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The Impact of Mask Use on Face Recognition in Adults with Autism Spectrum Disorder: An Eye-Tracking Study

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Abstract

Through comparing autistic and non-autistic adults in learning and recognizing masked faces, we found that although autistic participants generally had poorer face recognition performance than matched controls, the two groups were similarly impaired by mask use. Nevertheless, when viewing masked faces during learning, they showed reduced tendency to look at the eyes and reduced change in eye movement consistency as compared with controls; this was not observed during recognition. Across participants, selective attention ability and flexibility to change face scanning behavior according to mask conditions were two important factors accounting for individual differences in performance. Interestingly, autistic spectrum quotient accounted for additional variance when recognizing masked faces learned also with a mask, suggesting additional influence from one's autistic traits that could have impacted face learning experience during development. Our findings have important implications for identifying vulnerable populations whose face recognition ability may be particularly affected by mask use.

Keywords: autism spectrum disorder; eye movements; face recognition; face masks; EMHMM

Introduction

Wearing masks has been found effective in reducing the risk of contagious respiratory virus infection (Liang et al., 2020). However, as we typically perceive a face as a whole (Richler et al., 2012; Richler et al., 2011), mask use could significantly disrupt face processing in various tasks, including recognizing identity, emotion, gender, and age (Fitousi et al., 2021; Gulbetekin, 2021; Freud et al., 2020). This effect may induce greater challenge in individuals with face processing difficulties, such as autistic individuals, further interfering with their social functioning.

Autistic individuals are characterised by restricted interests in social interaction and impaired social cognition (cf., DSM-5; American Psychiatric Association, 2013). They are reported to have reduced attention to the eyes (Tanaka & Sung, 2016) particularly during passive viewing of faces or face learning in both children (Van Der Geest et al., 2002) and adults (Hernandez et al., 2009). In contrast, this behavior is less salient in face recognition tasks, where both autistic and non-autistic children (Chawarska & Shic, 2009) and adults (Kirchner et al., 2011) attend to the eyes more frequently than other facial features. This difference in eye movement behavior between passive viewing/face learning and face recognition in autistic participants may be driven by task demands. Indeed, recent research has suggested that eye movements are mainly driven by task demands, and people adopt different eye movement patterns on faces when performing different tasks (Hsiao et al., 2021a; Hsiao & Chan, 2023). It is possible that the reduced attention to the eyes in autistic individuals is more salient in tasks where no response is required and thus the task demand is less clear, such as in the case of passive viewing/ face learning. In contrast, in face recognition tasks where an old vs. new face judgment is required, autistic individuals attend to task-relevant features as well as non-autistic individuals, and thus the eye movement difference is attenuated.

In non-autistic individuals, mask use directs their eye fixation behavior towards the eye region (Frank et al., 2021), with a larger change associated with smaller performance impairment due to mask use (Hsiao et al., 2022b). Due to the reduced attention to the eyes in autistic individuals, adjusting eye movement strategies towards the eyes when viewing a face with a mask, especially during passive viewing/face learning, may be particularly difficult. This may affect face memory encoding during face learning and consequently lead to impaired face recognition performance. Indeed, a recent study reported that autistic individuals were particularly affected by mask use when recognizing a face that was learned with a mask on, and having higher autistic traits was associated with larger performance impairment in this condition (Tso et al., 2022). Nevertheless, whether this phenomenon was due to autistic individuals' eye-avoidance behavior during face learning remains unclear.

In addition, autistic individuals were found to have reduced consistency in eye movement patterns across trials during face recognition (Hsiao et al., 2022a), suggesting difficulty in developing consistent visual routines for face recognition. Learning or recognizing a masked face involves adaptively developing a new information extraction strategy through changes in eye movements. Indeed, a larger increase in eye movement consistency when recognizing a masked face was found to be associated with smaller performance impairment due to mask use (Hsiao et al., 2022b). This required adaptation for recognizing masked faces may be particularly challenging to autistic individuals.

A person's cognitive abilities may also be associated with the ability to adaptively change eye movement strategies to better recognize masked faces. Indeed, Hsiao et al (2022b) found that people with better executive planning ability had

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a larger increase in eye movement consistency due to mask use, which was associated with less performance impairment. Autistic individuals have been shown to have poorer selective attention and executive function abilities than non-autistic individuals (Robinson et al., 2009). These cognitive abilities may be associated with their potential difficulties in adjusting eye movement strategies for learning or recognizing masked faces. In addition, it remains unclear whether one's autistic traits predict performance impairment due to mask use in addition to eye movement and cognitive ability factors.

To fill these research gaps, here we aimed to examine: 1) whether mask use has differential impact on eye movement behavior in autistic and non-autistic adults in face learning and recognition, and 2) what factors, including autistic traits and changes in eye movement behavior, best predict performance impairment due to mask use with cognitive abilities controlled. We recruited autistic adults and matched non-autistic adults to learn and recognize faces with and without masks with eye-tracking. To quantitatively assess participants' eye movement pattern and consistency (Hsiao et al., 2022a), we adopted a machine-learning-based method, Eye Movement analysis with Hidden Markov Models (EMHMM; Chuk et al., 2014), which considers both spatial and temporal information of eye movements. We hypothesized that autistic adults may not look toward the eyes when viewing faces as much as non-autistic adults especially in face learning. Also, the performance impairment may be best predicted by change in face scanning behavior and cognitive abilities instead of autistic traits.

Method

Participants

We recruited 34 high-functioning autistic adults (14 females, 18-30 years old, M = 21.94, SD = 3.43) and 34 non-autistic adults (14 females, 18-28 years old, M = 21.97, SD = 2.56), with age and gender matched. According to a power analysis (α = 0.05, power = 0.80), to test for a within-between interaction in a 2 × 2 mixed design ANOVA, the sample size required is 34 per group, assuming a medium effect size f = 0.25. For correlation, the required sample size is 67, assuming medium effect size r = 0.30 using one-tailed test. For linear multiple regression assuming a medium effect size $f^2 = .15$, with two tested predictors testing R^2 increase, the required sample size is 68. Autistic participants were diagnosed by a qualified psychiatric professional. They had higher autism spectrum quotient (AQ; Baron-Cohen et al., 2001) scores than non-autistic participants, $t(66) = 6.88$, $p < .001$. The two groups did not differ in general intelligence by Raven's standard progressive matrices (Raven, 2000), p = .842. Participants had normal or corrected-to-normal vision.

Design

The face recognition task consisted of a learning and a recognition phase. For the learning phase, the design consisted of a between-participant variable participant group (autistic vs. non-autistic) and a within-participant variable mask condition (masked vs. unmasked). The dependent variables were eye movement pattern and consistency quantified by EMHMM. For the recognition phase, the design included a between-participant variable participant group and two within-participant variables: mask condition during learning (masked vs. unmasked), and mask condition during recognition (masked vs. unmasked). The dependent variables were recognition performance in discrimination sensitivity A' and eye movement measures. ANOVA was used. We also examined the mask effect under three scenarios defined in **Table 1**: 1) *Effect of mask use during learning* (Condition 4 - Condition 2); 2) *Effect of mask use during recognition* (Condition 4 - Condition 3); 3) *Effect of mask use in the whole task* (Condition 4 - Condition 1). The mask effect was calculated as $\frac{\textbf{Baseline} - \textbf{Mask condition}}{\textbf{Baseline} + \textbf{Mask condition}}$, in order to normalize for individual differences in overall performance level (Zheng et al., 2023). We performed partial correlation analyses to examine what factors, including AQ, mask effect in eye movement measures in learning and recognition phases, and cognitive abilities, were associated with the mask effect in performance with general intelligence controlled. Stepwise and hierarchical regression analysis was conducted to examine which correlated factors best predicted mask effect in performance.

Participants' eye movements were recorded by an EyeLink 1000 eye tracker (desk mount model; SR Research) with a 1000 Hz sampling rate. A keyboard was connected to a monitor (17 inches, resolution: 1024 × 768 pixels) to collect behavioral responses. A chinrest was placed in front of the monitor at 55-cm distance to minimize head movements.

Table 1: The four mask conditions in the task.

	Learning	Recognition
Condition 1	Masked	Masked
Condition 2	Masked	Unmasked
Condition 3	Unmasked	Masked
Condition 4 (baseline)	Unmasked	Unmasked

Materials

The stimuli consisted of 256 colored frontal-view Asian face images (half female) from a face database (Hsiao et al., 2022b). All faces were unfamiliar to the participants with a neutral expression. The face images were cropped along the face shape to reveal only the inner features. Each face subtended a horizontal visual angle of 6°, equivalent to the size of a face under a distance for face identification in real life (~2 m; McKone, 2009). The face images were randomly divided into target and foil sets in the face recognition task with an equal number of faces in each gender. The image of each face identity was edited into different mask conditions.

Procedure

Participants completed a set of questionnaires, a face recognition task and a set of cognitive tests (**Figure 1a**).

Questionnaires

Raven's Standard Progressive Matrices (nine-item version;

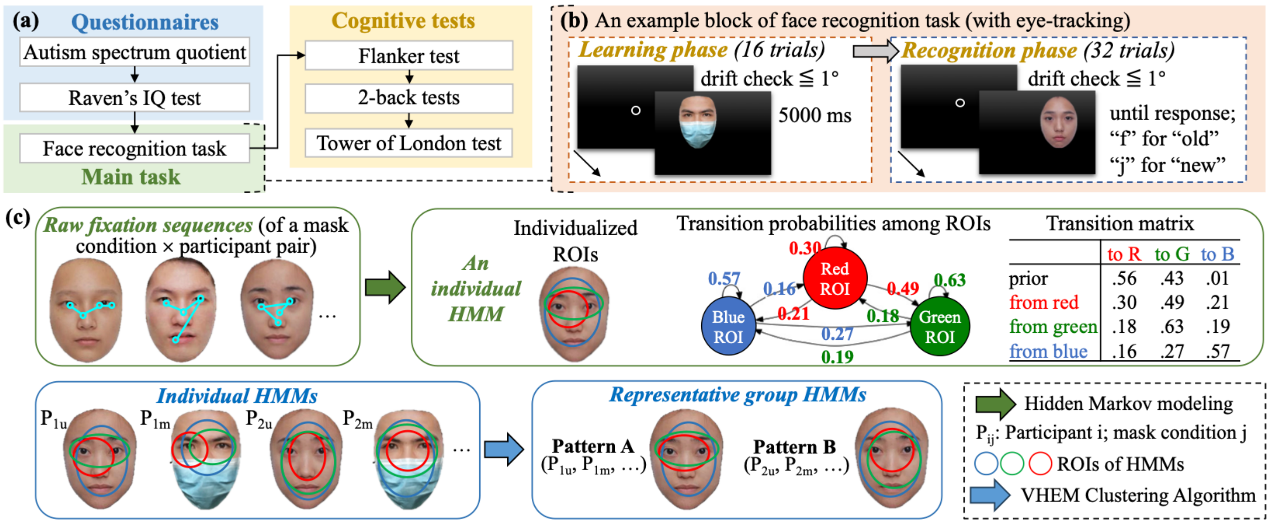


Figure 1: (a) Procedure of the experiment. (b) Procedure of the face recognition task. (c) Illustration of EMHMM: Raw fixation sequences were summarized into individual HMMs with individualized regions of interest (ROIs) and transition probabilities. Ellipses show ROIs as 2-D Gaussian emissions. Priors show the probabilities of the 1st fixation landing in that ellipse. The individual HMMs were then clustered into representative group HMMs using the variational hierarchical expectation maximization (VHEM) algorithm (Coviello et al., 2014).

Bilker et al., 2012) was used to assess general intelligence.

Autism Spectrum Quotient (AQ; 50-item version) was adopted to measure autistic traits (Baron-Cohen et al., 2001). Each item was scored from 1 to 4, and higher scores correspond to more autistic-like behavior **(**Tso et al., 2022).

Face Recognition Task

In the face recognition task, each block contained a learning phase and a recognition phase (**Figure 1b**). In the learning phase, participants viewed 16 face images one at a time, each for 5 s, for later recall. In the recognition phase, they were presented with old faces in a different lighting condition together with 16 new faces one at a time and judged whether they had seen the faces earlier. Each block contained 4 stimuli in each of the four mask condition combinations (**Table 1**). There were 8 blocks in total. The standard 9-point calibration and validation procedures were conducted before each block and whenever the drift check error was more than 1° of visual angle. Each trial started with a solid circle in the screen center for drift check. The experimenter inspected the drift check and pressed a key to present the stimulus. All stimuli were randomly presented at the center of one of the four quadrants.

Cognitive Tests

Two-back Tests were used to assess working memory ability (Jaeggi et al., 2010). In verbal/spatial subsets, participants judged whether the presented digit/symbol location in the current trial was the same as the one presented two trials before. Each symbol was presented for 1,000 ms followed by a 2,500 ms blank screen. Each subset had two blocks (26 trials each). Accuracy and RT of correct trials were measured.

Tower of London Test was adopted to assess executive planning ability (Berg & Byrd, 2002). Participants were presented with three color beads randomly placed on three pegs as an initial position and a goal position. They were instructed to move one bead at a time to reach the goal position with a minimum number of moves. There were 12 trials in total. We measured planning time (time before the first move) and execution times (time after the first move).

Flanker Test was used to assess selective attention (Ridderinkhof et al., 1999). In each trial, participants judged the direction of an arrow flanked by four other arrows. In congruent trials, the target and flanking arrows pointed in the same direction, whereas in incongruent trials, they pointed in the opposite directions. In neutral trials, the flankers were non-directional symbols. Each stimulus was presented for 500 ms, followed by a blank screen until response. There were 120 trials in total. We measured the congruency effect in accuracy and RT as $\frac{C-I}{C+I}$, where C and I denote accuracy or RT in the congruent and incongruent trials respectively.

Eye Movement Data Analysis

EMHMM was used to analyze eye movement data. A participant's eye movements in each of the mask conditions were summarized using a hidden Markov model (HMM, a type of time-series statistical model in machine learning) in terms of personalized ROIs and transition probabilities among the ROIs (**Figure 1c**). The individual models were then clustered to discover two representative group patterns, pattern A and B. Following previous studies (e.g., Hsiao et al., 2021a; Zheng et al., 2022; Zheng & Hsiao, 2023), we quantified each participant's eye movement pattern in a condition using A-B scale, calculated as $\frac{L_A - L_B}{|L_A|+|L_B|}$, where L_A and L_B represent Log-likelihoods of the participant's eye movement data being generated by pattern A and B group HMMs respectively. The log-likelihood measures reflect similarity of an individual's eye movement to the group patterns. A more positive A-B scale indicates higher similarity to pattern A. In addition, we examined individuals' eye movement consistency across trials using overall entropy of the HMMs. Previous studies suggested that the first 2-3 fixations in a trial play a more important role in face recognition (Hsiao & Cottrell, 2008). To better understand temporal dynamics of eye movement consistency, we measured conditional entropy of the second fixation given the first fixation and that of the third fixation given the second fixation, to quantify consistency of the transition from the first to second fixation, and that from the second to third fixation, respectively (Hsiao et al., 2021b).

For the learning phase, the group HMMs were from clustering 136 individual models (2 mask conditions × 68 participants). For the recognition phase, the group HMMs were from clustering 272 individual models (4 mask condition combinations in Table 1 × 68 participants).

Results

Effect of Mask Use on Recognition Performance

In A', a main effect of participant group was observed, $F(1,66) = 4.33$, $p = .041$, $\eta^2_p = .062$: non-autistic group performed better than autistic group. There was also a main effect of mask condition during learning, $F(1, 66) = 33.795$, $p < .001$, $\eta^2_p = .34$, a main effect of mask condition during recognition, $F(1,66) = 9.04$, $p = .004$, $\eta^2_p = .12$, and an interaction between them (**Figure 2**), $F(1,66) = 51.01$, $p < .001$, $\eta^2_p = .44$: after learning an unmasked face, participants performed poorer when recognizing the face with than without a mask, $t(66) = -8.54$, $p < .001$; in contrast, after learning a masked face, they performed poorer when recognizing the face without than with a mask, $t(66) = 2.61$, $p = .054$. Thus, participants performed poorer when the mask conditions during learning and recognition were inconsistent. These mask effects did not interact with participant group, suggesting that the two groups were similarly affected by mask use.

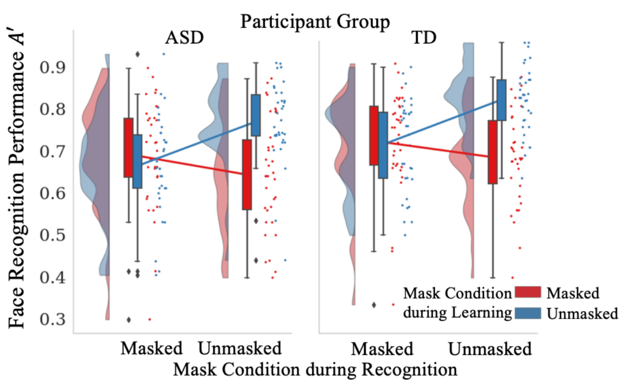


Figure 2: Face recognition performance across different mask conditions in autistic and non-autistic participants.

Effect of Mask Use on Eye Movement Behavior

Eye Movement Behavior during Face Learning

Two representative eye movement patterns were discovered: eyes-focused (**Figure 3a**) and nose-focused patterns (**Figure 3b**). This finding was consistent with previous studies using EMHMM (Chan et al., 2018; Hsiao et al., 2021a). After the first fixation at the face center to locate the face (red ROI: 98% probability), individuals using the eyes-focused pattern typically looked at the eye region afterwards (green, purple, and blue ROIs). In contrast, individuals using the nose-focused pattern started by looking at the face center (red ROI: 94%) and mainly continued looking at it. The two representative HMMs differed significantly according to KL divergence estimation, $F(1,134) = 90.98$, $p < .001$, $\eta^2_p = 0.40$.

Here we referred to A-B scale as EN scale (Eyes-Nose scale) to be consistent with previous studies. In EN scale, there was a main effect of participant group, $F(1,66) = 4.34$, $p = .041$, $\eta^2_p = .062$: autistic group was less eyes-focused than non-autistic group, and a main effect of mask condition, $F(1,66) = 130.52$, $p < .001$, $\eta^2_p = .66$: participants were more eyes-focused for masked than unmasked faces. There was an interaction between participant group and mask condition, $F(1,66) = 4.90$, $p = .030$, $\eta^2_p = .07$ **(Figure 3c)**: non-autistic group focused more on the eyes than autistic group in masked, $t(66) = 2.87$, $p = .028$, but not unmasked condition.

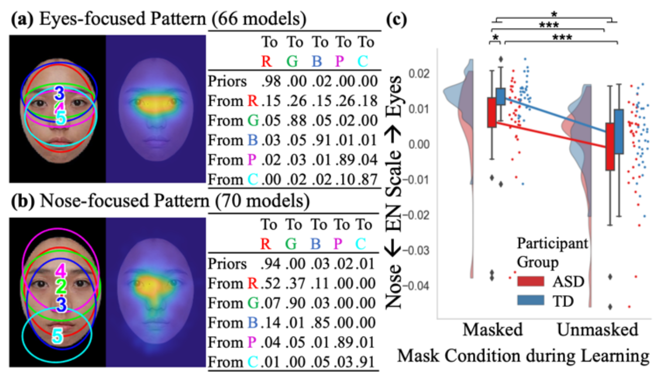
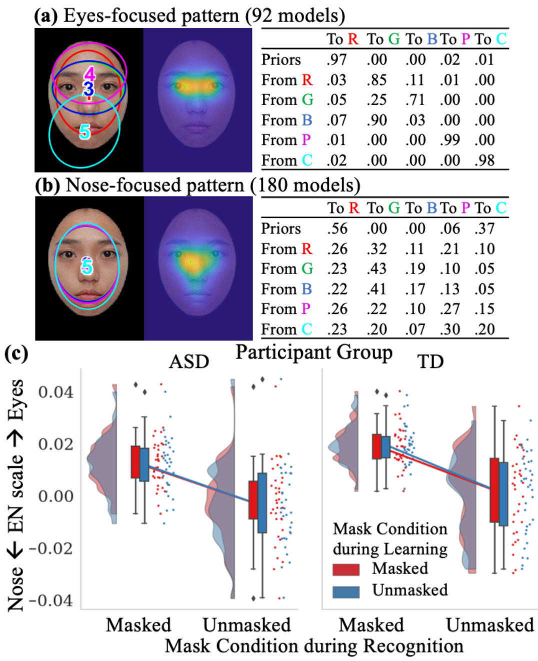


Figure 3: (a) Eyes-focused and (b) nose-focused patterns in face learning. The middle image shows the corresponding heatmap. (c) Eye movement pattern as measured in EN scale in different mask conditions in face learning.

In overall entropy, there was a main effect of participant group, $F(1,66) = 4.80$, $p = .032$, $\eta^2_p = .068$: autistic group had less consistent eye movement (higher entropy) than non-autistic group. A main effect of mask condition was observed, $F(1,66) = 30.92$, $p < .001$, $\eta^2_p = .32$: participants had more consistent eye movement (lower entropy) for masked than unmasked faces. An interaction between participant group and mask condition was observed, $F(1,66) = 5.68$, $p = .020$, $\eta^2_p = .08$: mask significantly reduced overall entropy in non-autistic, $t(66) = -5.62$, $p < .001$, but not in autistic participants, $t(66) = -2.25$, $p = .122$. This interaction was also found in conditional entropy of 2nd and 3rd fixation.

Eye Movement Behavior during Face Recognition

Two representative eye movement patterns were discovered during face recognition: eyes-focused (**Figure 4a**) and nose-focused patterns (**Figure 4b**). After the first fixation at the face center to locate the face (red ROI: 97% probability), individuals using the eyes-focused pattern typically looked at the eye region at the second fixation afterwards (green and blue ROIs). In contrast, individuals using the nose-focused pattern mainly looked at the face center. The two representative HMMs differed significantly according to KL divergence estimation, $F(1,270) = 433.27$, $p < .001$, $\eta^2_p = 0.62$.



(a) Eyes-focused pattern (92 models)

	To R	To G	To B	To P	To C
Priors	.97	.00	.00	.02	.01
From R	.03	.85	.11	.01	.00
From G	.05	.25	.71	.00	.00
From B	.07	.90	.03	.00	.00
From P	.01	.00	.00	.99	.00
From C	.02	.00	.00	.00	.98

(b) Nose-focused pattern (180 models)

	To R	To G	To B	To P	To C
Priors	.56	.00	.00	.06	.37
From R	.26	.32	.11	.21	.10
From G	.23	.43	.19	.10	.05
From B	.22	.41	.17	.13	.05
From P	.26	.22	.10	.27	.15
From C	.23	.20	.07	.30	.20

Figure 4: (a) Eyes-focused and (b) nose-focused patterns during face recognition. The image in the middle shows the heatmap. (c) Eye movement pattern as measured in EN scale in different mask conditions in face recognition.

In EN scale (**Figure 4c**), there was a main effect of participant group, $F(1,66) = 4.58$, $p = .036$, $\eta^2_p = .065$: autistic group was less eyes-focused than non-autistic group, and a main effect of recognition mask condition, $F(1,66) = 145.59$, $p < .001$, $\eta^2_p = .69$: adults were more eyes-focused for masked than unmasked faces during recognition. No interaction effect was found, suggesting that mask use affected non-autistic and autistic adults' eye movement pattern similarly.

In overall entropy, there was a main effect of participant group, $F(1,66) = 5.64$, $p = .020$, $\eta^2_p = .079$: autistic adults had less consistent eye movements (higher entropy) than non-autistic adults, and a main effect of mask condition during recognition, $F(1,66) = 49.80$, $p < .001$, $\eta^2_p = .43$: participants had more consistent eye movements (lower entropy) due to mask use. No interaction effect was found. In conditional entropy of 2nd and 3rd fixation, similarly, only a main effect of mask condition during recognition was found, $p < .001$, suggesting that eye movement consistency of non-autistic and autistic groups were affected by mask use similarly.

What Factors Best Predict Performance Impairment due to Mask Use?

In scenario one where the mask condition was manipulated only in face learning, the mask effect in performance was correlated only with the congruency effect in RT of Flanker test, $r(66) = -.23$, $p = .031$, suggesting that people with poorer selective attention had larger performance impairment.

In scenario two where the mask condition was manipulated only in face recognition, the mask effect in performance was correlated with the mask effect in overall entropy of eye movements, $r(66) = -.21$, $p = .041$, and conditional entropy of the 3rd fixation given the 2nd fixation in face recognition, $r(66) = -.34$, $p = .003$. The regression analysis showed that the mask effect in the conditional entropy of the 3rd fixation given the 2nd fixation, $\beta = -.33$, $p = 0.006$, was the only significant predictor of the mask effect in performance, accounting for a significant portion of variance, $R^2 = .111$, $F(1,66) = 8.22$, $p = .006$. This suggested that people with a smaller increase in eye movement consistency (i.e., smaller reduction in entropy) had larger performance impairment.

In scenario three where the mask condition was applied in both phases, the mask effect in performance was correlated with AQ score, $r(66) = .32$, $p = .005$, the mask effect in conditional entropy of the 3rd fixation given the 2nd fixation in face learning, $r(66) = -.25$, $p = .021$, the congruency effect in RT of Flanker test, $r(66) = -.21$, $p = .042$, and the accuracy of verbal working memory test, $r(66) = -.21$, $p = .045$. The regression analysis showed that AQ score, $\beta = .32$, $p = 0.007$, best predicted the mask effect in performance, accounting for a significant additional portion of variance, $\Delta R^2 = .102$, $F(1,64) = 7.91$, $p = .007$, after considering congruency effect in RT of Flanker test and accuracy of verbal working memory test in the first step, $R^2 = .044$, $F(2,65) = 2.54$, $p = .087$. It indicated that people with higher AQ had larger performance impairment with cognitive abilities controlled. To test whether AQ score could explain additional variance of the mask effect in performance in addition to mask effects in eye movement behavior and cognitive abilities, we conducted an exploratory hierarchical regression putting all significantly correlated factors except for AQ score in the first step using a stepwise procedure and including AQ score in the second step. We found that in the first step, the mask effect in conditional entropy of the 3rd fixation given the 2nd fixation in face learning, $\beta = -.30$, $p = .015$, and congruency effect in RT of Flanker test, $\beta = -.26$, $p = .031$, best predicted the mask effect in performance, $R^2 = .127$, $F(2,65) = 4.74$, $p = .012$. It indicated that participants with smaller change in eye movement consistency in face learning due to mask use and with poorer selective attention had larger performance impairment. Adding AQ score in the second step predicted additional variance, $\Delta R^2 = .059$, $F(1,64) = 4.64$, $p = .035$. This suggested that autistic traits accounted for additional variance in the mask effect in performance beyond eye movement measures and cognitive abilities.

Discussion

Through comparing adults with autism and matched controls in learning and recognizing masked faces, we found that although autistic adults performed poorer in face recognition than non-autistic adults in general, they were similarly affected by mask use. In eye movement behavior, we found that mask use influenced autistic and non-autistic individuals differentially only in face learning, but not in face recognition. More specifically, autistic adults did not look towards the eye region as much as non-autistic adults due to mask use in face learning. In contrast, they fixated more towards the eye region similarly to non-autistic adults during face recognition. Also, autistic adults had smaller change in eye movement consistency due to mask use than non-autistic adults only in face learning. These results were consistent with our hypothesis that difference in face scanning behavior between the two groups may be more salient in tasks where no response is required and thus the task demand is less clear, such as in face learning. Consistent with our finding, previous research has shown that autistic individuals tended to look more towards the mouth region of a face than non-autistic individuals regardless of whether they were primed to look at the eyes or the mouth (Kliemann et al., 2012). Their reduced attention to the eyes has been suggested to be because they perceive eyes as socially threatening (Tanaka & Sung, 2016). Similarly, the lower eye movement consistency may be related to lack of social motivation and reduced attention to faces during development, which could result in poorly learned visual routines for faces (Hsiao et al., 2022a).

In contrast to face learning, autistic and non-autistic individuals did not differ in the mask effect on eye movement behavior during face recognition. This suggested that autistic individuals were able to shift their attention toward the eyes when there was an explicit task demand to make judgments. Indeed, people's face scanning behavior was shown to be task-driven (Hsiao et al., 2021a). When the task demand is clear, such as in visual search or face recognition, typically no difference in fixation behavior was observed between autistic and non-autistic individuals (Kirchner et al., 2011; Joseph et al., 2009). This result suggested that the two groups did not differ significantly in the cognitive flexibility to adaptively change eye movement patterns for masked faces when the demands/responses required were clear. Consistent with this speculation, here the two groups did not differ in performance impairment due to mask use.

Tso et al. (2022) reported that autistic adults had poorer face recognition performance than non-autistic adults only when recognizing faces that were learned with a mask on. This result was inconsistent with the current study where no group difference in the mask effect was observed. Differences in the experiment procedure may be related to this inconsistency. More specifically, in Tso et al. (2022), face learning with unmasked and masked faces were tested in separate blocks so that during recognition participants knew whether a shown face was learned with or without a mask on. In contrast, here we presented masked and unmasked faces for learning in a mixed block. Nevertheless, we observed the autistic group had reduced attention to the eyes for masked faces during face learning as compared with the non-autistic group, consistent with Tso et al.'s (2022) finding that autistic adults may find it particularly difficult to recognize faces that were learned with a mask on. Future work may examine whether the procedure difference led to inconsistent results.

We also found that recognition performance impairment under different mask scenarios were associated with different cognitive abilities and face scanning behavior. When masks were applied only in face learning, larger performance impairment was predicted by poorer selective attention. This finding suggested that the ability to selectively attend to relevant features (i.e., the eyes) during face learning and to inhibit attention to irrelevant features not learned during face learning (i.e., the lower half of the face) is important in this scenario. When masks were applied only in face recognition, change in eye movement consistency was the best predictor for performance impairment, with smaller change predicting larger impairment. This finding was consistent with a recent study on healthy adults (Hsiao et al., 2022b), suggesting that the ability to adaptively adjust eye movement pattern based on the mask condition during recognition is crucial under this scenario. When a mask was applied in both learning and recognition phases, AQ score best predicted performance impairment, with higher AQ predicting larger impairment. This suggested that people with greater autistic traits may have particular difficulty in face recognition under this scenario. In an explorative analysis where we excluded the factor of AQ, we found that smaller change in eye movement consistency due to mask use during face learning and poorer selective attention predicted larger recognition performance impairment. This finding again suggested the importance of selective attention ability and the ability to adaptively adjust one's face scanning strategy. In addition, AQ score explained additional variation in performance impairment beyond the two factors. Autistic traits such as lack of social motivation and reduced attention to faces may lead to insufficient learning of faces during development, resulting in poorer internal representations for faces (Hsiao et al, 2022a). Consistent with this speculation, autistic adults were found to have difficulties in discriminating features in the eye region (Wolf et al., 2008). Future work will examine this possibility.

In conclusion, here we showed that although autistic adults generally performed poorer in face recognition with reduced attention to the eyes and lower eye movement consistency than non-autistic individuals, they were similarly affected by mask use in recognition performance. However, they differed from non-autistic adults in how they responded to a masked face in face scanning behavior particularly during face learning, with reduced looking towards the eyes and reduced change in eye movement consistency. We also found that across both autistic and non-autistic participants, the ability to adaptively change face scanning behavior according to mask conditions as measured in eye movement consistency, together with selective attention ability, were two important factors accounting for individual differences in face recognition performance impairment due to mask use. Interestingly, AQ score accounted for additional variance beyond these two factors when recognizing a masked face that was also learned with a mask on, suggesting additional influence from one's face learning experience during development. These findings have important implications for identifying vulnerable populations who may have particular difficulties in recognizing masked faces.

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References

Association, A. P. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-spectrum quotient (AQ): Evidence from asperger syndrome/high- functioning autism, male sand females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5–17.

Berg, W. K., & Byrd, D. L. (2002). The Tower of London spatial problem-solving task: Enhancing clinical and research implementation. *Journal of Clinical and Experimental Neuropsychology, 24*(5), 586–604.

Bilker, W. B., Hansen, J. A., Brensinger, C. M., Richard, J., Gur, R. E., & Gur, R. C. (2012). Development of abbreviated nine-item forms of the Raven's Standard Progressive Matrices Test. *Assessment, 19*(3), 354–369.

Chawarska, K., & Shic, F. (2009). Looking but not seeing: Atypical visual scanning and recognition of faces in 2 and 4-year-old children with autism spectrum disorder. *Journal of autism and developmental disorders*, *39*, 1663-1672.

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.

Coviello, E., Chan, A. B., & Lanckriet, G. R. G. (2014). Clustering Hidden Markov Models with Variational HEM. *Journal of Machine Learning Research, 15*, 697–747.

Fitousi, D., Rotschild, N., Pnini, C., & Azizi, O. (2021). Understanding the Impact of Face Masks on the Processing of Facial Identity, Emotion, Age, and Gender. *Frontiers in Psychology, 12,* 743793.

Frank, K., Schuster, L., Alfertshofer, M., Baumbach, S. F., Herterich, V., Giunta, R. E., ... & Cotofana, S. (2021). How does wearing a facecover influence the eye movement pattern in times of COVID-19?. *Aesthetic Surgery Journal*, *41*(8), NP1118-NP1124.

Freud, E., Stajduhar, A., Rosenbaum, R., Avidan, G., & Ganel, T. (2020). The COVID-19 pandemic masks the way people perceive faces. *Scientific Reports, 10*(1), 22344.

Gulbetekin, E. (2021). Effects of mask use and race on face perception, emotion recognition, and social distancing during the COVID-19 pandemic. *Preprint. https://doi. org/10*, *21203*.

Hernandez, N., Metzger, A., Magné, R., Bonnet-Brilhault, F., Roux, S., Barthelemy, C., & Martineau, J. (2009). Exploration of core features of a human face by healthy and autistic adults analyzed by visual scanning. *Neuropsychologia*, *47*(4), 1004-1012.

Hsiao, J. H., An, J., Hui, V. K. S., Zheng, Y., & Chan, A. B. (2022a). 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), 28–28.

Hsiao, J. H., An, J., Zheng, Y., & Chan, A. B. (2021a). Do portrait artists have enhanced face processing abilities? Evidence from hidden Markov modeling of eye movements. *Cognition, 211*, 104616.

Hsiao, J. H., Lan, H., Zheng, Y., & Chan, A. B. (2021b). 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. (2022b). Impact of mask use on face recognition: an eye-tracking study. *Cognitive Research: Principles and Implications, 7*(1), 32–32.

Hsiao, J. H., & Chan, A. B. (2023). Visual attention to own- versus other-race faces: Perspectives from learning mechanisms and task demands. *British Journal of Psychology*, *114*, 17-20.

Jaeggi, S. M., Buschkuehl, M., Perrig, W. J., & Meier, B. (2010). The concurrent validity of the N-back task as a working memory measure. *Memory, 18*(4), 394–412.

Joseph, R. M., Keehn, B., Connolly, C., Wolfe, J. M., & Horowitz, T. S. (2009). Why is visual search superior in autism spectrum disorder?. *Developmental science*, *12*(6), 1083-1096.

Kirchner, J. C., Hatri, A., Heekeren, H. R., & Dziobek, I. (2011). Autistic symptomatology, face processing abilities, and eye fixation patterns. *Journal of autism and developmental disorders*, *41*, 158-167.

Liang, M., Gao, L., Cheng, C., Zhou, Q., Uy, J. P., Heiner, K., & Sun, C. (2020). Efficacy of face mask in preventing respiratory virus transmission: A systematic review and meta-analysis. *Travel medicine and infectious disease*, *36*, 101751.

Mckone, E., Crookes, K., & Kanwisher, N. (2009). The cognitive and neural development of face recognition in humans. *The cognitive neurosciences*, 467–482.

Raven, J. (2000). The Raven's progressive matrices: Change and stability over culture and time. *Cognitive Psychology, 41*, 1–48.

Richler, J. J., Cheung, O. S., & Gauthier, I. (2011). Holistic Processing Predicts Face Recognition. *Psychological Science, 22*(4), 464–471.

Richler, J. J., Palmeri, T. J., & Gauthier, I. (2012). Meanings, Mechanisms, and Measures of Holistic Processing. *Frontiers in Psychology, 3*, 553–553.

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

Robinson, S., Goddard, L., Dritschel, B., Wisley, M., & Howlin, P. (2009). Executive functions in children with autism spectrum disorders. *Brain and cognition*, *71*(3), 362-368.

Tanaka, J. W., & Sung, A. (2016). The "eye avoidance" hypothesis of autism face processing. *Journal of autism and developmental disorders*, *46*, 1538-1552.

Tso, R. V., Chui, C. O., & Hsiao, J. H. (2022). How does face mask in COVID-19 pandemic disrupt face learning and recognition in adults with autism spectrum disorder?. *Cognitive Research: Principles and Implications*, *7*(1), 64.

Van Der Geest, J. N., Kemner, C., Verbaten, M. N., & Van Engeland, H. (2002). Gaze behavior of children with pervasive developmental disorder toward human faces: a fixation time study. *Journal of child psychology and psychiatry*, *43*(5), 669-678.

Wolf, J. M., Tanaka, J. W., Klaiman, C., Cockburn, J., Herlihy, L., Brown, C., ... & Schultz, R. T. (2008). Specific impairment of face-processing abilities in children with autism spectrum disorder using the Let's Face It! skills battery. *Autism Research, 1*(6), 329-340.

Zheng, Y., Chen, D., Hu, X., & Hsiao, J. (2022). The impact of mask use on social categorization. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 44, No. 44).

Zheng, Y., & Hsiao, J. H. (2023). Differential audiovisual information processing in emotion recognition: An eye-tracking study. *Emotion*, *23*(4), 1028.

Zheng, Y., de la Harpe, S., Yang, A. Y., Hayward, W. G., Palermo, R., & Hsiao, J. (2023). Cultural Differences in the Effect of Mask Use on Face and Facial Expression Recognition. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 45, No. 45).