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# Differential mask effects on emotion recognition and eye movements in Psychotic-like experiences and autism: Insights from hidden Markov Modeling

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ABSTRACT

*Background:* Facial mask wearing may disrupt facial emotion recognition (FER). The impact of masks on FER and associated eye movement patterns among individuals with autism spectrum disorder (ASD) and those with psychotic-like experiences (PLEs) remained unclear.
*Methods:* 180 ethnic Chinese individuals completed the FER task with eye-tracking, including two separate samples: 37 PLEs with 53 matched controls, and 45 ASD with 45 matched controls. The eye movement data were analyzed using Eye Movement analysis with Hidden Markov Models (EMHMM). MANCOVA was used to examine the mask and group effects on the performances and eye movements of FER, while regression analyses explored associations with subclinical measures.
*Results:* Facial masks impaired FER in all subjects. Differential effects of masks from matched controls on eye movement patterns and visual scanning consistency were only observed in the PLEs. The maladaptation of accuracy and visual scanning consistency due to masks were associated with subclinical psychotic symptoms and delusional ideations respectively. ASD presented poorer accuracy, slower reaction times, and less consistent eye movements compared to controls and PLEs. Imaginative cognition was related to the maladaptation of accuracy and eye movement due to masks in ASD. Schizotypal traits showed differential associations with eye movements in PLEs and ASD.
*Conclusions:* This study reveals maladaptation of eye movement behaviors during FER due to masks in PLEs, and distinct associations between FER with subclinical features in PLEs and ASD. It sheds light on the complex social cognitive processing and real-world social challenges faced by these populations in mask-prevalent environments.

## 1. Introduction

The global implementation of facial mask-wearing during the COVID-19 pandemic has persisted in many Asian regions, including China, Hong Kong, Singapore, Japan, and Korea, where masks remain common in schools, workplaces, and crowded areas (Fearnley and Wu, 2023; Nayani et al., 2023). Nonverbal languages, including gaze and facial expressions, are fundamental for effective social interactions (Ekman and Friesen, 1978; Meeren et al., 2005). However, facial masks obscure the lower part of the face, potentially hindering communication in daily life (Mheidly et al., 2020) and psychiatric settings (Dondé et al., 2022). Recent studies indicate that mask wearing impairs perception of

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facial details and expressions in the general population (Grahlow et al., 2022; Grundmann et al., 2021; Zheng and Hsiao, 2023; Hsiao et al., 2022a). Individuals with autism spectrum disorder (ASD) or autistic traits could be more vulnerable to these negative impacts of facial masks compared to neurotypical controls (NC) (Pazhoohi et al., 2021; Ventura et al., 2023; Tso et al., 2022). Escelsior et al. (2022) also found that patients with bipolar disorders, schizophrenia, and major depressive disorders encountered more difficulties in recognizing masked expressions than healthy controls. Psychotic-like experiences (PLEs) refer to subclinical psychotic symptoms in the non-help-seeking population, including delusion-like thoughts, perceptual abnormalities, and bizarre experiences (Kelleher and Cannon, 2010; Lee et al., 2016; Yung et al., 2009), and have been suggested to be transdiagnostic clinical makers of various psychiatric conditions besides psychotic disorders (Chan et al., 2021; Matheson et al., 2023; McGrath et al., 2016). Individuals with PLEs may struggle more with recognizing masked expressions, especially given their heightened sensitivity to threatening faces (Arguedas et al., 2006; Prochwicz et al., 2020; Provencio et al., 2011) as studies suggested that masks may enhance the perception of threat (Grahlow et al., 2022; Grundmann et al., 2021). Investigating the effects of facial masks on emotion recognition in individuals with PLEs could provide valuable insights into their social cognitive processes and informed strategies for targeted supports (see Fig. 1, Fig1a-1d).

Facial emotion recognition (FER) refers to the ability to accurately perceive and interpret others' facial expressions (Frith and Frith, 2008). Impairments in FER are well-documented in ASD (Yeung, 2022), schizophrenia (Kohler et al., 2010), and clinical high risk for psychosis (CHR) (Tsui et al., 2024b). However, findings on FER impairments in individuals with PLEs are limited and inconsistent, with evidence both supporting the presence of impairments (Pena-Garijo et al., 2023; Roddy et al., 2012) and refuting them (Köther et al., 2018; Pelletier et al., 2013; Steenhuis et al., 2020; Thompson et al., 2011
).

Eye movement abnormalities have been observed in ASD, schizophrenia, and high psychosis risk population, potentially serving as diagnostic markers (Ekin et al., 2024; Hamner and Vivanti, 2019; Myles et al., 2017; Wolf et al., 2021). In ASD, atypical visual attention strategies during FER, such as reduced focus on the eyes and increased fixation on non-salient features, have been reported (Black et al., 2017). However, findings in high-functioning ASD remain inconsistent (Corden et al., 2008; Tsang, 2018; Hanley et al., 2013). No studies have examined eye movements during FER in individuals with PLEs. The eye movement analysis with hidden Markov model (EMHMM) offers a promising tool to analyze eye movement data, quantifying visual attentional patterns and scanning consistency beyond traditional measures (Chuk et al., 2014; Hsiao et al., 2022b; Zhang et al., 2019). This machine learning approach has been successfully applied in schizophrenia and ASD (Chan et al., 2022; Hsiao et al., 2022b; Zheng and Hsiao, 2023), providing additional insights into the FER-related eye movements.

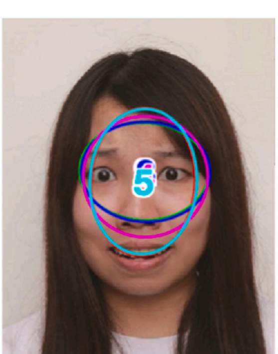
The presence of potentially overlapping and opposing mechanisms of social cognition in ASD and psychosis populations have been suggested (Colizzi et al., 2022; Crespi and Badcock, 2008; Martinez et al., 2017). While both ASD and schizophrenia exhibit FER impairments (Oliver et al., 2020), findings on their underlying neural and visual attentional mechanisms are mixed (Ciaramidaro et al., 2018; Martínez et al., 2019; Sugranyes et al., 2011). Comparing FER performances and eye movements in individuals with PLEs and ASD has not been directly addressed, despite possible overlapping characteristics such as schizotypal traits (Fonseca Pedrero and Debbane, 2017; Zhou et al., 2019). Investigating mask effects on FER in these groups can elucidate their unique and shared psychopathological and social cognitive processes related to emotion recognitions across neurodevelopmental and psychotic spectrums.

This study primarily aimed to investigate FER performances and eye movements patterns in individuals with PLEs and ASD. We also explored the associations with subclinical measures, including psychotic features, autistic traits, and schizotypal traits, and the effect of facial mask. Eye movement data were analyzed using EMHMM to quantify eye movement patterns (nose- or eye-focused patterns) and visual scanning consistency (quantified with entropy). We hypothesized that individuals with PLEs and ASD would exhibit similar FER impairments, aberrant eye movements, and difficulties adjusting to facial masks compared with NC, but expected distinct associations with subclinical features. To our knowledge, this is the first study to examine eye movements of FER with the effect of facial masks in individuals with PLEs and ASD. Results of the study will shed light on the mechanisms of the impairment of FER in autistic individuals and PLEs, the role of different subclinical symptom dimensions. This may facilitate further understanding of the real-world challenges in the social functioning of vulnerable individuals due to more prevalent use of facial masks.

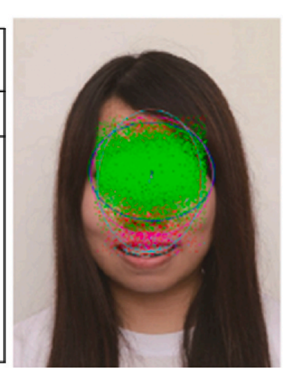
## 2. Methods

### 2.1. Participants & procedures

A total of 180 ethnic Chinese participants aged from 16 to 30 were recruited from the university and community: 45 autistic individuals, 45 neurotypical controls (NC) matched by age, gender, and education, 37 individuals with PLEs, and 53 matched NC (Table 1). All autistic participants provided formal diagnostic confirmation letters from psychiatrists, and were recruited via the university support centers, clinician referrals, and community sources. Among the 45 autistic individuals, 13 were identified with comorbid ADHD. PLEs participants were recruited from the Hong Kong Youth Epidemiological Study of Mental Health (HK-YES) community project using a two-phase sampling design (Chan et al., 2021; Wong et al., 2023). In Phase 1, all consenting adults completed the Psychosis Screening Questionnaire (PSQ; Bebbington and Nayani, 1995) which assesses five symptom domains (hypomania, paranoia, thought



| | To Red | To Green | To Blue | To Magenta | To Aqua |
|---|---|---|---|---|---|
| Priors | .72 | .00 | .00 | .00 | .27 |
| From Red | .00 | .94 | .01 | .03 | .02 |
| From Green | .00 | .68 | .21 | .10 | .01 |
| From Blue | .00 | .27 | .57 | .09 | .06 |
| From Magenta | .00 | .66 | .22 | .04 | .08 |
| From Aqua | .00 | .57 | .35 | .05 | .03 |



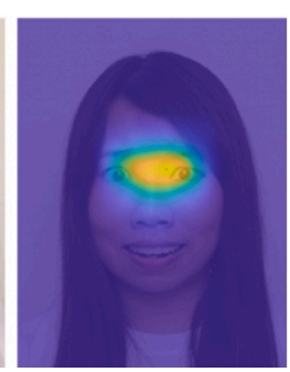
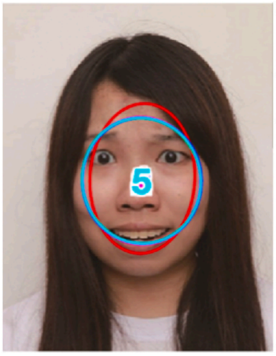


**Fig. 1a.** HMM models and heatmaps of PLEs and ASD.
The overall representative Hidden Markov Model (HMM) of eyes-focused pattern (pattern A) and the heatmap in PLEs and NC.




| | To Red | To Green | To Blue | To Magenta | To Aqua |
|---|---|---|---|---|---|
| Priors | .95 | .01 | .01 | .04 | .00 |
| From Red | .04 | .41 | .06 | .37 | .13 |
| From Green | .13 | .28 | .43 | .11 | .06 |
| From Blue | .00 | .03 | .60 | .19 | .18 |
| From Magenta | .12 | .08 | .05 | .60 | .14 |
| From Aqua | .14 | .41 | .33 | .01 | .11 |

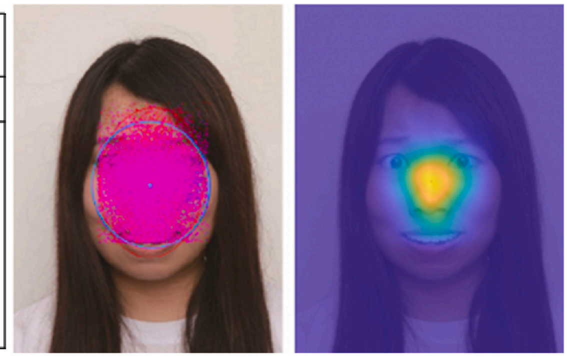


**Fig. 1b.** The overall representative Hidden Markov Model (HMM) of nose-focused pattern (pattern B) and the heatmap in PLEs and NC.


| | To Red | To Green | To Blue | To Magenta | To Aqua | To Yellow |
|---|---|---|---|---|---|---|
| Priors | .97 | .01 | .01 | .00 | .02 | .00 |
| From Red | .01 | .36 | .34 | .01 | .23 | .06 |
| From Green | .00 | .49 | .49 | .02 | .00 | .00 |
| From Blue | .00 | .48 | .51 | .02 | .00 | .00 |
| From Magenta | .00 | .46 | .49 | .06 | .00 | .00 |
| From Aqua | .00 | .00 | .00 | .00 | 1.0 | .00 |
| To Yellow | .01 | .02 | .02 | .00 | .00 | .95 |

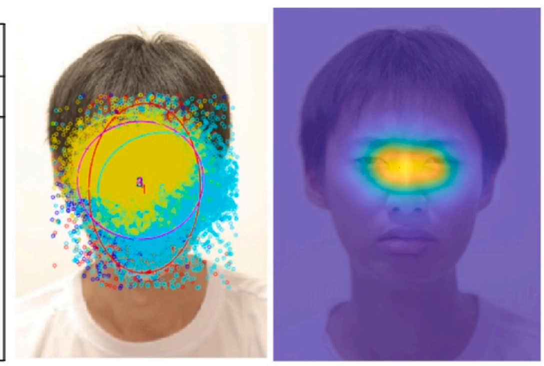


**Fig. 1c.** The overall representative Hidden Markov Model (HMM) of eyes-focused pattern (pattern A) and the heatmap in ASD and NC.


| | To Red | To Green | To Blue | To Magenta | To Aqua | To Yellow |
|---|---|---|---|---|---|---|
| Priors | .55 | .26 | .15 | .04 | .00 | .00 |
| From Red | .00 | .79 | .04 | .02 | .08 | .07 |
| From Green | .00 | 1.0 | .00 | .00 | .00 | .00 |
| From Blue | .00 | .00 | .79 | .21 | .00 | .00 |
| From Magenta | .00 | .00 | .69 | .30 | .00 | .00 |
| From Aqua | .00 | .00 | .00 | .00 | .28 | .72 |
| To Yellow | .01 | .02 | .02 | .00 | .26 | .74 |

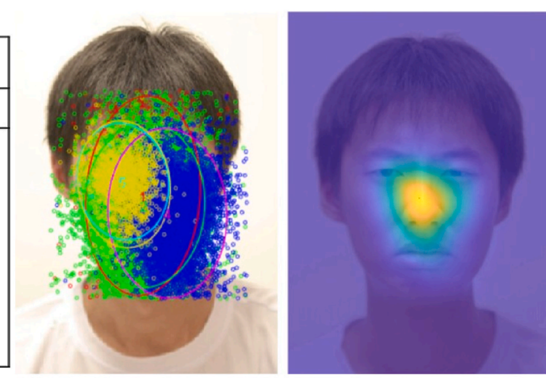


**Fig. 1d.** The overall representative Hidden Markov Model (HMM) of nose-focused pattern (pattern B) and the heatmap in ASD and NC.

insertion, strange experiences, hallucinations). In Phase 2, respondents endorsing any PSQ items underwent a psychiatrist-administered Structured Clinical Interview for DSM-IV (So et al., 2004) and people fulfilling the diagnosis of psychotic disorders were excluded. Those who screened positive on the PSQ but did not meet criteria for a psychotic disorder were classified as PLEs and were invited for this study. They were further screened with the Community Assessment of Psychic Experiences–-Positive 15-item scale (CAPE-P15), with a cutoff of ≥20 on both frequency and distress subscales (Linscott and van Os, 2013; Knight et al., 2020; Welham et al., 2008), yielding 37 PLE participants. Based on power analyses (effect size $f = 0.2$, $\alpha = 0.05$, power = 0.95), a minimum sample size of 84 participants was required for each sample to detect groups by mask condition interactions. We rounded up the target number to 90 participants per sample. Exclusion criteria encompassed psychiatric comorbidities, intellectual disability, significant brain injury, neurological disorders, and hearing or vision impairments. Participants completed a 2-h face-to-face assessment after providing written informed consent. This study and its protocol were approved by the Human Research Ethics Committee of the University of Hong Kong (Reference number: EA200090), and Institutional Review Board of the University of Hong Kong and the Hospital Authority Hong Kong West Cluster (IRB reference number: UW 20–708), and conformed to the provisions of the Declaration of Helsinki.

## 2.2. Measures

### 2.2.1. Subclinical assessments and estimated intelligence

Subclinical measures for PLEs and ASD groups are detailed in Supplementary Table 1. The CAPE-P15 assessed psychotic-like experiences (Knight et al., 2020; Stefanis et al., 2002), and the Peters et al. Delusion Inventory (PDI-21) measured delusional ideations (Peters et al., 2004), administered only to PLEs and their matched NCs. The Schizotypal

**Table 1**
Comparisons between PLEs and NC, and ASD and matched-NC on demographics and subclinical characteristics.

| | PLEs (N = 37) | NC (N = 53) | | | ASD (N = 45) | NC (N = 45) | | |
|---|---|---|---|---|---|---|---|---|
| Variables | Mean, SD | Mean, SD | *t* | *p* | Mean, SD | Mean, SD | *t* | *p* |
| Age | 20.00, 1.915 | 19.98, 2.232 | 0.042 | 0.967 | 25.29, 6.871 | 22.82, 6.538 | 1.745 | 0.085 |
| Gender[a] (No. of female, %) | 19, 51.4 % | 34, 64.2 % | 1.474 | 0.225 | 20, 44.4 % | 20, 44.4 % | 0.00 | 1 |
| Years of education | 14.05, 1.699 | 14.15, 2.004 | −0.240 | 0.811 | 15.89, 2.279 | 15.44, 2.321 | 0.917 | 0.362 |
| RSPM | 5.54, 2.231 (Range: 1–9) | 6.68, 1.969 (Range: 2–9) | −2.555 | **0.012** | 7.44, 1.686 (Range: 2–9) | 7.69, 1.184 (Range: 5–9) | −0.796 | 0.428 |
| ***CAPE-P15*** | | | | | | | | |
| Total | 51.57, 10.410 | 35.23, 4.317 | 9.022 | **<0.001** | N/A | N/A | N/A | N/A |
| Frequency | 26.59, 5.914 | 18.00, 2.038 | 8.495 | **<0.001** | N/A | N/A | N/A | N/A |
| Distress | 24.97, 5.299 | 17.23, 3.315 | 7.881 | **<0.001** | N/A | N/A | N/A | N/A |
| ***PDI-21*** | | | | | | | | |
| Total | 71.78, 36.073 | 21.40, 15.641 | 7.989 | **<0.001** | N/A | N/A | N/A | N/A |
| Endorsement | 7.62, 3.467 | 2.96, 2.009 | 7.358 | **<0.001** | N/A | N/A | N/A | N/A |
| Distress | 19.16, 10.595 | 5.23, 4.200 | 7.595 | **<0.001** | N/A | N/A | N/A | N/A |
| Preoccupation | 20.19, 11.448 | 5.28, 4.478 | 7.529 | **<0.001** | N/A | N/A | N/A | N/A |
| Conviction | 24.81, 12.206 | 7.92, 6.006 | 7.783 | **<0.001** | N/A | N/A | N/A | N/A |
| ***AQ*** | | | | | | | | |
| Total | N/A | N/A | N/A | N/A | 136.44, 15.019 | 116.44, 13.527 | 6.638 | **<0.001** |
| Social skill | N/A | N/A | N/A | N/A | 28.49, 5.845 | 23.84, 5.608 | 3.846 | **<0.001** |
| Attention switching | N/A | N/A | N/A | N/A | 28.78, 4.247 | 25.91, 2.898 | 3.740 | **<0.001** |
| Attention to detail | N/A | N/A | N/A | N/A | 25.76, 4.553 | 23.47, 3.546 | 2.660 | **<0.001** |
| Communication | N/A | N/A | N/A | N/A | 27.02, 4.515 | 20.89, 4.030 | 6.799 | **<0.001** |
| Imagination | N/A | N/A | N/A | N/A | 26.40, 4.438 | 22.33, 3.643 | 4.751 | **<0.001** |
| ***SPQ*** | | | | | | | | |
| Total | 36.38, 15.637 | 21.94, 12.217 | 4.911 | **<0.001** | 37.05, 12.048 | 19.27, 11.723 | 5.045 | **<0.001** |
| Positive | 15.76, 6.370 | 6.47, 4.952 | 7.773 | **<0.001** | 12.48, 5.869 | 5.89, 5.073 | 5.670 | **<0.001** |
| Negative | 17.70, 8.765 | 11.28, 6.712 | 3.933 | **<0.001** | 18.68, 7.031 | 9.58, 7.085 | 6.084 | **<0.001** |
| Disorganized | 8.70, 3.950 | 5.74, 3.633 | 3.677 | **<0.001** | 10.00, 3.498 | 4.84, 3.711 | 6.742 | **<0.001** |

*Note.* PLEs indicates individuals with psychotic-like experiences, NC neurotypical controls, ASD individuals with autism spectrum disorders, RSPM Raven's Standard Progressive Matrices, CAPE-P15 Community Assessment of Psychic Experiences – Positive 15-item Scale, PDI-21 Peters et al. Delusion Inventory, AQ Autism Spectrum Quotient, SPQ Schizotypal Personality Questionnaire. a. Chi-square test was used for group differences in gender. Bold p-value indicates a significant result.

Personality Questionnaire (SPQ) evaluated schizotypal traits with the three-factor model in both PLEs and ASD groups (Raine, 1991; Raine et al., 1994). The Autism-Spectrum Quotient (AQ) assessed autistic traits with the five-factor model in ASD and NC groups (Baron-Cohen et al., 2001). The Raven's Standard Progressive Matrices (RSPM) measured abstract reasoning and fluid intelligence (Bilker et al., 2012; Raven, 2000).

### 2.2.2. Facial emotion recognition task (FER)

A Chinese version of FER was implemented to assess emotion recognition using 160 coloured frontal-view face stimuli displaying four emotions (anger, fear, happiness, sadness) under masked and unmasked conditions (Supplementary Fig. 1; Zhang et al., 2019). White facial masks were digitally added using Adobe Photoshop. The orders and distribution of emotions, masks conditions, and stimuli models were randomized. Participants were required to identify the emotion by pressing the corresponding button on a keyboard (A: anger, D: fear, H: happiness, K: sadness) with no time limit. Stimuli remained on screen until the participant made a response. A practice block was provided before the actual task for participants to familiarize with the task operation. Eye movements data was obtained using the EyeLink 1000 desktop-mounted eye-tracker with nine-point calibration and a chinrest to minimize head movements. Participants sat 57 cm from a 22-inch monitor with a resolution of 1024x768 pixels (Zheng and Hsiao, 2023). Under this viewing distance, each presented face subtended about 6° of visual angle horizontally, equivalent to the size of a real face under a view distance of 2 m (McKone, 2009) (Supplementary Method).

## 2.3. Eye movement data analysis & statistical analysis

Version 0.80 of the Eye Movement Analysis with Hidden Markov Model (EMHMM) toolbox was used to analyze the eye movement data during FER using MATLAB (version R2021a) (Chuk et al., 2014; the toolbox is available at: http://visal.cs.cityu.edu.hk/research/emhmm/). EMHMM analysis was performed separately for PLE and ASD groups with their matched NCs. Two Hidden Markov Models (HMMs) were derived from fixation data to summarize the visual patterns for masked and unmasked expressions for each participant with 80 trials. Each HMM estimated the number of regions of interest (ROIs) using the variational Bayesian algorithm from a preset range of 1–5. Using the variational hierarchical expectation maximization algorithm, individual HMMs were then clustered into two representative visual patterns: eye-focused pattern and nose-focused pattern. The median number of ROIs among individual HMMs was used to generate the representative HMMs for each pattern. The degree of similarity of the visual pattern of each participant to the representative patterns was quantitatively assessed using the EN scale, which was computed as: (eye-focused pattern log-likelihood − nose-focused pattern log-likelihood)/(eye-focused pattern log-likelihood + nose-focused pattern log-likelihood). A more positive EN scale indicates a greater similarity to eye-focused pattern, and a more negative EN scale indicates a greater similarity to nose-focused pattern. Entropy of the HMMs from participants was calculated to examine the consistency and predictability of eye movement behaviors in different mask conditions, where a lower entropy indicates a higher visual scanning consistency and predictability.

To quantitatively manifest the impacts of mask conditions, interference indexes of accuracy, reaction time, EN scale, and entropy were calculated (Supplementary method for detailed calculation). For the sake of clarity, the directions of interference indexes are consistent: a positive interference index indicates a more maladaptive impact of mask with poorer performance or more abnormal eye movements, whereas a negative interference index indicates an adaptive change due to mask with better performance or less abnormal eye movements.

MANCOVA was used to examine the interaction and main effects of groups (PLEs vs NC, ASD vs NC) and mask conditions on the four FER parameters: accuracy, reaction time, eye-nose scale (EN scale), and entropy controlling for age, gender, years of education and RSPM. Post hoc pairwise comparisons with Bonferroni corrections were conducted to identify specific group differences within each mask condition. Regression controlling for the four covariates was conducted to investigate the association between FER performances and subclinical features (CAPE-P15, PDI-21, SPQ, AQ) in the two samples separately. While the PLEs and ASD samples were not well-matched, additional comparisons of demographics and FER were explored.

## 3. Results

### 3.1. PLEs and matched NC

Individuals with PLEs had significantly lower RSPM score, higher total scores and subscales on the CAPE-P15, PDI-21, and SPQ, except for SPQ odd speech and constricted affect subscales compared with their NC (Table 1). No significant difference in age, gender, or years of education was found between PLEs and NC. Fig. 1a and b shows the heatmaps and representative HMM models of PLE and their NC.

A two-way MANCOVA revealed a significant effect of masks on the four measures of FER (Table 2). Significant group effects were found on EN scale ($F = 15.402$, $p < 0.001$, $\eta^2p = 0.021$) and entropy ($F = 11.840$, $p < 0.001$, $\eta^2p = 0.016$). Interaction effects of group and mask on EN scale ($F = 3.906$, $p = 0.048$, $\eta^2p = 0.005$) and entropy ($F = 4.796$, $p = 0.029$, $\eta^2p = 0.007$) were also observed; other main and interaction effects were not statistically significant. Post hoc comparisons indicated that PLEs had a significantly lower EN scale and higher entropy than NC in the masked condition only (Supplementary Table 2), suggesting PLEs had less eye-focus and more inconsistent eye movement patterns during the masked condition. Interference index in entropy was significantly higher for PLEs than NC ($t = 2.508$, $p = 0.014$), indicating a maladjustment in the consistency of eye movements in the masked condition.

Regression analysis revealed that in the masked condition, the accuracy had negative association with CAPE-P15 ($\beta = -0.277, p = 0.014$) and SPQ disorganized ($\beta = -0.227$, $p = 0.034$), and entropy was significantly associated with PDI-21 ($\beta = 0.276, p = 0.027$) score and SPQ positive ($\beta = 0.275, p = 0.031$) (Table 3). The Interference index of accuracy was significantly related to CAPE-P15 ($\beta = 0.237, p = 0.024$), whereas the interference index of entropy was significantly associated with PDI-21 ($\beta = 0.232, p = 0.049$) (Table 4).

### 3.2. ASD and matched NC

Total scores and subscales of AQ and SPQ were significantly higher in ASD than NC, except for SPQ odd beliefs (Table 1). Age, gender, years of education, and RSPM did not differ between ASD and NC. Fig. 1c and d shows the heatmaps and representative HMM models of ASD and their NC.

A two-way MANCOVA showed a significant main effect of mask condition on the four measures of FER (Table 2). Significant group effects were found on accuracy ($F = 4.348$, $p = 0.037$, $\eta^2p = 0.006$), reaction time ($F = 5.365$, $p = 0.021$, $\eta^2p = 0.007$), and entropy ($F = 47.425$, $p < 0.001$, $\eta^2p = 0.063$). No significant group and mask interaction effects were found. Post hoc comparisons revealed that ASD had a significantly higher entropy in both masked and unmasked conditions, and slower reaction time in the masked condition than that of NC (Supplementary Table 3). No significant group differences were found in interference indexes of FER performance.

Regression analysis controlling for the same covariates indicated that in the masked conditions, accuracy was significantly related to AQ imagination ($\beta = -0.229, p = 0.034$), entropy was positively associated with AQ total ($\beta = 0.221, p = 0.024$), AQ attention to detail ($\beta = 0.234$, $p = 0.016$) and SPQ total score ($\beta = 0.219, p = 0.027$) (Table 3). In the unmasked conditions, accuracy was negatively associated with AQ communication ($\beta = -0.218$, $p = 0.033$) and SPQ total score ($\beta = -0.209$, $p = 0.045$), and entropy was positively associated with AQ attention to detail ($\beta = 0.201, p = 0.045$). Additionally, AQ imagination had a significant role on the interference index of accuracy ($\beta = 0.226$, $p = 0.037$) and that of EN scale ($\beta = 0.220$, $p = 0.047$) (Table 4).

### 3.3. ASD and PLEs

The ASD group had significantly higher age, years of education, and RSPM than that of the group with PLEs (Supplementary Table 4). Only the score of SPQ positive was significantly higher in the PLEs group than the ASD group, while SPQ total score and other subscales were not significantly different. MANCOVA revealed significant group effects in accuracy, reaction time, and entropy: ASD performed significantly poorer, slower and exhibited more inconsistent in eye movement behaviors than PLEs (Table 2 & Supplementary Table 5).

## 4. Discussion

This study examined the impact of facial masks on the FER performances and eye movement behaviors in autistic individuals and PLEs, and explored the associations between performance and eye movement behaviors of FER and self-reported subclinical traits. Across groups, mask-wearing significantly disrupted FER performances and altered eye movement behaviors. Notably, a significant interaction effect between group and mask conditions was only observed in the PLEs group, which exhibited more nose-focused eye movements and lower visual scanning consistency compared to NC under masked condition. This phenomenon was absent in the ASD group, where only eye movement inconsistency

**Table 2**
MANCOVA of facial emotion recognition of PLEs versus matched-NC, ASD versus matched-NC, and PLEs versus ASD.

| | Variables | PLEs vs NC | | | ASD vs NC | | | PLEs vs ASD | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | F | P | $\eta^2p$ | F | P | $\eta^2p$ | F | P | $\eta^2p$ |
| Group | Accuracy | 2.643 | 0.104 | 0.004 | 4.348 | **0.037** | 0.006 | 4.127 | **0.043** | 0.006 |
| | Reaction Time | 0.082 | 0.775 | <0.001 | 5.365 | **0.021** | 0.007 | 7.904 | **0.005** | 0.012 |
| | EN Scale | 15.220 | **<0.001** | 0.021 | 0.237 | 0.627 | 0.000 | N/A | N/A | N/A |
| | Entropy | 11.816 | **<0.001** | 0.017 | 47.425 | **<0.001** | 0.063 | 88.254 | **<0.001** | 0.122 |
| Mask condition | Accuracy | 66.214 | **<0.001** | 0.085 | 52.721 | **<0.001** | 0.069 | 68.227 | **<0.001** | 0.097 |
| | Reaction Time | 13.172 | **<0.001** | 0.018 | 15.558 | **<0.001** | 0.021 | 14.137 | **<0.001** | 0.022 |
| | EN Scale | 285.090 | **<0.001** | 0.286 | 110.015 | **<0.001** | 0.134 | N/A | N/A | N/A |
| | Entropy | 86.967 | **<0.001** | 0.109 | 46.897 | **<0.001** | 0.062 | 26.170 | **<0.001** | 0.040 |
| Group * Mask condition | Accuracy | 0.267 | 0.605 | <0.001 | 0.087 | 0.769 | <0.001 | 0.000 | 0.984 | 0.000 |
| | Reaction Time | 0.001 | 0.974 | <0.001 | 0.724 | 0.395 | 0.001 | 1.133 | 0.287 | 0.002 |
| | EN Scale | 3.906 | **0.048** | 0.005 | 0.287 | 0.592 | <0.001 | N/A | N/A | N/A |
| | Entropy | 4.796 | **0.029** | 0.007 | 0.287 | 0.592 | <0.001 | 0.814 | 0.367 | 0.001 |

*Note.* PLEs indicates individuals with psychotic-like experiences, NC neurotypical controls, EN Scale eye-nose scale. MANCOVA was controlled for age, gender, years of education, and Raven's Standard Progressive Matrices. Bold p-value indicates a significant result.

**Table 3**
Associations between facial emotion recognition and subclinical traits using regression controlling for age, gender, years of education, and RSPM.

| | Masked | | | | Unmasked | | | |
|---|---|---|---|---|---|---|---|---|
| | Accuracy | RT | EN | Entropy | Accuracy | RT | EN | Entropy |
| ***PLEs & NC*** | | | | | | | | |
| CAPE-P15 Total | **−0.277*** | −0.003 | −0.031 | 0.160 | −0.173 | 0.067 | 0.078 | 0.030 |
| PDI-21 | −0.123 | −0.079 | −0.112 | **0.276*** | −0.207 | −0.010 | 0.004 | 0.137 |
| SPQ Total | −0.160 | −0.085 | −0.074 | 0.136 | −0.134 | 0.113 | 0.106 | 0.097 |
| SPQ Positive | −0.102 | −0.128 | −0.076 | **0.275*** | −0.156 | −0.193 | 0.143 | 0.200 |
| SPQ Negative | −0.153 | −0.069 | −0.050 | 0.040 | −0.102 | −0.091 | 0.163 | 0.024 |
| SPQ Disorganized | **−0.227*** | −0.134 | −0.075 | 0.096 | −0.145 | −0.100 | 0.076 | 0.059 |
| ***ASD & NC*** | | | | | | | | |
| AQ Total | −0.176 | 0.020 | −0.082 | **0.221*** | −0.144 | −0.006 | 0.066 | 0.168 |
| AQ Social skill | −0.121 | −0.033 | −0.015 | 0.129 | −0.093 | −0.024 | 0.144 | 0.081 |
| AQ Attention switching | −0.037 | −0.068 | −0.070 | 0.112 | −0.040 | −0.051 | 0.060 | 0.080 |
| AQ Attention to detail | −0.049 | 0.037 | −0.183 | **0.234*** | −0.009 | 0.004 | −0.130 | **0.201*** |
| AQ Communication | −0.195 | 0.053 | −0.012 | 0.174 | **−0.218*** | −0.001 | 0.086 | 0.102 |
| AQ Imagination | **−0.232*** | 0.089 | −0.051 | 0.170 | −0.146 | 0.056 | 0.041 | 0.174 |
| SPQ Total | −0.177 | −0.029 | 0.020 | **0.219*** | **−0.209*** | −0.067 | 0.186 | 0.191 |
| SPQ Positive | −0.087 | −0.012 | 0.018 | 0.179 | −0.097 | −0.038 | 0.114 | 0.199 |
| SPQ Negative | −0.071 | −0.085 | 0.010 | 0.185 | −0.093 | −0.108 | 0.185 | 0.155 |
| SPQ Disorganized | −0.120 | −0.091 | 0.064 | 0.148 | −0.153 | −0.123 | 0.149 | 0.104 |

*Note.* PLEs indicates individuals with psychotic-like experiences, NC neurotypical controls, RT reaction time, EN eye-nose scale, RSPM Raven's Standard Progressive Matrices, CAPE-P15 Community Assessment of Psychic Experiences – Positive 15-item Scale, PDI-21 Peters et al. Delusion Inventory, SPQ Schizotypal Personality Questionnaire, AQ Autism Spectrum Quotient, FER Facial Emotion Recognition; numbers presented in the table are standardized beta coefficients; * indicates $p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

**Table 4**
Associations between the interference index of facial emotion recognition with subclinical traits using regression controlling for age, gender, years of education, and RSPM.

| | FER Interference Index | | | |
|---|---|---|---|---|
| | Accuracy | RT | EN | Entropy |
| ***PLEs & NC*** | | | | |
| CAPE-P15 Total | **0.239*** | 0.134 | 0.013 | 0.207 |
| PDI-21 | −0.048 | 0.024 | 0.021 | **0.232*** |
| SPQ Total | 0.064 | 0.015 | 0.048 | 0.073 |
| SPQ Positive | −0.022 | 0.108 | 0.092 | 0.143 |
| SPQ Negative | 0.081 | 0.022 | 0.042 | 0.027 |
| SPQ Disorganized | 0.149 | −0.058 | 0.021 | 0.067 |
| ***ASD & NC*** | | | | |
| AQ Total | 0.062 | −0.028 | 0.083 | 0.113 |
| AQ Social skill | 0.032 | 0.049 | 0.005 | 0.107 |
| AQ Attention switching | −0.028 | 0.023 | 0.031 | 0.066 |
| AQ Attention to detail | 0.087 | 0.003 | 0.051 | 0.072 |
| AQ Communication | −0.035 | −0.129 | 0.030 | 0.159 |
| AQ Imagination | **0.226*** | −0.049 | **0.220*** | −0.020 |
| SPQ Total | −0.027 | −0.088 | 0.116 | 0.051 |
| SPQ Positive | 0.021 | −0.039 | 0.042 | −0.073 |
| SPQ Negative | −0.037 | −0.051 | 0.112 | 0.058 |
| SPQ Disorganized | −0.050 | −0.059 | 0.130 | 0.090 |

*Note.* PLEs indicates individuals with psychotic-like experiences, NC neurotypical controls, RT reaction time, EN eye-nose scale, RSPM Raven's Standard Progressive Matrices, CAPE-P15 Community Assessment of Psychic Experiences – Positive 15-item Scale, PDI-21 Peters et al. Delusion Inventory, SPQ Schizotypal Personality Questionnaire, AQ Autism Spectrum Quotient, FER Facial Emotion Recognition; numbers presented in the table are standardized beta coefficients; * indicates $p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

(entropy) differed significantly among all groups – with ASD showing the most inconsistent visual scanning patterns, followed by PLEs, and NC the lowest. Behaviorally, autistic individuals demonstrated significantly poorer and slower FER performance compared to both PLEs and NC groups, while PLEs and NC performed similarly. Regression analyses demonstrated that FER performance and eye movement behaviors were associated with specific subclinical traits: in PLEs, psychotic symptoms and delusional ideations influenced FER accuracy and visual consistency, while in ASD, imaginative cognition and attention to detail were linked to FER impairments and eye movement patterns.

This was the first study to examine the impact of masks on FER performances and eye movements in individuals with PLEs and ASD, and results showed that the use of facial masks negatively impacts on the FER performances and significantly changes the eye movement behaviors across populations. Masks obscure most facial features, leaving the eye regions as the primary source of information for emotion recognition, thus increasing ambiguity and difficulty in interpreting facial expressions. This necessitates adjustments in visual attentional strategies with more eye-focused and consistent eye movement patterns to discern the subtle nuances of facial expressions (Hsiao et al., 2022b; Zheng and Hsiao, 2023; Zheng and Hsiao, 2023). Our results suggest that individuals with PLEs exhibited less consistent visual scanning behavior and more nose-focused eye movement patterns particularly in the masked condition compared with HC, indicated by the significant group by mask interactions. This reflects difficulties of the PLE population in adapting coherent and purposeful visual scanning patterns to compensate for the reduced facial cues. In fact, individuals with PLEs exhibited these eye movement abnormalities during FER, despite showing similar behavioral performance to HC regardless of masks. The tendency of nose-focused eye movement pattern was also seen in the schizophrenia population during a gaze perception task (Chan et al., 2022). These findings suggest that eye movement patterns, which reflect information processing during emotional or intentional judgment, may exist on a continuum across the psychosis spectrum. The regression results further revealed that only in the mask condition, a positive relationship between the inconsistent eye movement pattern (entropy) and positive subclinical symptoms was present. Individuals with higher overall psychotic-like experiences had poorer FER accuracy only in the mask condition. These results suggest that the positive subclinical psychotic symptoms contribute to the increase in visual scanning inconsistency and the reduction in performance accuracy when under stress such as in the mask condition. Therefore, the maladaptive visual information processing strategies could be an earlier feature than behavioral abnormality indicating a full-blown psychosis and may also be a possible mechanism of poor emotion recognition with masks in patients with schizophrenia and bipolar affective disorder (Escelsior et al., 2022).

On the other hand, the lack of group by mask interaction for ASD individuals and their matched control suggests that ASD and HC are affected by facial masks equally in the emotional perception processes. While ASD individuals generally exhibited poorer accuracy and slower reaction times compared with both HC and individuals with PLEs, post hoc comparisons revealed that the processing speed of ASD individuals was particularly impaired in the masked condition. This could be a response of ASD individuals with increased difficulties of recognizing masked expressions (Ventura et al., 2023). Developing a consistent visual scanning routine plays an important role for efficient and effective face recognition (Hsiao et al., 2022a; Peterson and Eckstein, 2013). The reduced visual scanning consistency in ASD, regardless of the presence of masks, suggests their difficulty in developing a consistent visual scanning routine for face processing in general. In fact, ASD individuals also had a more inconsistent visual scanning routine compared with individuals with PLEs. This suggests that the lack of a consistent visual scanning routine for face processing might be unique and more prominent to autistic individuals. Indeed, the regression analysis showed that visual scanning consistency was associated with attention to detail subscale of AQ in both mask and unmask conditions, consistent with the speculation that the reduced visual attention consistency may be related to over-attentive to the details and thus failed to capture social salience in faces or expressions in the ASD population (Hsiao et al., 2022b). These findings also align with the local processing bias observed in people with autism as part of the Weak Central Coherence theory (Happé and Frith, 2006; Happé and Booth, 2008).

In ASD and their matched NC, imaginative cognition measured by AQ had a prominent role on impairments of FER accuracy due to facial masks. Difficulties in imaginative and mentalizing thinking may hinder the interpretation of salient facial features especially when some facial cues are covered (Crespi et al., 2016). Besides, the negative correlation between communication skills and accuracy in the unmasked condition aligned with established relationships between emotion recognition, social communication processes, and psychosocial functioning in ASD (Trevisan and Birmingham, 2016). Furthermore, in the masked condition, the positive association between the visual scanning consistency and both the AQ and SPQ total score suggest that overall schizotypy and autistic traits contribute to the increase of inconsistency in the visual scanning strategies during stressed circumstances. On the other hand, for the PLE and their matched NC, only positive schizotypal traits and delusional ideations were positively associated with inconsistent visual scanning strategies in the mask condition. These differential associations may reflect distinct mechanisms of social cognition impairment in these vulnerable populations (Zouraraki et al., 2023). While previous studies have also suggested that the co-occurrence of autistic and schizotypal or subclinical psychotic traits would exacerbate mood symptoms and psychosocial functioning (Karcher et al., 2023; Klang et al., 2022; Upthegrove et al., 2018), future studies could assess these subclinical features in other psychiatric conditions to investigate the underlying psychopathological mechanisms of emotional processing. Additionally, PLEs are diagnostically nonspecific phenomena that can precede a wide range of psychiatric outcomes. This study focused on investigating early, subclinical social cognitive vulnerabilities that may emerge before the onset of diagnosable psychotic disorders. While research on well-defined clinical cohorts, such as individuals with schizophrenia, remains essential for understanding established illness mechanisms, our approach aimed to identify potential early markers and compensatory mechanisms within subclinical or at-risk populations. Future research should build upon these findings by including clinically diagnosed samples to clarify the progression and specificity of facial emotion recognition deficits across the psychosis spectrum, thereby enhancing the clinical relevance of these observations.

Although autism and psychotic illnesses typically show male predominance, our sample had a relatively balanced gender distribution. Gender, along with age, education, and cognitive ability, was controlled for in all analyses to minimize confounding effects. Nonetheless, given known sex differences in facial search strategies and accuracy (Hall et al., 2011; Wingenbach et al., 2018), future research with larger, gender-balanced samples is needed to explore how sex moderates FER impairments and eye movement patterns in autistic and psychotic-like populations.

### 4.1. Limitations

Several limitations should be considered. First, the relatively small sample size limited the statistical power and generalizability of the analysis. While primary hypotheses targeted overall group differences in facial emotion recognition and eye movement patterns related to mask conditions, some analyses of associations with individual subdomains and multiple subscales were exploratory due to sample size limitations and should therefore be interpreted with caution. Second, the current study also focused on young adults, restricting applicability to other age groups. A larger sample size for PLEs could reveal more details of the diverse subclinical population. Third, the cross-sectional design limited the ability to examine developmental trajectories or deduce predictions, highlighting the need for longitudinal studies. Fourth, self-reported subclinical measures could be susceptible to response bias and social desirability bias (Atkinson et al., 1997). Also, the experimental design of FER posed a challenge to ecological validity as identifying others' emotions in a complex social scenario with more social cues could be different from perceiving pictures of emotional expression in isolation (Hanley et al., 2013; Sasson et al., 2015). Future studies could incorporate ecological tasks and clinical assessments by trained professionals to enhance validity and objectivity. Fifth, systematic cross-condition assessment was lacking, as autistic participants were not evaluated for subclinical psychotic features and PLE participants were not assessed for autistic traits. Separate recruitment sources and differing protocols prevented merging control groups and harmonizing assessments, limiting statistical power and direct cross-group comparisons. Therefore, interpretations of direct comparisons between ASD and PLE should be made cautiously. Future research should employ comprehensive, transdiagnostic evaluation batteries across groups to more accurately capture overlapping and distinct features between autism and psychotic-like experiences. Another limitation of this study is the lack of systematic assessment for ADHD symptoms, despite 13 of the autistic participants having comorbid ADHD diagnoses. Future research should incorporate structured evaluations of ADHD to better understand its potential impact on social cognitive performance in autism. Additionally, extensive cognitive functions were not measured in this study given their known relationships with social cognition (Tsui et al., 2024a; Ventura et al., 2013). Further research could also apply neuroimaging techniques to explore the neural processes underlying altered eye movement behaviors and their relationship to symptom expression.

### 4.2. Conclusion

The current paper is the first to examine FER performances and eye movement behaviors with and without facial masks in PLEs and ASD. Results indicated that masks significantly impaired the FER performances and changed eye movement behaviors across populations. Compared with the NC, only a significant mask effect on eye movement behaviors was seen in the PLEs group but not the ASD group. ASD exhibited impairments in accuracy, reaction time, and visual scanning consistency in FER compared with matched NC regardless of the mask conditions. Moreover, our findings highlighted the distinct associations between FER performances and subclinical features in the two populations. Particularly, the maladjustment of visual scanning consistency due to masks was mainly associated with delusional ideations in PLEs, while the maladjustment of eye movement patterns was related to imaginative cognition in ASD. This study advanced our understanding of emotional perception impairments and visual abnormalities in autism and psychotic-like experiences, highlighting the possible real-world difficulties in daily communications, social interactions among vulnerable populations in mask-wearing environments. Future research should consolidate these findings and explore interventional strategies to enhance emotional processing and effective communication with facial masks among the vulnerable population.

## CRediT authorship contribution statement

**Harry Kam Hung Tsui:** Formal analysis, Conceptualization, Writing – original draft, Data curation. **Sherry Kit Wa Chan:** Supervision, Conceptualization, Writing – review & editing, Methodology. **Abby Chi Kiu Cheung:** Methodology, Formal analysis, Project administration, Investigation. **Tsz Wa Yeung:** Methodology, Formal analysis, Project administration, Investigation. **Janet Hui-wen Hsiao:** Writing – review & editing, Software, Conceptualization, Supervision, Methodology.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpsychires.2025.07.025.

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