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From attentional bias to neural dysfunction: Multimodal evidence for emotion processing deficits in individuals with problematic social media use

Journal of Behavioral Addictions

15 (2026) 2, 661–671

DOI:
10.1556/2006.2025.00306

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FULL-LENGTH REPORT

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Received: July 13, 2025 • Revised manuscript received: February 3, 2026 • Accepted: March 20, 2026
Published online: April 15, 2026

ABSTRACT

Background and Aims: Problematic social media use (PMSMU) shows strong mental health associations, yet its neurocognitive mechanisms remain unclear. This study investigates emotion processing deficits in PMSMU, focusing on valence-specific attentional biases and neural dysfunction. *Methods:* 113 Chinese college students stratified into low-risk ($n = 55$) and high-risk PMSMU ($n = 58$) groups completed psychological assessments and an emotion recognition task using facial stimuli depicting the seven basic emotions selected from the Chinese Facial Affective Picture System (CFAPS) during simultaneous eye-tracking and fNIRS recording prefrontal-temporal activation. *Results:* High-risk PMSMU showed enhanced accuracy for joy emotion (82.58% vs. 74.31%, $p = 0.013$) but impaired negative emotion recognition (64.29% vs. 69.87%, $p = 0.006$). Eye-tracking revealed reduced nose-root fixation and increased mouth and the middle of nose attention. fNIRS identified negative-emotion-specific hyperactivation in right temporal (c1, $p = 0.017$) and left frontal lobes (c9, $p = 0.021$). Temporal activation correlated with slower sadness recognition ($r = 0.345$), while attention deficits linked to reduced fear accuracy ($r = -0.261$) and temporal hyperactivity ($r = 0.377$). High-risk subjects reported poorer psychosocial functioning (poorer interpersonal skills, attentional control, and higher levels of anxiety and depression, $p < 0.001$), with frontal activation moderating negative-emotion-impairment relationships. *Conclusion:* PMSMU is characterized by valence-specific disruptions—including attentional bias toward positive cues, impaired fear processing, and prefrontal-temporal hyperactivation during negative emotion decoding—that collectively define it as a neurobehavioral condition leading to psychosocial impairment.

KEYWORDS

problematic social media use, emotion processing deficits, attentional bias

INTRODUCTION

Social media has become an integral component of modern society, significantly influencing daily life and social interactions. Globally, the number of social media users continues to rise, particularly among younger populations (Montag et al., 2024). Platforms such as Facebook, Instagram, TikTok, and WeChat cater to diverse social needs, facilitating the creation of personal networks and enabling online interactions. However, despite the convenience and

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immediate access to information that social media offers, its potential negative effects warrant consideration (Powell & Pring, 2024). Information overload and constant social comparison can lead to increased anxiety and a decline in self-esteem, especially when individuals are exposed to the curated, idealized representations of others' lives. Excessive use of social media may lead to addictive behaviors, contributing to time mismanagement and negatively affecting work, academic performance, and real-life social interactions (Bányai et al., 2017).

Problematic social media use (PMSMU) is defined as excessive and uncontrolled engagement with social media platforms that significantly disrupts an individual's daily functioning, well-being, and relationships, and may be considered either a separate clinical entity or a manifestation of underlying psychiatric disorders (Cataldo, Lepri, Neoh, & Esposito, 2020). Due to a lack of sufficient neurobiological evidence, PMSMU does not have clear diagnostic criteria in ICD-11 and DSM-5 (Billieux, Maurage, Lopez-Fernandez, Kuss, & Griffiths, 2015). Researchers typically use scales designed to measure PMSMU. These scales assess the severity of core addiction symptoms to determine an individual's level of risk (Sisi, Pallesen, & Fernandez-Martin, 2025). A meta-analysis revealed that a strong and often bidirectional relationship between social media use and depression or anxiety (Lopes et al., 2022). This relationship was frequently related to PMSMU (Lopes et al., 2022). Recent advances highlight emotion processing deficits as a transdiagnostic mechanism underlying addictive behaviors, yet how such deficits manifest in PMSMU—particularly through attentional and neural pathways—remains poorly understood. Furthermore, extant research on PMSMU has predominantly focused on reward hyperactivity and inhibitory control, leaving a critical gap in understanding the attentional and neural mechanisms underlying emotion recognition—a core process in maladaptive social interactions.

Existing research on PMSMU has primarily focused on reward system hyperactivity or inhibitory control deficits (Kuss & Griffiths, 2017), overlooking the critical role of emotion recognition in shaping maladaptive social media behaviors. In substance addiction, impaired negative emotion decoding and heightened sensitivity to reward-related cues are well-documented (Koob & Volkow, 2016), but analogous mechanisms in PMSMU are underexplored. Crucially, emotion processing is a multilevel construct involving early attentional allocation (e.g., gaze patterns), neural activation during emotion decoding, and downstream psychosocial outcomes (Adolphs, 2002). Disentangling these components in PMSMU could resolve current theoretical debates about its classification while identifying intervention targets.

Emerging evidence suggests that PMSMU individuals exhibit altered responses to emotional stimuli (Zhao et al., 2022). Behavioral studies report paradoxical patterns, such as enhanced recognition of positive emotions (e.g., joy) but blunted responses to negative ones (e.g., fear) (Di Domenico, Palumbo, Mammarella, & Fairfield, 2015), potentially reflecting attentional biases that prioritize socially rewarding cues. Neuroimaging work implicates prefrontal-temporal circuits in regulating emotion-cognition interactions (Kohn et al., 2014), yet no study has directly linked PMSMU-related attentional biases to dysfunction in these circuits. Furthermore, the lack of multimodal integration—combining eye tracking (attention), neuroimaging (neural activation), and psychometrics (behavioral outcomes)—limits mechanistic insights into how fragmented attentional patterns translate into real-world social impairment.

This study addresses these gaps through a multimodal investigation of PMSMU's emotion processing architecture. We hypothesize that: 1) H1: high-risk PMSMU individuals exhibit attentional bias toward positive emotional stimuli as reflected by longer fixation duration and/or more fixations, while avoiding negative stimuli, leading to higher positive emotion recognition accuracy and lower negative emotion recognition accuracy; 2) H2: the attentional bias will be associated with valence-specific neural dysregulation, as indicated by significantly hyperactivation in the prefrontal and temporal cortices specifically during negative emotional processing in high-risk compared to low-risk PMSMU individuals; 3) H3: these attentional and neural anomalies will collectively correlate with poorer psychosocial functioning (interpersonal skills, attentional control, and symptoms of anxiety and depression) in the high-risk group. By integrating eye-tracking, functional near-infrared spectroscopy (fNIRS), and psychometric assessments, we provide the first evidence linking attentional bias to neural dysregulation in PMSMU. Our findings advance the conceptualization of PMSMU as a neurobehavioral disorder rooted in emotion processing deficits, offering biomarkers for diagnosis and targets for neuromodulation therapies.

METHODS

Participants

College students between 18 and 25 were recruited to participate in this cross-sectional study. Participants, used at least one social media app (such as Tik Tok, WeChat, REDnote) in the past year, were required to be right-handed and to report having no history of drug or alcohol abuse, general neurological or psychiatric disorders. Subjects who are color blind or have low vision, or who are unable to cooperate in completing the study were excluded.

This study initially screened participants through online PMSMU questionnaire, targeting college students from Chengdu, China. Total 212 participants received the questionnaire (distributed) and 201 completed questionnaires were returned (response rate: 94.8%). Non-return was attributed to incomplete responses or loss of contact. In situations where research funding is limited, the extreme groups method is often used to increase the differences between groups and thus reduce the required sample size, in order to improve statistical efficiency (Preacher, Rucker, MacCallum, & Nicewander, 2005; Taris & Kompier, 2006).

So, the upper and lower rule was used to stratify the participants into lower 30% of PMSMU cohort (n = 60) and upper 30% of PMSMU cohort (n = 60). The upper and lower rule is commonly used in item analysis in psychology based on Kelley's derivation (Kelley, 1939).

The 120 participants in these two cohorts were invited to the Assessment Room for face-to-face interviews and psychological assessments. Seven were excluded prior to any testing for not meeting inclusion criteria: 3 for left-handedness, 2 for a self-reported history of psychiatric treatment, 1 for color blindness, and 1 who declined further participation. Consequently, 113 participants (55 low-risk, 58 high-risk) completed the psychological assessments and were included in the behavioral analyses.

During the subsequent eye-tracking and fNIRS testing phase, data from additional participants were excluded from the respective modality analyses due to technical issues or data quality thresholds. For eye-tracking, data from 9 participants (3 low-risk, 6 high-risk) were excluded due to poor calibration or excessive track loss. For fNIRS, data from 41 participants (19 low-risk, 22 high-risk) were excluded due to excessive head motion artifacts or insufficient signal quality, which is a common and necessary step in optical neuroimaging data preprocessing. Therefore, the final sample sizes for the multimodal analyses were: eye-tracking (low-risk: n = 52, high-risk: n = 52) and fNIRS (low-risk: n = 33, high-risk: n = 30). A detailed flow diagram is presented in Fig. 1.

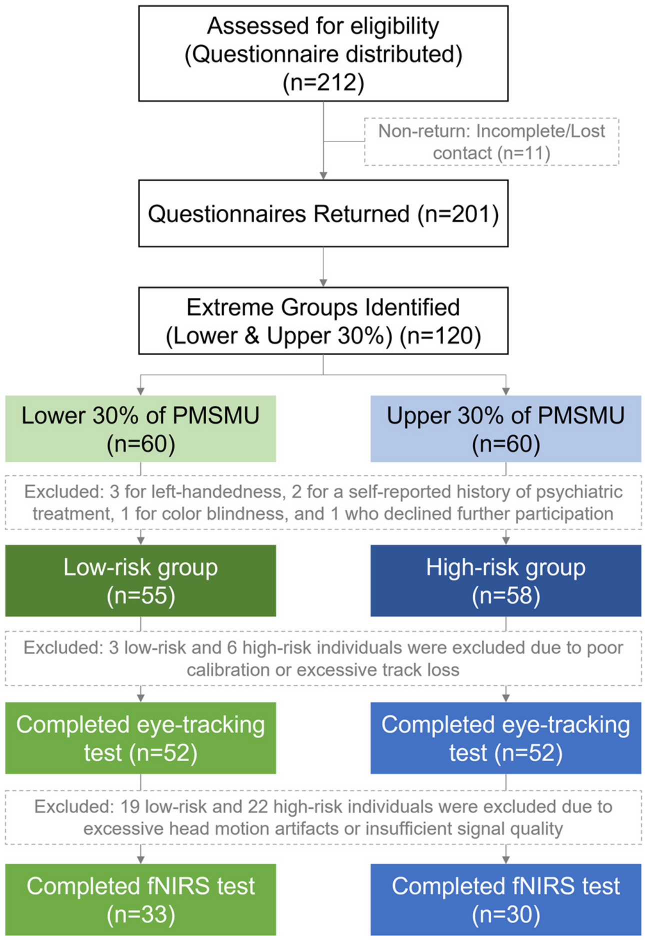

Fig. 1. Participant's flow chart

Behavioral and psychological assessment

The PMSMU questionnaire with 20 items was used to measure participants' social media usage and addiction (Pi, Wang, Zou, Mo, & Guo, 2024). It assesses severity across five distinct factors: viscosity increase, physiological damage, omission anxiety, cognitive failure, and guilt. Similar to other scales, the 20 items are rated on a 5- point Likert scale with a total score range of 20–100; higher cumulative scores indicate a greater severity of problematic usage. Researchers commonly use a cut-off score of 63 or higher to indicate "at-risk" use. In previous studies, the Cronbach α coefficient of this scale was 0.91 (Chen, Zhang, Zhang, & Wang, 2022). The scale demonstrated high internal consistency in this study, with a Cronbach's α coefficient of 0.93 and McDonald's ω coefficient of 0.90.

The interpersonal skills self-assessment scale (Dearing & Steadman, 2011), attention control scale (Judah, Grant, Mills, & Lechner, 2014), self-rating anxiety scale (SAS) (Dunstan & Scott, 2020), and self-rating depression scale (SDS) (Biggs, Wylie, & Ziegler, 1978) were used to test the participants' interpersonal skills, attention, anxiety and depression levels. For all four scales, higher scores indicated poorer ability or performance. The reliability and validity of the four scales were high in adolescents.

Emotional stimuli design

Emotional stimuli were designed as Facial Expressions of Emotion Stimuli and Tests (FEEST) (Kuhlmann & Margraf, 2023). The stimuli consisted of 42 frontal-view, grayscale photographs selected from the Chinese Facial Affective Picture System (CFAPS), a standardized database developed and validated for use with Chinese populations (Gong, Huang, Wang, & Luo, 2011). The set included six images for each of the seven basic emotions: anger, disgust, fear, sadness, surprise, joy, and neutral. The set was perfectly gender-balanced, comprising three male and three female models for each emotion category. All selected images had a high baseline recognition agreement rate (range 80.07–90.93%) for their intended emotion, as established in the CFAPS validation studies where raters performed a forced-choice labeling task. The images were characterized by normative ratings on the affective dimensions provided by CFAPS (arousal ratings, range 5.70–7.02). De-identified examples of the facial stimuli and a table of their characteristics were provided in the Supplementary Table S1 and Supplementary Figure S1. The CFAPS does not provide normative ratings for dominance or attractiveness. Regarding dominance, its contribution to differentiating basic emotions within a standardized set is often secondary to valence and arousal (Jerram, Lee, Negreira, & Gansler, 2014). To address potential confounding effects of attractiveness of the emotional faces, the selection followed two principles: 1) excluded emotional faces rated at the extreme ends (very high or very low) on attractiveness in an informal pilot rating, and 2) all emotional faces presented with a neutral, non-distinctive appearance in their neutral expression photo, ensuring consistency across emotion blocks. This approach aligns with recommendations to control for this extraneous variable in facial perception research (Siemensma, 2023). The seven emotions were further divided into positive (joy), negative (anger, disgust, fear, sadness, and surprise), and neutral stimuli. Each photograph is presented for 30 s on a computer screen and participants are asked to choose which emotion label best describes the emotion shown. There is 15 s restriction for answering. The FEEST has shown to have good reliability and validity and has proven to be sensitive in various patient groups.

Eye-tracking test

The EyeLink 1000 system (SR Research Ltd., Canada) was used for the video-based eye-tracking tests. Dominant eye movements were recorded at a sampling rate of 1,000 Hz. With the Experiment Builder software (SR Research Ltd., Canada), the FEEST was presented on a computer monitor (1,024 × 768 resolution, 60 Hz refresh rate) at a distance of 50 cm from the participants' eyes. Parameters such as correct rate (calculated as the ratio of correct answers to the total number of trials), reaction time (RT, average reaction time in the tests which were correctly answered), fixation counts (average number of fixation count in the tests which were correctly answered), and fixation duration (fixduration, the length of time the eyes remain on a particular area) were recorded in the FEEST. Fixation density analysis was also conducted between the groups. The eye-tracking test data were preprocessed and extracted using DataViewer (SR Research Ltd., Canada). Heatmaps, only allowing comparisons between groups, were used to detect further the difference in the eye-tracking fixation count between the low- and high-risk group by DataViewer. A circular region extending 20 pixels outwards from the center of significantly different points in the heatmap was used for quantitative analysis of fixation count.

fNIRS test

fNIRS data were collected using the Brite 24 (Artinis Medical Systems, Netherlands) fNIRS system operating at 760- and 850-nm wavelengths and a 50-Hz sampling frequency. The fNIRS cap included a probe of 9 light sources and 9 detectors to make up 20 channels with a distance of approximately 30 mm. The probe was designed using the OxySoft. Optode distribution detailed in Fig. 2. Brain regions in the frontal and bilateral temporal lobes were selected a priori based on previous studies that have demonstrated that these brain regions are involved in emotional processing and regulation. This study measured changes in levels of oxygenated hemoglobin (HbO) and deoxygenated hemoglobin (HbR) in the brain regions above during the FEEST performed by the participants. fNIRS data including the beta values of HbO and HbR in each channel were preprocessed and extracted using NIRS_SPM toolbox.

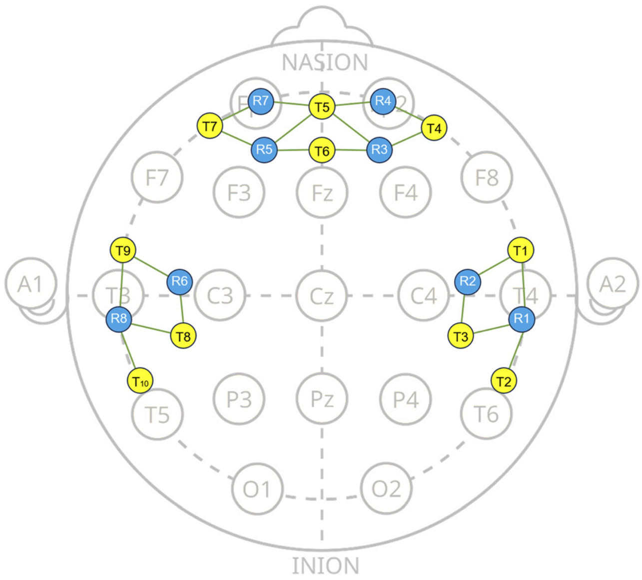

Fig. 2. The Optode distribution map

Statistical analysis

All the statistical analyses were performed using SPSS 22.0 (IBM Co., United States). To examine the differences in the demographic, PMSMU behavioral, psychological indicators, eye-tracking and fNIRS data between the groups, x^2 and t-tests were used for the categorical and continuous variables, respectively. Pearson or Spearman correlation analysis was used to detect the associations among data from different sources. To limit the number of statistical models tested in accordance with the primary hypothesis (H3) that neural dysregulation is associated with psychosocial impairment, a single, primary moderation analysis was conducted. This analysis examined whether left middle frontal lobe activation moderated the relationship between negative emotion recognition accuracy and depression or anxiety symptoms, as measured by the SDS or SAS. Depression and anxiety were selected as the central functional outcome for this analysis due to its established relevance and validation within the problematic social media use literature (Lopes et al., 2022; Nagata et al., 2025; Puukko, Hietajarvi, Maksniemi, Alho, & Salmela-Aro, 2020). Generally, the statistical analyses were two-tailed, and the level of statistical significance was adjusted to $p < 0.05$.

To control the false discovery rate (FDR) across multiple comparisons, the Benjamini-Hochberg (BH) procedure was applied separately to distinct, pre-specified families of hypothesis tests (Thissen, Steinberg, & Kuang, 2002). The following five families were defined and corrected independently: 1) family 1 (emotion recognition accuracy): the seven independent-samples t-tests comparing group accuracy for each basic emotion; 2) family 2 (eye-tracking parameters): the eye-tracking parameters' t-tests comparing group differences in the entire face or area of interest; 3) family 3 (primary fNIRS channel activation): the t-tests comparing group-level beta values across primary channels in the prefrontal or temporal cortices for the negative emotion condition; 4) family 4 (primary correlations): the Pearson correlations testing the a priori hypothesized relationships between key neural, behavioral, and psychometric variables; 5) family 5 (moderation models): model's test examined whether left middle frontal lobe activation moderated the relationship between negative emotion recognition accuracy and SDS/SAS. For each family, all raw p-values from the included tests were ranked from smallest to largest. Each p-value was then compared against a corrected critical value calculated as (i/m) × Q, where "i" is the p-value's rank, "m" is the total number of tests in that family, and "Q" was set to 0.05. The largest p-value that remained smaller than its corrected critical value defined the significance threshold for that family.

Sample size

This study hypothesized a difference in the correct recognition rate of negative facial expressions between subjects with high- and low-risk PMSMU groups, with a between-group difference of 5.7%. Given $\alpha = 0.05$ and $\beta = 0.2$, at least 50 subjects per group were required. Considering that approximately 15% of subjects might experience experimental failure or data loss, at least 58 subjects per group needed to be enrolled, which was rounded up to 60 subjects per group. Considering that these 60 high-risk and 60 low-risk subjects represent the upper and lower 30% of the overall questionnaire ranking, a minimum of 200 questionnaires needed to be distributed.

Ethics

The studies involving human participants were reviewed and approved by the Medical Ethics Committee of Chengdu Medical College (CMCIR2025NO.024). The participants provided their written informed consent to participate in this study.

RESULTS

Sample characteristics

Demographic and PMSMU behavioral characteristics of the participants are presented in Table 1. There were no significant differences in mean age, gender distribution, residence distribution, and social media type used by participants between the low- and high-risk groups ($p > 0.05$). The high-risk group had significantly higher ratio of social media duration >4 h/d (75.86% vs. 40.00%, $x^2 = 14.945$, $p < 0.001$) and PMSMU scores (84.05 ± 6.45 vs. 53.61 ± 7.53, $t = 23.464$, $p < 0.001$) than the low-risk group.

Attentional bias: emotion recognition accuracy

In the FEEST, the low- and high-risk participants showed dissociable emotion recognition accuracy (Fig. 3). The high-risk group had significantly higher correct rate in joy (positive) emotion (82.58 ± 16.95% vs. 74.31 ± 17.53%, $t = 2.525$, $p = 0.013$ surviving BH correction), but significantly lower correct rate in sadness and fear (negative) emotions (sadness: 42.58 ± 22.22% vs. 52.92 ± 26.92%, $t = -2.137$, $p = 0.035$ did not survive BH correction; fear: 36.85 ± 22.47% vs. 51.27 ± 27.70%, $t = -2.916$, $p = 0.004$ surviving BH correction; negative: 64.29 ± 9.49% vs. 69.87 ± 10.67%, $t = -2.816$, $p = 0.006$ surviving BH correction) than the low-risk group. There was no significant difference in correct rate of neutral emotional stimuli between the two groups ($p > 0.05$).

Table 1. The characteristics of the two groups

Characteristics	Low-risk group ($n = 55$)	High-risk group ($n = 58$)	t/x^2	p
Age (years, mean ± sd)	19.87 ± 1.55	19.67 ± 1.02	−0.807	0.422
Gender (male/female, n)	23/32	16/42	2.530	0.112
Residence (urban/rural, n)	35/20	35/23	0.130	0.719
SM type (relationship/others, n)	45/10	40/18	2.502	0.114
SM duration >4 h/d (yes/no, n)	22/33	44/14	14.945	<0.001
PMSMU (scores, mean ± sd)	53.61 ± 7.53	84.05 ± 6.45	23.464	<0.001

Fixation pattern: eye-tracking parameters

Eye-tracking test was further used to reveal the dynamic components of attentional bias. No significant differences were found in the overall reaction time, fixation count, or average fixation duration across all emotion trials between the two groups ($p > 0.05$, Fig. 4). Eye-tracking heatmap were used to detect further the differences in the fixation between the low- and high-risk group. The high-risk group exhibited a significantly lower fixation count on the nose root compared to the low-risk group (18.44 ± 4.06 vs. 24.65 ± 4.51, $t = -7.384$, $p < 0.001$ surviving BH correction), and a significantly higher fixation count on areas near the corners of mouth (23.87 ± 6.22 vs. 20.88 ± 6.50, $t = 2.391$, $p = 0.019$ surviving BH correction) and the middle of nose (31.17 ± 7.29 vs. 22.10 ± 4.86, $t = 7.472$, $p < 0.001$ surviving BH correction). This differential fixation pattern is visually summarized in the heatmaps presented in Fig. 5.

Neural dysfunction: fNIRS activation

fNIRS test and eye-tracking test performed simultaneously in FEEST. As shown in Figs 6 and 7, the high-risk group had hyperactivation in the right middle temporal lobe (c1) and left middle frontal lobe (c9) than low-risk group in the negative emotional stimuli (c1: 0.15 ± 0.31 vs. −0.11 ± 0.45, $t = 2.452$, $p = 0.017$ surviving BH correction; c9: 0.25 ± 0.51 vs. −0.01 ± 0.49, $t = 2.365$, $p = 0.021$ surviving BH correction). The activation level differences between the two

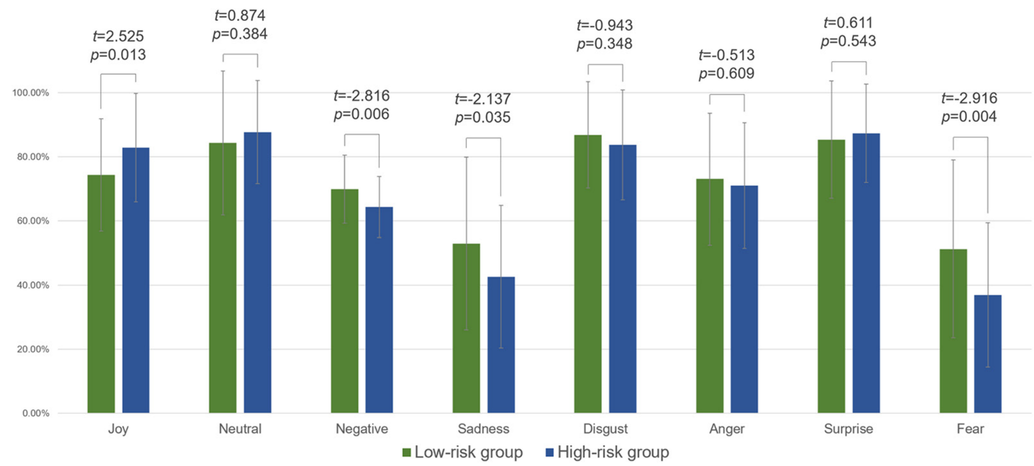

Fig. 3. The difference of correct rate of emotion recognition between groups

Emotion	RTs	Fixation counts	Fixduration
Joy	-0.506	-0.916	0.300
Neutral	-0.978	-1.177	-0.266
Negative	-0.093	-0.061	-0.665
Sadness	0.935	0.751	-0.234
Disgust	-0.645	-0.315	-1.353
Anger	0.746	0.722	-0.820
Surprise	-0.056	-0.128	-0.088
Fear	-1.493	-1.409	-0.507

Fig. 4. The difference of eye-tracking parameters of emotion recognition between groups (*t*-value)

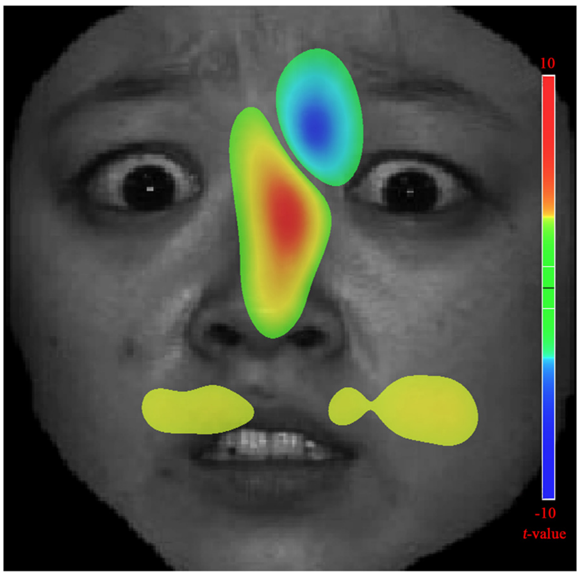

Fig. 5. The difference of fixation counts heatmap between groups

groups in other brain areas were not significant after BH correction. In addition, there was no significant difference in brain activation level in the positive or neutral emotional stimuli between the two groups ($p > 0.05$).

Psychological profile: psychological assessments

Psychological assessments showed that the high-risk group had significantly higher scores in interpersonal skills (95.33 ± 19.92 vs. 80.67 ± 19.28, $t = 3.971$, $p < 0.001$ surviving BH correction), attention (25.48 ± 5.30 vs. 19.11 ± 4.98, $t = 6.583$, $p < 0.001$ surviving BH correction), SAS (36.33 ± 6.84 vs. 29.42 ± 4.55, $t = 6.287$, $p < 0.001$ surviving BH correction), and SDS (39.97 ± 8.78 vs. 32.87 ± 6.84, $t = 4.774$, $p < 0.001$ surviving BH correction) than low-risk group (Fig. 8).

Correlations and moderation effects

In the correlation analysis, the activation level in the right middle temporal lobe (c1) was positively associated with RT in sadness emotional stimuli ($r = 0.354$, $p = 0.009$ surviving BH correction). Further, as shown in Supplementary Table S2, the attention score was negatively associated with the correct rate of fear emotional stimuli ($r = -0.261$, $p = 0.007$ surviving BH correction) and positively associated with activation level in the right middle temporal lobe ($r = 0.377$, $p = 0.003$ surviving BH correction), and the SAS score was negatively associated with the RT of fear emotional stimuli ($r = -0.224$, $p = 0.022$ did not survive BH correction). As shown in Table 2, the interaction term between negative emotion recognition and left middle frontal lobe is significant (SDS: $t = 2.662$, $p = 0.010$ surviving BH correction, $\Delta R^2 = 0.113$; SAS: $t = 2.750$, $p = 0.008$ surviving BH correction, $\Delta R^2 = 0.120$). This means that when negative emotion recognition affects SDS/SAS, the influence of the moderating variable (left middle frontal lobe) at different levels has significant differences. Other models of moderation analysis were summarized in Supplementary Table S3. The simple slope plots for moderation effects of each model were presented in Supplementary Figure S2.

DISCUSSION

The present study employed a multimodal approach to investigate the neurocognitive architecture of emotion

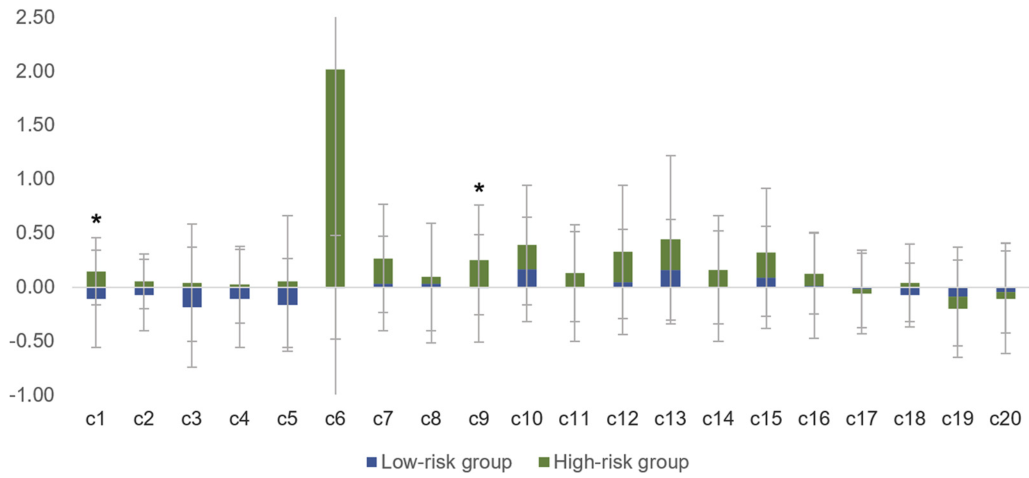

Fig. 6. The difference of beta values in fNIRS between groups

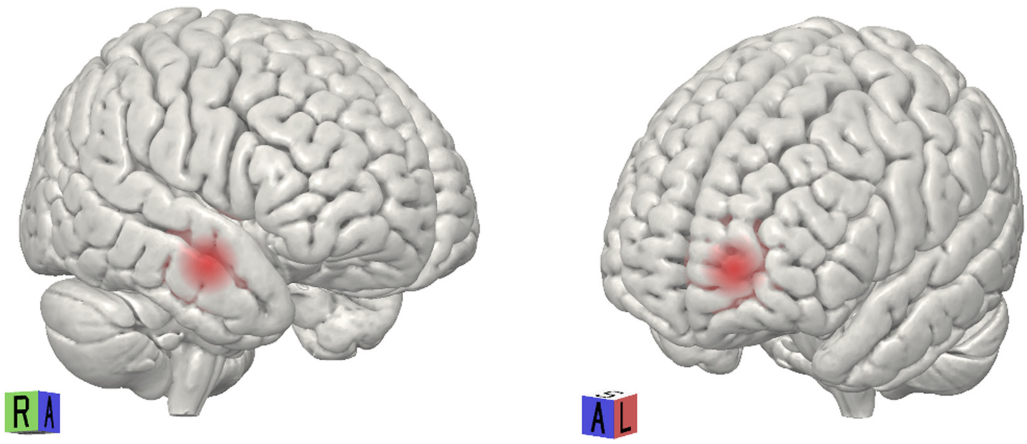

Fig. 7. The activation difference between groups

processing deficits in PMSMU. By integrating eye-tracking, fNIRS, and psychometric assessments, we tested specific hypotheses regarding valence-specific attentional biases, their underlying neural correlates, and their association with psychosocial functioning. The findings provide coherent evidence that PMSMU is characterized by a dissociable pattern of emotion processing, supporting its conceptualization as a neurobehavioral condition with distinct mechanistic pathways.

Attentional bias drives valence-specific emotion recognition

Our first hypothesis proposed that high-risk PMSMU individuals would exhibit an attentional bias favoring positive cues and avoiding negative ones, leading to corresponding patterns in emotion recognition accuracy. The results strongly support this hypothesis.

We observed the predicted behavioral asymmetry: the high-risk group demonstrated significantly enhanced accuracy for joyful expressions but significantly impaired accuracy for fearful expressions and a negative emotion composite score compared to the low-risk group. It is noteworthy that the group difference in sadness recognition, while initially significant at the uncorrected level, did not survive strict correction for multiple comparisons. This may suggest that the processing deficit in high-risk PMSMU is more robust for certain negative emotions like fear than for others like sadness. Potential reasons could include differences in the perceptual salience or social threat urgency conveyed by these expressions, with fear potentially representing a more direct and immediate social threat signal that is preferentially avoided (Marsh, Kozak, & Ambady, 2007).

Crucially, this performance profile was underpinned by the hypothesized attentional bias in visual scanning. Quantitative eye-tracking analysis revealed that during the viewing of negative emotional faces, the high-risk group exhibited a significantly reduced proportion of fixation time on the nose root—a central hub for holistic face processing essential for integrating features into a unified emotional percept (Tian, Kanade, & Cohn, 2001)—and a significantly increased fixation on the mouth region.

We interpret this pattern through the lens of the attention-avoidance model (Wang & Huang, 2022). In the context of PMSMU, where social feedback is often quantified, positive expressions like joy—primarily signaled by the

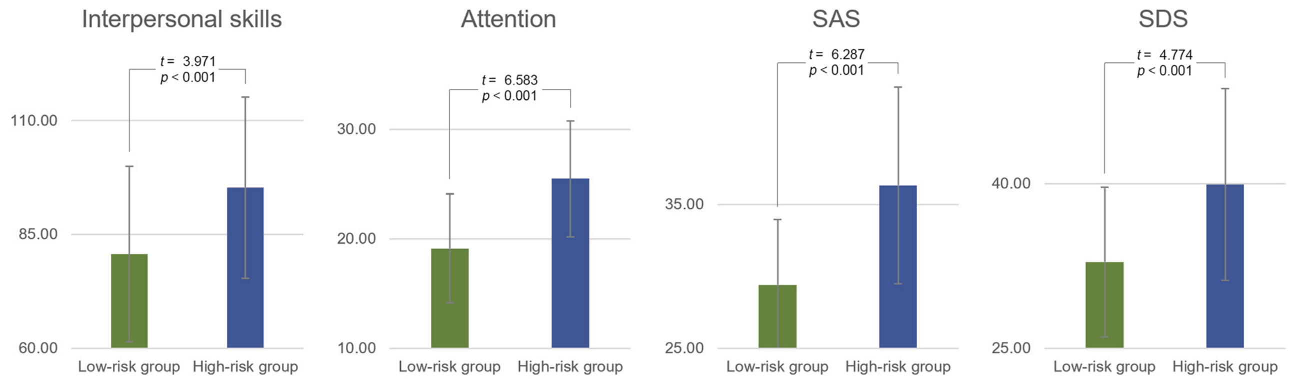

Fig. 8. The difference of psychological assessments between groups

Table 2. Moderator effect analyses (non-standardized coefficient β)

Model	SAS	SDS
Negative emotion recognition (A)	5.773	−6.139
Left middle frontal lobe (C)	5.269**	5.910**
A*C	43.470**	48.558**
Δ information	$\Delta R^2 = 0.120$	$\Delta R^2 = 0.113$
	$\Delta F = 7.565$	$\Delta F = 7.084$
	$p = 0.008$	$p = 0.010$

mouth—may become potent social reward cues. The observed bias toward the mouth likely reflects a learned selective attention toward these reward-predicting stimuli, akin to mechanisms in other behavioral addictions (Wang & Huang, 2022). Conversely, the reduced fixation on the nose root impairs the holistic processing necessary for decoding complex negative emotions, constituting an implicit avoidance of detailed negative social threat signals (Lorenz et al., 2013; Pomrenze, Paliarin, & Maiya, 2022). This systematic re-allocation of attentional resources—toward simplistic reward detection and away from integrative threat processing—provides a mechanistic explanation for the observed behavioral outcome: enhanced decoding of positive cues but impaired recognition of negative emotions.

Attentional bias maps onto valence-specific neural dysregulation

Our second hypothesis posited that this attentional bias would be associated with valence-specific neural dysregulation in prefrontal-temporal circuits. The neuroimaging data confirm this prediction.

Specifically, during the processing of negative emotional stimuli, the high-risk group showed significant hyperactivation in the right middle temporal gyrus (c1) and the left middle frontal gyrus (c9). No such group differences were found for positive or neutral stimuli, confirming the valence-specificity of the neural response.

Hyperactivation here likely reflects compensatory neural effort—a struggle to interpret avoided cues due to attentional deficits (Gutchess et al., 2005; Mouga, 2020; Zamorano et al., 2017). The right middle temporal gyrus is deeply involved in social threat decoding and semantic analysis of emotional scenes (Zahn et al., 2007), while the left middle frontal gyrus is a key node for top-down cognitive control and effortful emotional appraisal (George & Koob, 2010). We propose a cascade model: the fragmented, avoidant visual scanning (identified in H1) provides impoverished sensory input to downstream neural decoders. To resolve this ambiguous input, these systems—particularly the temporal lobe for analysis and the frontal lobe for controlled processing—must recruit additional resources, manifesting as hyperactivation. This compensatory account is directly supported by the positive correlation between right temporal activation and reaction time for sadness recognition. Slower, less efficient behavioral performance was associated with greater neural activity, a classic signature of neural inefficiency, where more cognitive work is required to achieve a suboptimal outcome (Zamorano et al., 2017). This finding directly links the neural result to a functional processing cost.

Multimodal anomalies converge to predict psychosocial impairment

Our third hypothesis proposed that the attentional and neural anomalies would collectively correlate with poorer psychosocial functioning. The results provide strong, integrative support for this hypothesis.

As predicted, the high-risk group reported significantly greater impairment, including poorer interpersonal skills, worse attentional control, and higher levels of anxiety and depression. More importantly, correlation and moderation analyses revealed how these functional deficits are linked to the core cognitive and neural measures. Self-reported attention deficits were negatively correlated with fear recognition accuracy and positively correlated with right temporal hyperactivity, sketching a direct pathway from subjective cognitive difficulty to objective behavioral and neural dysfunction. Furthermore, moderation analysis showed that left frontal (c9) activation significantly moderated the relationship between negative emotion recognition and symptoms of anxiety and depression. This suggests that individual differences in prefrontal regulatory capacity may buffer or exacerbate the psychosocial impact of emotion decoding deficits.

Collectively, these findings support an integrated neurocognitive model for emotion processing deficits in PMSMU. We propose a causal cascade wherein attentional deficits—manifest as reduced fixation on the holistic face-processing hub (nose root)—lead to insufficient acquisition of nuanced visual cues from negative faces. This impoverished input necessitates compensatory hyperactivation in prefrontal-temporal circuits (right temporal lobe for decoding, left frontal lobe for regulatory effort) to interpret the ambiguous social signal. This inefficient, effortful neural process subsequently results in impaired behavioral accuracy and slower recognition of negative emotions, which in turn contributes to the heightened social misinterpretation, anxiety, and psychosocial dysfunction observed in high-risk individuals. This cascade elucidates how a basic attentional bias may escalate into broader neural and social impairment.

Theoretical and practical implications

Our findings offer nuanced insights for the classification of PMSMU. While emotion processing deficits align it with substance and behavioral addictions, a key distinction lies in its valence-specificity. Substance addictions often involve global blunting of emotional reactivity and recognition (Koob & Volkow, 2016). In contrast, PMSMU here presents with preserved or enhanced processing of positive cues alongside selective deficits for negative cues. This pattern suggests PMSMU may be uniquely reinforced by maladaptive social reward learning, where the platform's architecture amplifies the salience of positive social feedback while enabling avoidance of negative complexities (Pi et al., 2024). This supports arguments for considering PMSMU as a distinct diagnostic entity within the behavioral addiction spectrum, characterized by this specific socio-emotional profile.

Our multimodal model identifies clear, testable targets for intervention. First, the documented attentional bias suggests that Attentional Bias Modification (ABM) protocols could be adapted for PMSMU (Heeren, Mogoaşe, McNally, Schmitz, & Philippot, 2015). Training individuals to automatically direct attention toward the eye/nose region of emotional faces could "recalibrate" early perceptual habits, potentially improving negative emotion recognition. Second, the identified prefrontal-temporal hyperactivation offers a target for neurofeedback. Individuals could learn to modulate activity in these circuits, potentially enhancing regulatory efficiency and reducing the compensatory effort needed for social-emotional tasks, thereby weakening the link between social media use patterns and neural inefficiency (Sitaram et al., 2017).

Limitations and future directions

The findings should be considered with several limitations in mind. First, the cross-sectional design precludes causal inference regarding whether the observed deficits precede or result from PMSMU. Relatedly, the elevated anxiety and depression in the high-risk group represent a potential confound, making it difficult to isolate effects specific to PSMU from those associated with general affective distress. Second, fNIRS has limited spatial resolution, preventing examination of subcortical regions like the amygdala. Third, the use of static facial stimuli lacks ecological validity compared to dynamic social media interactions. Finally, group definition via an extreme-groups approach, while methodologically justified for contrast, limits direct clinical generalizability despite supportive continuous analyses (Supplementary Table S2). Future longitudinal studies using dynamic stimuli, controlling for mood symptoms, and employing clinical criteria are needed to establish causality and enhance real-world relevance.

CONCLUSION

In conclusion, this multimodal study confirms that PMSMU involves valence-specific disruptions across attentional, neural, and psychosocial domains. High-risk individuals show a behavioral and visual attention bias toward positive social reward cues, coupled with impaired negative emotion processing linked to compensatory prefrontal-temporal hyperactivation. These anomalies collectively correlate with and predict significant real-world psychosocial impairment. Our findings support reconceptualizing PMSMU as a neurobehavioral condition defined by distinct emotion-processing deficits, offering clear targets for future mechanistic research and clinical intervention.

Funding sources: This study was supported by grants from the Sichuan Applied Psychology Research Center Project (CSXL-24201), Sichuan Sexual Sociology and Sexuality Education Research Center Project (No. 17), Chengdu Medical College Science and Technology Fund Project (CYZYB23-24), and Sichuan Psychological Association Scientific Research Planning Project (SCSXLXH202403075).

Authors' contribution: All authors contributed to the data analysis, drafting and revision of this manuscript agreed on the journal to which the article will be submitted, gave final approval of the version to be published, and agreed to be accountable for all aspects of the work.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data availability: The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

SUPPLEMENTARY MATERIAL

Supplementary data to this article can be found online at https://doi.org/10.1556/2006.2025.00306.

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