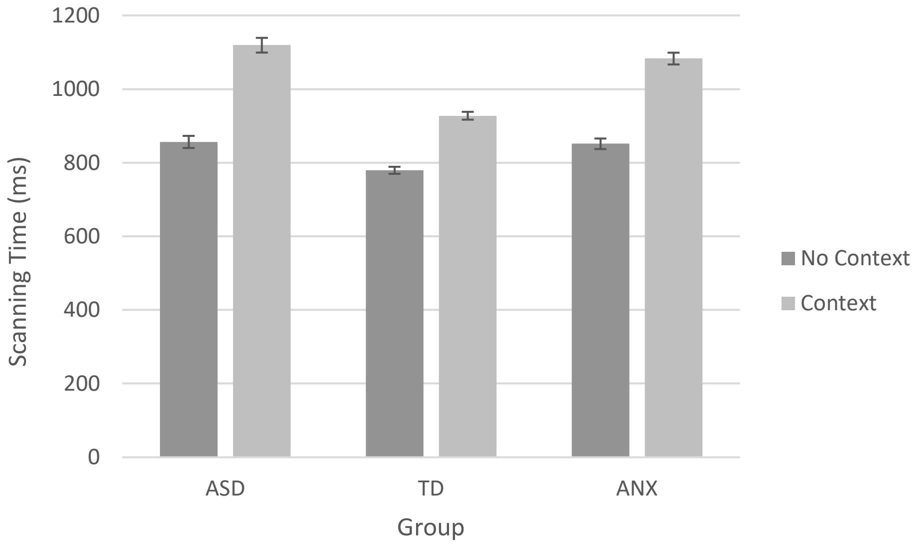

Figure 6. Scanning Time (ms) for the autism (ASD), control (TD) and anxious (ANX) groups in both the context and no context conditions.

Verification time. The fixed effects for the verification time can be seen in Table 6. In the context condition, all participants took less time to decide that they were looking at the target. Controlling for condition, the ASD group had a longer verification time than the TD group but there was no different between the ASD group and the ANX group (Figure 7). The interaction was not significant.

Table 6

Verification Time

	b	SE	*t*-value	*p*-value
(Intercept)	7.47	0.056	134.35	< .001
Context Search	-0.41	0.028	-14.88	< .001
Group: ANX	-0.027	0.043	-0.63	0.53
Group: TD	-0.11	0.037	-3.01	< .01

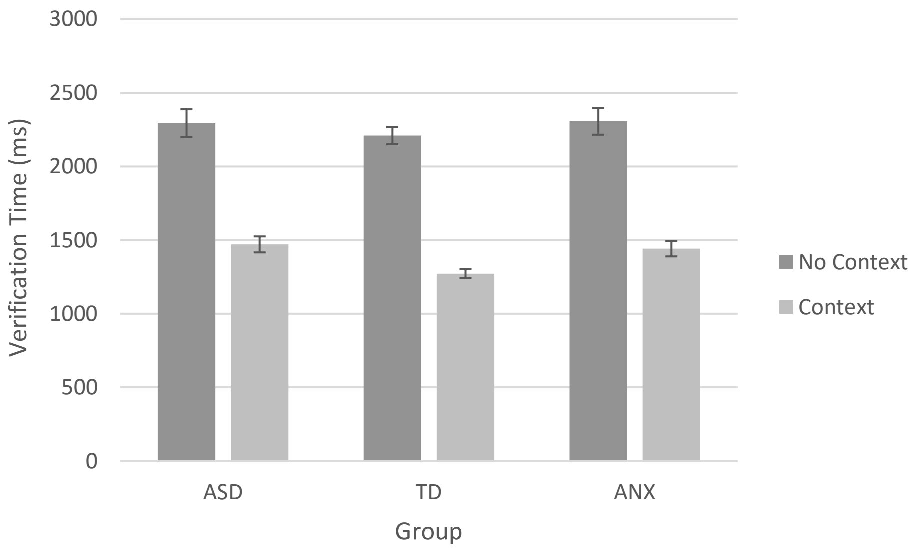

Figure 7. Verification Time (ms) for the autism (ASD), control (TD) and anxious (ANX) groups in both the context and no context conditions.

Follow-up Analysis

Number of runs. The fixed effects for the total number of runs during each search can be seen in Table 7. All participants performed more runs in the context condition that the no context condition. The ASD group performed significantly more runs than the TD group, controlling for condition, while there was no difference between the ASD and ANX groups (Figure 8). The interaction was not significant.

Table 7

Number of Runs

	b	SE	*t*-value	*p*-value
(Intercept)	1.41	0.040	35.00	< .001
Context Search	0.20	0.019	10.31	< .001
Group: ANX	-0.056	0.033	-1.71	0.090
Group: TD	-0.11	0.028	-3.92	< .001

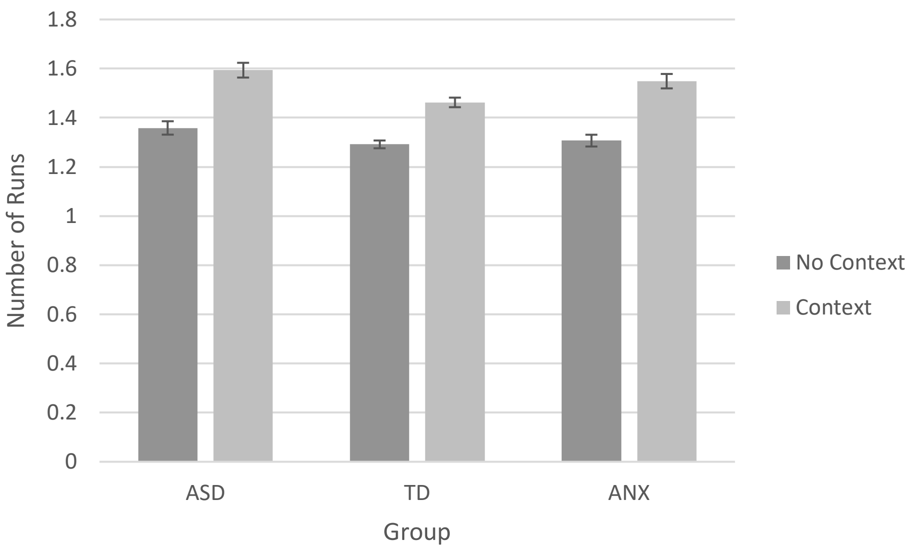

Figure 8. Mean number of runs for the autism (ASD), control (TD) and anxious (ANX) groups in both the context and no context conditions.

Discussion

Accuracy and Reaction Time

The outcome of the accuracy and reaction time analyses suggested generally poorer accuracy and slower reaction times for ASD individuals, across both the context and no context conditions. The advantage of ASD individuals in lab-based visual search is a robust one but this study, utilizing more naturalistic scenes, did not yield this same advantage. It is usual to seek to understand this in terms of perceptual differences (i.e WCC or EPF). However, another theory, that does not implicate perception as the main source of the ASD advantage, has recently been posited. Instead of perceptual differences, this theory (Kaldy, Giserman, Carter, & Blaser, 2016) suggests that an "atypically functioning attentional system" plays an important role. That is, individuals with ASD have been seen to demonstrate a tendency to over-focus and have difficulty disengaging this attention. Kaldy et al. (2016) suggest that the ability individuals have to over-focus leads to the advantage they have in simplified visual searches. Extending this theory to real-world scenes, it could be suggested that while traditional visual search may provide a finite source of attentional opportunities—and, thus, allow over-focusing on individual areas to benefit search—real-world scenes have a myriad of options. Therefore, if an individual with ASD is bombarded with different elements vying for attention, it could be suggested that trying to temper an over-focusing tendency within the confounds of a real-world visual search may prove difficult.

While the ASD group was less accurate in both conditions, it is interesting to note that, like the TD and ANX groups, they did perform better in the context condition than the no context condition. Previous theories reporting the ASD search advantage have suggested that either they have a lack of drive for coherence and favour local processing (as in WCC theory; Frith, 1989), or, that they have superior local processing with global processing being optional (as in EPF theory; Mottron & Burack, 2001). Either way, local processing has been seen to yield better performance. However, their improvement in the context condition (over the no context condition) suggests that local processing is potentially not an advantage ASD individuals can draw upon in naturalistic scene search and that, relative to local processing, they do not exhibit a deficit in global processing. Indeed, the extent of their improvement in the context condition, while still not as accurate as the other groups, was again similar to that of the other groups (Figure 3). These findings suggest that in a real-world visual search, individuals with ASD are able to integrate contextual information to guide their search, albeit, not as well as TD individuals. In addition, for the tasks used here, real-world scenes do not allow them to take advantage of any benefits from local processing they may have in lab-based tasks.

Similar to the accuracy analyses, the RT of the ASD group was slower than both the TD and ANX groups. Previous research with simplified target-distractor visual searches has suggested that, not only are individuals with ASD at least as accurate as controls, they are usually quicker to identify the target (Keehn et al., 2009; Kemner et al., 2008; O'Riordan 2004). However, this was not the case with the naturalistic scenes used in this study, in either condition. Furthermore, while they were slower than the TD group in both conditions, they found the target quicker in the context condition than in the no context condition, again suggesting that they were able to integrate contextual information to improve their search time.

In terms of perception, these results suggest that individuals with ASD neither have a lack of drive for coherence (as in WCC) nor are they superior at local processing (as in EPF) when applied to real-world images. If, indeed, their global processing is optional, then it appears that they may be able to use it to their benefit in real-world situations. However, as the results suggested they are impaired, relative to TD individuals, at visual search in real-world settings with or without target context, there may be something about the real-world scenes that is driving this disparity. Top-down processing is commonly used in visual search (Wolfe, 1998) and particularly so with real-world scenes (Chen & Zelinsky, 2006). However, it has been suggested that individuals with ASD attend to visually salient aspects of visual scenes—a more bottom-up process (Freeth, Foulsham, and Chapman, 2011). Given the nature of the real-world scenes—with numerous objects, colors, contours, contrast, and shapes—it is possible that there may have been multiple visually salient areas which may have prevented them from treating the visual search as a no context search. This increased complexity and accompanying increased processing demands with local, bottom-up processing could have reduced RT and accuracy. Further, an often-cited aspect of the ASD visual search advantage is their ability to discriminate between the target and distractor objects (O'Riordan & Plaistead, 2001). It would have been expected that finding a superimposed number (as in the no context condition) would have allowed this benefit to be manifest, plus, individuals with ASD are more resistant than controls to distractor set-size in usual visual search tasks (Kemner et al., 2008). However, the number, variety, and relative interest of distractors in the real-world scenes may have required too great a cognitive load to allow them to exhibit the usual benefit in local processing. In other words, there could have been too many things for them to process locally which, instead of aiding search, could have hampered it relative to the standard search of the TD group.

Search Mechanics

In order to learn more about why there might be a difference between the ASD group and the TD and ANX groups, we looked at certain aspects of their search, breaking down target location into smaller stages—initiation time, scanning time, and verification time. Compared to the TD group, the ASD group was characterized by: slower search initiation; taking longer to initially fixate the target; longer time needed to verify the target was the target; and a greater number of runs (visits to the target area before identifying it as the target). Initially, this might suggest that some of the difference in their search performance (i.e. accuracy and RT) may be due to these aspects of their search. Indeed, previous research has shown that individuals with ASD exhibit slower initiating and longer fixations in more naturalistic visual searches (Kourkoulou et al., 2013). However, with the exception of search initiation time, none of these aspects were significantly different from the ANX group, suggesting that a level of anxiety often present in individuals with ASD may, at least partially, account for the extended length of time taken navigate the search steps and to decide on whether they had found the target and move on. However, the ASD and ANX groups were significantly different in their accuracy. Therefore, it appears that there may be something other than anxiety that accounts for the reduction in accuracy for the ASD group.

Implications

Encouragingly, this study suggests that individuals with ASD may be better at integrating contextual information than previously thought. Not only that, it enabled them to perform better in the context condition than in the no context condition, to a similar degree to the TD and ANX groups.

The previously suggested visual search advantage for individuals with ASD has been used to support the idea that this could possibly be used to enhance their career prospects (Gonzalez et al., 2013). However, in light of the difference in accuracy and RT for the ASD group, compared to the TD group, we would urge caution and advocate further research before such suggestions are taken further. While individuals with ASD may hold an advantage in certain situations, more information is needed about what these situations are and what aspect of visual search with real-world images might be giving rise to this discrepancy. At the simplest level, this study suggests that individuals with ASD may struggle with visual searches approximating real-world situations and, potentially, real world visual situations generally. This could add to our understanding of the difficulties that they have navigating physical and social interactions and, in many respects, the larger world, without the grounding of routines or familiar individuals.

Limitations and Future Directions

As suggested, there may have been aspects of the real-world images that influenced the performance of the ASD group (e.g. the shapes, colors, and number of different objects, or image complexity). Therefore, it would be beneficial to control these aspects in the images to see if they lead to any variation in search performance. We would expect changes in the images to potentially have some effect even for the TD group but it would be the impact of these changes in the ASD group relative to the TD groups that would be of interest.

Much of the research into the visual search advantage in ASD has been conducted with children. While it has been shown that this advantage persists into adulthood, it would be useful to understand whether children shown the same reduction in performance with real-world images as the adults in this study showed. This would help to narrow down the mechanism(s) involved in this potential difference in real-world search.

Given the attribution of the ASD visual search advantage to atypical attention in ASD and its potential relevance in this study, this should be incorporated in future. Kaldy et al. (2012) attribute this atypicality to a dysregulated and hyperphasic locus coeruleus (LC). As they suggest, it is possible to use pupillometry as a biomarker for tonic and phasic LC activity. This would help to establish whether individuals with ASD are over-focusing.

In the context condition, it is assumed that finding the object quickly relied on contextual knowledge of the item and its likely position—therefore, superior performance would demonstrate superior integration abilities. However, this relies upon knowledge or experience of the item and its context. Given the desire for many with ASD to stick with routine and simplicity, and the extra assistance and restricted experience they may have had as children, it is possible that those with ASD performed worse because they were less familiar with some of the objects and their contexts. While efforts were made to ensure the images represented generally familiar objects, this could be controlled further with a pre-screen (given in advance to reduce priming effects) matching items with likely locations.

This study looked at visual searches intended to model "real-world" visual search. However, while the searches may represent general search situations in scenes, there are other "real-world searches" that these scenes may not approximate (e.g. finding a specific bottle on a medicine cabinet). Therefore, there may be elements of searches in the real-world that may lend themselves to the skills of individuals with ASD. This needs to be further delineated by comparing the results of visual search with real-world scenes with those of other more focused visual searches.

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