# Real-World Visual Search in Autistic Individuals

**Alice Yumeng Yang**
u3555074@connect.hku.hk
Department of Psychology, University of Hong Kong

**Janet H. Hsiao**
jhhsiao@ust.hk
Division of Social Science, Hong Kong University of Science & Technology

**Abstract**

Recent research has found that autistic individuals have poorer performance and lower eye movement consistency in face recognition, which may be related to less face processing experience due to lack of social interests. Here we showed that this phenomenon was not observed in visual search tasks, as autistic individuals and matched neurotypicals had similar hit rate and precision as well as eye movement behavior when searching for either social (human) or non-social (vehicle) stimuli. However, autistic individuals had longer search time and made more and longer fixations, suggesting difficulties in identifying potential targets. This difficulty was not limited to social stimuli, supporting a domain-general view of deficits in autism spectrum disorder (ASD). Our findings have important implications for understanding the core mechanisms underlying social-cognitive impairment in ASD.

**Keywords:** Autism spectrum disorder (ASD); visual search; eye-tracking; eye movement consistency; EMHMM

## Introduction

Autism spectrum disorder (ASD) is characterized by persistent difficulties with social communication and social interaction, along with restricted and repetitive patterns in behaviors and interests (DSM–5; American Psychiatric Association, 2013). Autistic individuals across ages often exhibit difficulties in the social domain or failure in preferential looking at social stimuli. Consistent with their atypical eye movement behavior, they performed poorly in face recognition (Falkmer et al., 2010) and facial expression recognition (Loth et al., 2018). These are critical social skills, and deficits in processing social stimuli may lead to negative consequences; for example, a person who misrecognizes their boss as a friend might behave inappropriately, and it could hurt their social relationships (Griffin et al., 2021).

Recent research has suggested that individuals have preferred eye movement patterns for face recognition, and deviation from such visual routines results in reduced face recognition performance (Mehoudar et al., 2014; Peterson et al., 2013). This finding suggested that individuals optimize real-world face recognition by consistently fixating the same locations (Peterson et al., 2016). Consistent with this finding, Hsiao, An et al. (2022) showed that children gradually develop a more consistent visual routine for face recognition during development, and higher eye movement consistency for face recognition predicts better recognition performance. In addition, they found that autistic children had lower eye movement consistency for face recognition than matched non-autistic children, and lower eye movement consistency for face recognition was associated with children's autistic traits, particularly in social skills. Their computational modeling results suggested that this phenomenon may be related to autistic children's insufficient experience in face recognition to develop a consistent visual routine due to a lack of social interests or motivation (Chevallier et al., 2012).

It remains unclear whether a similar phenomenon can be observed in other tasks where autistic individuals may have less experience with, such as searching for and identifying social stimuli in complex scenes, due to their lack of social interests. Indeed, it has been reported that autistic individuals display increased visual attention to non-social stimuli as opposed to social stimuli (Bhat et al., 2010; Sasson et al., 2012). Thus, as compared with neurotypicals (NT), they may not have developed a consistent visual routine and thus may have lower eye movement consistency and poorer performance when searching for social stimuli as compared with NTs, but not when searching for non-social stimuli.

Nevertheless, related visual search studies in the literature have not obtained consistent results regarding autistic individuals' search performance and behavior. For example, New et al. (2010) found that when participants were asked to spot the difference between two images of natural scenes involving either an animate or inanimate object, autistic individuals displayed the same prioritized social attention for animate categories, indicating that social attention impairment may not be a unitary phenomenon as reported in previous studies (New et al., 2010; Sturm et al., 2004). In a typical visual search paradigm where participants search for a target (either letters or simple shapes) in a display among an array of distractors (Wolfe, 1998), autistic individuals often show superior visual search performance than NTs. This has been attributed to their enhanced local visual information processing ability to discriminate between targets and distractors (Kaldy et al., 2016; Happe & Frith, 2006). Consistent with this finding, autistic individuals have been found to outperform matched controls on the Embedded Figures Test, which required identifying simple shapes within a complex form (Shah & Frith, 1983), and Block Design tasks, which required the ability to see the whole



In L. K. Samuelson, S. L. Frank, M. Toneva, A. Mackey, & E. Hazeltine (Eds.), *Proceedings of the 46th Annual Conference of the Cognitive Science Society*. 

design in terms of its parts (Caron et al., 2006; also see Simmons et al., 2009 for a review). However, these studies have typically used impoverished stimuli such as colored shapes. When visual search tasks involve more elements of naturalistic conditions, results may differ from the aforementioned laboratory studies (as observed in Russell et al., 2019). Kingstone et al. (2003) specifically discussed the importance of studying attention using stimuli with real-life situations. It remains unclear whether superior visual search performance in ASD could still be observed when visual search tasks involve rich visual information with high relevance to real-life situations (New et al., 2010). In a recent study, Russell et al. (2019) used real-world scene stimuli and found that autistic adults were consistently slower in visual search and less accurate in locating a specified target than a neurotypical comparison group. Consistent with Kingstone et al. (2003)'s speculation, this finding suggests that ASD's superior visual search does not transfer to situations involving real-world scenes.

Accordingly, in the current study, we aimed to examine whether autistic individuals differ from NTs in performance and eye movement behavior when searching for social *vs*. non-social stimuli in complex scene stimuli with high resemblance to real-life search scenarios: detecting humans *vs*. vehicles during driving scenarios. We hypothesized that autistic individuals may perform poorer than NTs when searching for humans but not when searching for vehicles, and this performance difference may be related to differences in eye movement behavior, particularly in eye movement consistency.

# Method

## Participants

We recruited 33 participants with autism diagnosis (ASD group) and 33 neurotypical controls (NT group) matched in sex. The groups did not differ in age, $t(64) = 0.89$, $p = .377$, or IQ as measured in Raven's Standard Progressive Matrices (RSPM; Raven, 2000), $t(64) = 0.67$, $p = .505$. All participants had normal or corrected-to-normal vision. A power analysis showed a sample size of 54 ($\eta^2_p = .25$, $\alpha = .05$, $\beta = .05$) was required for a 2 x 2 mixed ANOVA, and a sample size of 55 was required ($f^2 = .15$, $\alpha = .05$, $\beta = .2$) for linear multiple regression with one tested predictor. The required sample size for independent sample t-test ($d = 0.8$, $\alpha = .05$, $\beta = .2$) was 52.

Table 1: Characteristics of the participant groups.

| Participant group | | ASD group | NT group |
|---|---|---|---|
| Age (years) | Mean | 24.8 | 23.6 |
| | SD | 6.2 | 5.1 |
| | Range | 18-41 | 18-38 |
| Sex | Male | 15 | 15 |
| | Female | 18 | 18 |
| RSPM (score) | Mean | 8.0 | 7.8 |
| | SD | 1.1 | 1.5 |
| | Range | 5-9 | 3-9 |

## Materials and Apparatus

We used the same stimuli from Yang et al. (2023), which were sampled from the Berkeley DeepDrive 100K Image Dataset (Yu et al., 2020), for the vehicle search and the human search task. The stimuli were displayed one at a time at the center of a 15.6-inch monitor (1920 x 1080 pixels), spanning 34.2 ° x 20.8° of visual angle at a viewing distance of 55 cm. Participants' eye movements were recorded using an EyeLink 1000 Plus. A nine-point calibration procedure was performed before the experiment and whenever the drift check error exceeded 1° of visual angle.

## Procedure

Participants performed a vehicle and a human search task with the task order counterbalanced across the participants, followed by cognitive ability tests, Autism-Spectrum Quotient (AQ), and RSPM.

**Visual search tasks** We adopted Yang et al. (2023)'s procedure. In the vehicle search task, participants searched for cars, trucks, and buses; in the human search task, they searched for pedestrians and riders. Each trial started with a drift check at the screen center. The experimenter initiated the stimulus presentation when a stable fixation was observed. Participants were asked to search for all targets and press a key as soon as they thought they had detected all. Their eye movements during the visual search before the key press were used for data analysis. To assess visual search performance, immediately after the key press, participants were asked to use a mouse click to place a marker at each detected target location on a blank screen. Then, they were asked to click again on the same targets they had clicked previously on the original image to confirm their selection (Figure 1). Here we reported the results based on the clicks on the blank screen (similar results were obtained using the clicks on the original image). We separated the visual search phase from the clicking phase to avoid interference from sensorimotor planning of clicking during the eye movement recording of visual search. Haladjian and Pylyshyn (2011) reported an average location error of 2.2° of visual angle in a spatial memory task with clicking responses. Accordingly, we used

64-pixel (2.2°) location error tolerance when calculating the hit rate, i.e., clicks falling within the location error tolerance of each target's bounding box were counted as a hit.

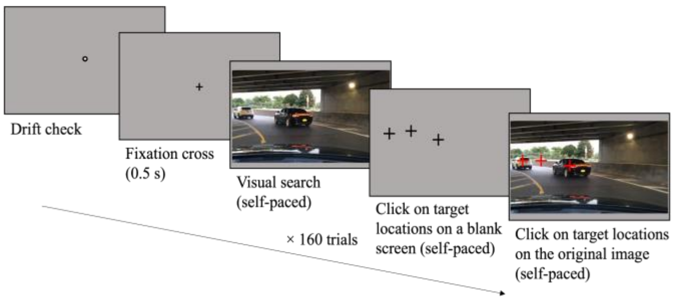


Figure 1. Procedure of the visual search tasks.

**Navon task** Navon task was used to measure participants' global and local information processing abilities (Navon, 1977). Participants were presented with a hierarchical letter pattern, i.e., a larger letter consisting of smaller letters, and judged whether a target letter was presented regardless of whether it was at the global or local level. We measured the accuracy and RT of the trials where there was a target letter at the global and local level separately as the measure of global and local information processing ability respectively.

**Tower of London (TOL) task** TOL task was used to assess participants' executive function abilities (Phillips et al., 2001). In each trial, participants saw a move board on the right with three balls in different colors (red, blue, and blue) and a target board on the left, and were asked to preplan and move the balls on the move board to match the target board using the fewest possible moves for 12 trials. We measured their accuracy, average number of moves, execution time, and planning time.

**Verbal/Spatial Two-back task** Two-back tasks were used to assess participants' working memory (Lau et al., 2010). Participants saw a number or a symbol at a time and judged whether the current number or symbol location (regardless of the symbol's identity) was the same as the one presented two trials back in the verbal or spatial test respectively. Each test had two blocks with 28 trials per block. We measured their accuracy and response time (RT).

**Flanker task** Flanker task was used to assess participants' selective attention (Eriksen & Eriksen, 1974; Ridderinkhof et al., 1999). In each trial, participants judged the direction of the central arrow flanked by four other arrows. The flanking arrows pointed in the same direction as the central arrow in congruent trials and the opposite direction in incongruent trials. In neutral trials, the flankers were nondirectional symbols. The flanker effect in accuracy and RT was measured as (C – I)/(|C| + |I|), where C and I are the accuracy/RT for congruent and incongruent trials respectively.

**AQ** We administered AQ to measure participants' autistic traits (Baron-Cohen et al., 2001). We calculated the total AQ score and subscores in the five areas of autistic traits. A cut-off total score of 32 or above indicates a possible risk of ASD.

**RSPM** We used RSPM to assess participants' general intelligence (Raven, 2000). Participants were asked to choose a missing piece to complete a matrix-like pattern among the given six choices. We used the nine-item version (Bilker et al., 2012).

## Design

Participants' performance in visual search was assessed in hit rate (the ratio of the number of hits to the number of hits plus misses), precision[1] (the ratio of the number of hits to the number of hits plus false alarms), and visual search RT. Eye movement behavior was assessed by number of fixations per trial, average fixation duration, and eye movement pattern and consistency as assessed using Eye Movement analysis with Hidden Markov Model (EMHMM) with co-clustering (see Eye Movement Analysis for details). We conducted 2 x 2 mixed ANOVAs on performance and eye movement behavior with target category (vehicle *vs*. human) as a within-subject variable and group (ASD *vs*. NT) as a between-subject variable. We also conducted linear regression analyses to examine whether any group difference in performance could be predicted by eye movement behavior with cognitive ability difference controlled, and whether eye movement consistency was associated with autistic traits as observed in previous studies (Hsiao, An et al., 2022).

## Eye Movement Analysis

Using the same stimuli and visual search procedure, Yang et al. (2023) discovered focused and explorative eye movement pattern groups in healthy young adults through EMHMM with co-clustering (Hsiao, Chan et al., 2021; Chuk et al., 2014) in both human and vehicle search. As shown in Figure 2, participants using the focused pattern scanned narrowly along the horizon, whereas those using the explorative pattern had larger ROIs, scanning across a broader area beyond the horizon. Yang et al. (2023) used the two representative pattern group models to quantify each participant's eye movement pattern in each stimulus along the dimension contrasting the focused and explorative patterns using FE (Focused-Explorative) scale: $(L_F - L_E)/(|L_F|+|L_E|)$, where $L_F$ and $L_E$ were the log-likelihoods of a participant's data generated by the Focused and Explorative patterns respectively. A higher FE scale reflected higher similarity to the Focused pattern in contrast to the Explorative pattern. To

[1] d' could not be calculated since the number of correct rejections during the visual search was unknown.

make the current results with ASD participants comparable to Yang et al. (2023), we directly used the representative focused and explorative models from Yang et al. (2023) to quantify each participant's pattern using FE scale[2]. For quantifying participants' eye movement consistency, following previous studies (e.g., Hsiao, An et al., 2022; Hsiao, Liao et al., 2022; Hsiao, Chan et al., 2021), we summarised each participant's eye movement pattern for viewing each stimulus using one hidden Markov model (HMM) with personalized regions of interest (ROIs) and a transition matrix indicating the transition probabilities among the ROIs. The optimal number of ROIs for each HMM was determined from a preset range of 1 to 5 using a variational Bayesian approach. Each HMM was trained 300 times to select the model with the greatest log-likelihood. We then used entropy of the HMM (Cover & Thomas, 2006) as the measure of eye movement consistency (entropy is a measure of randomness or unpredictability; higher entropy indicates lower consistency).

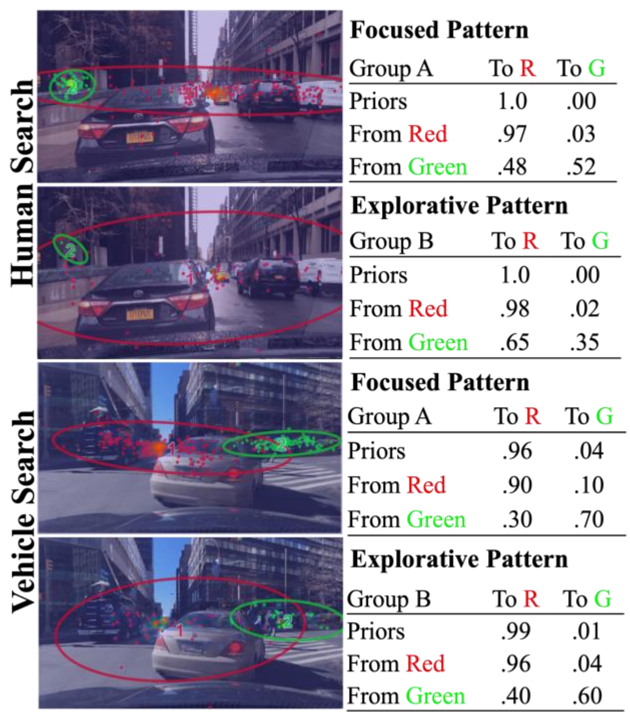


Figure 2: The focused and explorative eye movement pattern groups for human and vehicle search. Ellipses show ROIs as 2-D Gaussian emissions. Priors show probabilities of the first fixation landing on each ROI and transition matrices show transition probabilities among the ROIs.

## Results

The ASD and NT group differed significantly in AQ total score, $t(64) = 7.51$, $p < .001$, $d = 1.85$, and all AQ subscores, $ps < .05$. The two groups did not differ significantly in the cognitive ability tests assessed except for the TOL task, where the NT group had shorter execution time, $t(37.8) = 2.95$, $p = .005$, $d = 0.73$, and a smaller number of moves, $t(42.5) = 3.03$, $p = .004$, $d = 0.75$, than the ASD group, suggesting that the ASD group had worse executive function than the NT group.

### Performance in Visual Search

Since the ASD and NT groups differed in TOL's execution time and average number of moves, we included them as covariates using ANCOVA. For either hit rate or precision, no significant results were observed, suggesting that the two groups did not differ in either human or vehicle search performance (Figure 3).

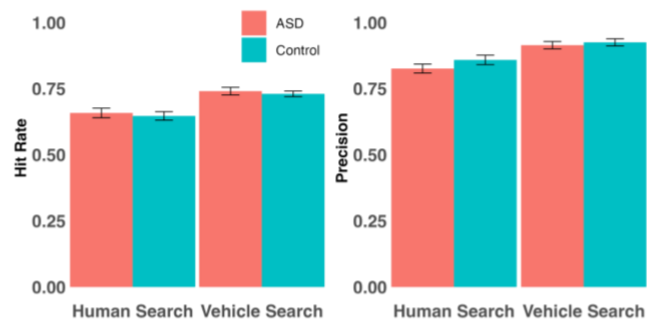


Figure 3: ASD *vs*. NT group in visual search performance.

In RT, a main effect of group was observed, $F(1, 62) = 7.99$, $p = .006$, $\eta^2_p = .13$: the ASD group had longer RT than the NT group. This effect was significant in both human search[3], $t_{Welch}(55.3) = 2.65$, $p = .010$, $d = 0.65$, and vehicle search, $t_{Welch}(56.5) = 2.63$, $p = .011$, $d = 0.65$. No other effect was found.

[2] Similar results were obtained if we used current participants' eye movement data to generate the representative pattern group models for FE scale.

[3] Welch's t-tests were used whenever equal variance assumption was not met.

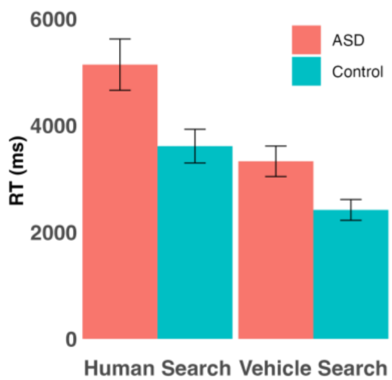


Figure 4: ASD *vs*. NT group in RT.

### Eye Movement Behavior in Visual Search

In either FE scale or entropy, no significant effect was found. These results suggested that the two groups had similar eye movement patterns and consistency in both visual search tasks (Figure 5). However, linear regression analysis predicting entropy in vehicle search showed that total AQ score contributed significantly to the regression model, $\Delta R^2 = 6.5\%$, $F(1, 64) = 4.42$, $p = .040$, suggesting that autistic traits were associated with greater eye movement consistency. This effect was not found in human search.

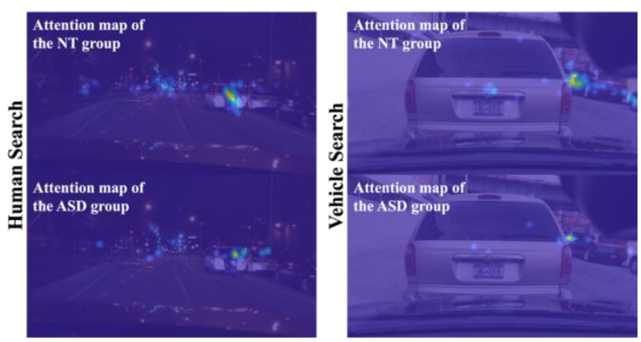


Figure 5: Attention maps of the ASD and NT group during visual search tasks.

In number of fixations per trial, a main effect of group was observed, $F(1, 62) = 5.52$, $p = .022$, $\eta^2_p = .08$: the ASD group had a larger number of fixations per trial than the NT group. This effect was significant in both human search: $t_{Welch}(57.8) = 2.38$, $p = .021$, $d = 0.59$, and vehicle search: $t_{Welch}(54.6) = 2.20$, $p = .032$, $d = 0.54$. In fixation duration, a main effect of group was also observed, $F(1, 62) = 9.33$, $p = .003$, $\eta^2_p = .13$: the ASD group had longer fixation duration. This effect was significant in either human search: $t(64) = 2.56$, $p = .013$, $d = 0.63$, or vehicle search: $t(64) = 2.41$, $p = .019$, $d = 0.59$ (Figure 6). In both visual search tasks, linear regression analyses showed that RT was a significant predictor for number of fixations per trial (human search: $\Delta R^2 = 89.4\%$, $F(1, 64) = 538$, $p < .001$; vehicle search: $\Delta R^2 = 87.9\%$, $F(1, 64) = 465$, $p < .001$), and fixation duration (human search: $\Delta R^2 = 49.6\%$, $F(1, 64) = 63$, $p < .001$; vehicle search: $\Delta R^2 = 35.2\%$, $F(1, 64) = 34.8$, $p < .001$). These results suggested that RT was associated with a greater number of fixations per trial and longer fixation duration in either human or vehicle search.

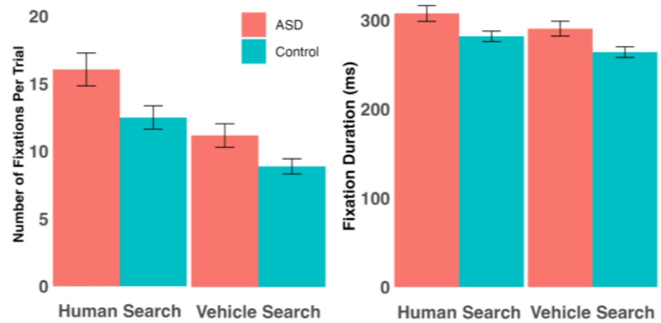


Figure 6: ASD *vs*. NT group in number of fixations per trial.

## Discussion

Here we investigated whether autistic individuals performed worse than non-autistic individuals when searching for social stimuli as compared with non-social stimuli and whether their poorer performance was related to lower eye movement consistency. Recent research has shown that autistic individuals have reduced eye movement consistency when recognizing faces as compared with matched controls, and computational modeling results suggested this phenomenon may be related to their reduced face processing experience due to lack of social motivation, resulting in less well-learned visual routines (Hsiao et al., 2022). Thus, we hypothesized that a similar phenomenon may be observed in visual search tasks when the targets are social stimuli such as humans, as autistic individuals' lack of social motivation may lead to lack of experience in searching and identifying social stimuli. Contrary to our hypothesis, autistic individuals showed comparable hit rate and precision, and adopted similar eye movement strategy and consistency to non-autistic individuals in both human and vehicle search. Thus, the findings of Hsiao, An et al. (2022) may be limited to face processing.

Indeed, face recognition and visual search tasks differ in task demands, which can shape how visual routines are developed. Specifically, faces all share the same configurations, and thus viewers know in advance what features can be obtained through a saccade to a specific location. Thus, a visual routine can be learned by reinforcing/repeating fixation locations that lead to better performance (i.e., important features for recognition such as eyes; Hsiao, An et al., 2022). In contrast, a visual search task can happen in all kinds of scenarios and thus the stimuli can differ significantly in feature layout, and targets can appear in different locations. A consistent routine may not necessarily lead to better performance, and thus would not be reinforced during learning. In contrast, a more adaptive eye movement pattern, which typically leads to lower eye movement consistency, may be beneficial to visual search

(Yang et al., 2023; Eckstein, 2011). Thus, although autistic individuals may have less experience in human search as compared with non-autistic individuals due to lack of social interests, they did not differ from NTs in performance or eye movement behavior.

Despite similar search strategies, autistic individuals had longer RT in both human and vehicle search. Their longer RT was found to be associated with longer fixation duration and a larger number of fixations per trial. This result suggested that although autistic individuals had similar eye movement patterns and consistency to non-autistic individuals, they may have repeated the pattern for longer, suggesting that they may have difficulties in identifying objects but not in visual search strategies. This aligns with past findings that autistic individuals were slower in detecting changes or searching for a target item in real-world scenes (Russell et al., 2019; Hochhauser et al., 2018). Indeed, autistic individuals have been reported to have difficulties in processing a vast amount of visual information with high complexity (Kana et al., 2011), or more specifically in selecting relevant information (i.e., search targets) and inhibiting unwanted information (i.e., distractors). Our results showed that autistic individuals' deficits in visual search were not limited to social stimuli, as they showed longer RT than NTs in both human and vehicle search. This result was consistent with the proposal that deficits in autism may be domain-general rather than specific to social stimuli. For example, Scherf et al. (2018) found that autistic individuals performed poorly in both face and novel object recognition, suggesting a generalized deficit in perceptual processing across both social and non-social domains. Recent studies have revealed an atypical bias towards high spatial frequency information (i.e., details) in ASD during object recognition, deviating from coarse-to-fine processing typically observed in neurotypicals (Caplette et al., 2016; Sasson et al., 2008). Such deficits may lead to atypical perceptual category learning, which could be related to the poorer visual search performance observed here. These perceptual deficits may in turn impact social-cognitive processes related to core autism symptoms (Mercado et al., 2020).

In conclusion, here we showed that autistic individuals performed similarly in hit rate and precision to non-autistic individuals when searching for either social or non-social stimuli. More importantly, they did not differ in eye movement strategy or consistency during visual search. These results demonstrated that the association between ASD diagnosis and reduced eye movement consistency observed in face recognition did not generalize to visual search tasks. This result may be because face recognition and visual search tasks differ in task demands. While a consistent visual routine can be learned for face recognition by reinforcing/repeating fixation locations that lead to better performance, a more adaptive eye movement pattern, which typically leads to lower eye movement consistency, is more beneficial to visual search. Nevertheless, autistic individuals had longer search RT and made more and longer fixations regardless of having similar eye movement patterns to non-autistic individuals, suggesting difficulties in identifying potential targets. This deficit was not limited to social stimuli, supporting a domain-general view of deficits in SD. Our findings have important implications for the understanding of the core mechanisms underlying social-cognitive impairment in ASD.

## Acknowledgments

We are grateful to Research Grant Council of Hong Kong (CRF #C7129-20G). We thank Yunke Chen for her help in data collection.

## References

Adolphs, R., Sears, L., & Piven, J. (2001). Abnormal processing of social information from faces in autism. *Journal of Cognitive Neuroscience*, 13, 232–240.

Arkush, L., Smith-Collins, A. P. R., Fiorentini, C., & Skuse, D. H. (2013). Recognition of Face and Non-Face Stimuli in Autistic Spectrum Disorder. *Autism Research*, 6(6), 550-560.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of autism and developmental disorders*, 31, 5-17.

Bhat, A. N., Galloway, J. C., & Landa, R. J. (2010). Social and non-social visual attention patterns and associative learning in infants at risk for autism. *The Journal of Child Psychology and Psychiatry*, 51, 989–997.

Benson, V., Castelhano, M. S., Howard, P. L., Latif, N., & Rayner, K. (2016). Looking, seeing and believing in autism: Eye movements reveal how subtle cognitive processing differences impact in the social domain. *Autism Research*, 9(8), 879-887.

Burack, J.A., Enns, J.T., Stauder, J.E.A., Mottron, L., & Randolph, B. (1997). Attention and autism: behavioral and electrophysiological evidence. In D.J. Cohen, & F.R. Volkmar (Eds.), *Autism and pervasive developmental disorders: A handbook* (pp. 226–247). New York: John Wiley and Sons.

Caplette, L., Wicker, B. & Gosselin, F. (2016). Atypical time course of object recognition in autism spectrum disorder. *Scientific Report*, 6, 35494.

Caron M., Mottron L., Berthiaume C., Dawson M. (2006) Cognitive mechanisms, specificity and neural underpinnings of visuospatial peaks in autism. *Brain* 129: 1789–1802.

Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Science*, 16(4), 231-239.

Cover, T. M., & Thomas, J. A. Elements of Information Theory (John Wiley & Sons, 2006).

Chuk, T., Chan, A. B., & Hsiao, J. H. (2014). Understanding eye movements in face recognition using hidden Markov models. *Journal of Vision*, 14(11), 8–8.

Dalton, K. M., Nacewicz, B. M., Johnstone, T., Schaefer, H. S., Gernsbacher, M. A., Goldsmith, H. H., et al. (2005).

Gaze fixation and the neural circuitry of face processing in autism. *Nature Neuroscience*, 8, 519–526.

Eckstein, M. P. (2011). Visual search: a retrospective. *Journal of Vision*, 11(5).

Eriksen, B. A. & Eriksen, C. W. Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics*. 16, 143–149 (1974).

Falkmer, M., Larsson, M., Bjällmark, A., & Falkmer, T. (2010). The importance of the eye area in face identification abilities and visual search strategies in persons with Asperger syndrome. *Research in Autism Spectrum Disorders*, 4(4), 724-730.

Griffin, J. W., Bauer, R., & Scherf, K. S. (2021). A quantitative meta-analysis of face recognition deficits in autism: 40 years of research. *Psychological Bulletin*, 147(3), 268-292.

Guillon, Q., Hadjikhani, N., Baduel, S., & Rogé, B. (2014). Visual social attention in autism spectrum disorder: Insights from eye tracking studies. *Neuroscience & Biobehavioral Reviews*, 42, 279-297.

Happe, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 36, 5–25.

Hsiao, J. H., An, J., Hui, V. K. S., Zheng, Y., & Chan, A. B. (2022). Understanding the role of eye movement consistency in face recognition and autism through integrating deep neural networks and hidden Markov models. *NPJ Science of Learning*, 7(1), 28.

Hsiao, J. H., Chan, A. B., An, J., Yeh, S.-L., & Jingling, L. (2021). Understanding the collinear masking effect in visual search through eye tracking. *Psychonomic Bulletin & Review*, 28(6), 1933–1943.

Hsiao, J. H., Lan, H., Zheng, Y., & Chan, A. B. (2021). Eye movement analysis with hidden Markov models (EMHMM) with co-clustering. *Behavior Research Methods*, 53(6), 2473–2486.

Hsiao, Liao, W., & Tso, R. V. Y. (2022). Impact of mask use on face recognition: an eye-tracking study. *Cognitive Research: Principles and Implications*, 7(1), 32–32.

Haladjian, H. H., & Pylyshyn, Z. W. (2011). Enumerating by pointing to locations: A new method for measuring the numerosity of visual object representations. *Attention, Perception, & Psychophysics*, 73(2), 303-308.

Hanley, M., McPhillips, M., Mulhern, G., Riby, D.M. (2013). Spontaneous attention to faces in Asperger syndrome using ecologically valid static stimuli. *Autism The International Journal of Research and Practice*. 17 (6), 754–761.

Hochhauser, M., Hochhauser, M., Aran, A., Aran, A., Grynszpan, O., & Grynszpan, O. (2018). How adolescents with autism spectrum disorder (ASD) spontaneously attend to real-world scenes: Use of a change blindness paradigm. *Journal of Autism and Developmental Disorders*, 48(2), 502–510.

Kaldy, Z., Giserman, I., Carter, A. S., & Blaser, E. (2016). The Mechanisms Underlying the ASD Advantage in Visual Search. *Journal of Autism and Developmental Disorders*, 46(5), 1513-1527.

Kana, R. K., Libero, L. E., & Moore, M. S. (2011). Disrupted cortical connectivity theory as an explanatory model for autism spectrum disorders. *Physics of Life Reviews*, 8(4), 410–437.

Kingstone, A., Smilek, D., Ristic, J., Kelland Friesen, C., & Eastwood, J. D. (2003). Attention, researchers! It is time to take a look at the real world. *Current Directions in Psychological Science*, 12(5), 176-180.

Lau, E. Y. Y., Eskes, G. A., Morrison, D. L., Rajda, M., & Spurr, K. F. (2010). Executive function in patients with obstructive sleep apnea treated with continuous positive airway pressure. *Journal of the International Neuropsychological Society*, 16(6), 1077–1088.

Loth, E., Garrido, L., Ahmad, J., Watson, E., Duff, A., & Duchaine, B. (2018). Facial expression recognition as a candidate marker for autism spectrum disorder: how frequent and severe are deficits? *Molecular Autism*, 9(1), 7.

Mehoudar, E., Arizpe, J., Baker, C. I., & Yovel, G. (2014). Faces in the eye of the beholder: unique and stable eye scanning patterns of individual observers. *Journal of Vision*, 14(7), 6.

Mercado, E., Chow, K., Church, B. A., & Lopata, C. (2020). Perceptual category learning in autism spectrum disorder: Truth and consequences. *Neuroscience & Biobehavioral Reviews*, 118, 689-703.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology*, 9(3), 353-383.

New, J. J., Schultz, R. T., Wolf, J., Niehaus, J. L., Klin, A., German, T. C., & Scholl, B. J. (2010). The scope of social attention deficits in autism: prioritized orienting to people and animals in static natural scenes. *Neuropsychologia*, 48(1), 51-59.

Peterson, M. F. & Eckstein, M. P. Individual differences in eye movements during face identification reflect observer-specific optimal points of fixation. *Psychological Science*. 24, 1216–1225 (2013).

Peterson, M. F., Lin, J., Zaun, I., & Kanwisher, N. (2016). Individual differences in face-looking behavior generalize from the lab to the world. *Journal of Vision*, 16(7), 12.

Phillips, L. H., Wynn, V. E., McPherson, S., & Gilhooly, K. J. (2001). Mental planning and the Tower of London task. *The Quarterly Journal of Experimental Psychology*, 54(2), 579– 597.

Raven, J. (2000). The Raven's progressive matrices: change and stability over culture and time. *Cognitive psychology*, 41(1), 1-48.

Plaisted, K.C. (2000). Aspects of autism that theory of mind cannot easily explain. In S. Baron-Cohen, H. Tager-Flusberg, & D.J. Cohen (Eds.), *Understanding other minds: Perspectives from autism and cognitive neuroscience* (2nd edn., pp. 222–250). Oxford: Oxford University Press.

Ridderinkhof, R. K., Band, G. P. H., & Logan, G. D. (1999). A study of adaptive behavior: Effects of age and irrelevant information on the ability to inhibit one's actions. *Acta Psychologica*, 101(2), 315–337.

Russell, N. C. C., Luke, S. G., Lundwall, R. A., & South, M. (2019). Not So Fast: Autistic traits and Anxious Apprehension in Real-World Visual Search Scenarios. *Journal of Autism and Developmental Disorders*, 49(5), 1795-1806.

Sasson, N. J., Dichter, G. S., & Bodfish, J. W. (2012). Affective responses by adults with autism are reduced to social images but elevated to images related to circumscribed interests. *PLoS One*, 7(8), e42457.

Sasson, N. J., Turner-Brown, L. M., Holtzclaw, T. N., Lam, K. S. L., & Bodfish, J. W. (2008). Children with autism demonstrate circumscribed attention during passive viewing of complex social and nonsocial picture arrays. *Autism Research*, 1(1), 31–42.

Schultz, R. T., Gauthier, I., Klin, A., Fulbright, R. K., Anderson, A. W., Volkmar, F., et al. (2000). Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and Asperger syndrome. *Archives of General Psychiatry*, 57, 331–340.

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: a research note. *Journal of Child Psychology and Psychiatry*, 24(4), 613-620.

Simmons D. R., Robertson A. E., McKay L. S., Toal E., McAleer P., Pollick F. E. (2009) Vision in autism spectrum disorders. *Vision Research* 49: 2705–2739.

Sturm, H., Fernell, E., & Gillberg, C. (2004). Autism spectrum disorders in children with normal intellectual levels: Associated impairments and subgroups. *Developmental Medicine & Child Neurology*, 46, 444–447.

Suzanne Scherf, K., Behrmann, M., Minshew, N., & Luna, B. (2008). Atypical development of face and greeble recognition in autism. *Journal of Child Psychology and Psychiatry*, 49(8), 838-847.

Wolfe, J. M. (1998). Visual search. In H. Pashler (Ed.), *Attention* (pp. 13–73). Psychology Press/Erlbaum (UK) Taylor & Francis.

Yang, A., Liu, G., Chen, Y., Qi, R., Zhang, J., & Hsiao, J. (2023). Humans vs. AI in detecting vehicles and humans in driving scenarios. *Proceedings of the Annual Meeting of the Cognitive Science Society*, 45.

Yu, F., Chen, H., Wang, X., Xian, W., Chen, Y., Liu, F., Madhavan, V., & Darrell, T. (2020). Bdd100k: A diverse driving dataset for heterogeneous multitask learning. *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition.*