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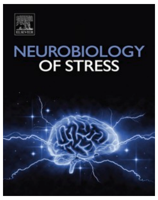

The neurocomputational signature of decision-making for unfair offers in females under acute psychological stress

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ABSTRACT

Stress is a crucial factor affecting social decision-making. However, its impacts on the behavioral and neural processes of females' unfairness decision-making remain unclear. Combining computational modeling and functional near-infrared spectroscopy (fNIRS), this study attempted to illuminate the neurocomputational signature of unfairness decision-making in females. We also considered the effect of trait stress coping styles. Forty-four healthy young females (20.98 ± 2.89 years) were randomly assigned to the stress group ($n = 21$) and the control group ($n = 23$). Acute psychosocial stress was induced by the Trier Social Stress Test (TSST), and participants then completed the one-shot ultimatum game (UG) as responders. The results showed that acute psychosocial stress reduced the adaptability to fairness and lead to more random decision-making responses. Moreover, in the stress group, a high level of negative coping style predicted more deterministic decision. fNIRS results showed that stress led to an increase of oxy-hemoglobin (HbO) peak in the right temporoparietal junction (rTPJ), while decreased the activation of left middle temporal gyrus (lMTG) when presented the moderately unfair (MU) offers. This signified more involvement of the mentalization and the inhibition of moral processing. Moreover, individuals with higher negative coping scores showed more deterministic decision behaviors under stress. Taken together, our study emphasizes the role of acute psychosocial stress in affecting females' unfairness decision-making mechanisms in social interactions, and provides evidences for the "tend and befriend" pattern based on a cognitive neuroscience perspec

1. Introduction

Stress encompasses physiological, psychological, and behavioral reactions to situations that individuals perceive as stressful (Cannon, 1932; Folkman and Lazarus, 1986). The experience of acute psychosocial stress is pervasive in diverse life circumstances and can affect basic cognitive processes such as perception, attention, and memory (Chu et al., 2023; DiMenichi et al., 2018; Lin et al., 2020; Maeda et al., 2019; Olver et al., 2015). Additionally, it influences social interaction dynamics, including cooperation, competition, empathy, and prosocial behavior (Nitschke et al., 2022; Singer et al., 2020, 2021; Wolf et al., 2015; Zhang et al., 2021). Thus, research on the impact of acute psychosocial stress on the dynamics of social interaction is crucial.

1.1. Acute psychosocial stress and decision-making regarding unfairness

Previous studies have primarily concentrated on examining the impact of acute psychosocial stress on decision-making related to unfairness, an important aspect of social interaction. However, definitive conclusions have not yet been reached. Unfairness decision-making

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Abbreviations: F, fair; MU, moderately unfair; VU, very unfair.

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typically involves the allocation of social resources, such as money, between two or more individuals in an unequal manner. The ultimatum game (UG) serves as a classic paradigm for studying this type of decision-making (Debove et al., 2016; Suleiman, 1996). In the UG, the responder must decide whether to accept or reject the proposer's offer for regarding the allocation of a sum of money. If the offer is accepted, both individuals receive money according to the proposal. If rejected, neither participant receives any money (Guo et al., 2014; Lois et al., 2020; Zheng et al., 2017). Existing studies examining the effect of acute psychosocial stress on decision-making in the UG have yielded mixed results, likely due to the use of oversimplified behavioral indicator such as rejection rates and a limited number of decision trials (Dawans et al., 2012; Nickels et al., 2017; Prasad et al., 2017; Vinkers et al., 2013; Youssef et al., 2018; Zhang et al., 2019). Conversely, some studies have reported a decrease in rejections under acute stress (Dawans et al., 2018, 2019; Steinbeis et al., 2015). However, these studies involved sequential UG with a fixed proposer, which may influence the responder's decision-making due to considerations about future allocations by the proposer (Ogawa et al., 2023). Therefore, it is imperative to employ comprehensive behavioral indicators to investigate the impact of acute psychosocial stress on decision behavior in one-shot UG. This approach will illuminate the underlying mechanisms through which stress influences unfairness decision-making.

1.2. *Neural mechanisms involved in the impact of acute psychosocial stress on decision-making in the UG*

Notably, the existing studies examining the influence of acute psychosocial stress on decision-making during the UG have yet to investigate its underlying neural mechanisms. Previous studies have identified various brain regions associated with decision-making during the UG, including the right temporoparietal junction (rTPJ), prefrontal cortex (PFC), anterior cingulate cortex (ACC), the bilateral anterior insula (Cheng et al., 2017, 2022; Gabay et al., 2014; Guo et al., 2014; Lois et al., 2020; Ogawa et al., 2023; Pan et al., 2022; Servaas et al., 2015; Speer and Boksem, 2019; Speitel et al., 2019; Wu et al., 2015, 2023). Given the important role of the rTPJ in mentalization processes, also known as theory of mind (ToM) (Ogawa and Kameda, 2020; Park et al., 2021), it has been observed to be responsive to the disadvantageous inequity caused by unfair proposals and linked to decision utility that can affect the final decision-making behavior (Guroglu et al., 2010; Ogawa et al., 2023; Wu et al., 2023). The dorsolateral prefrontal cortex (dlPFC) has been suggested to be involved in cognitive control during UG (Servaas et al., 2015; Speer and Boksem, 2019), assisting responders in effectively navigating conflicts that may arise from unfair allocations (Cheng et al., 2022; Guo et al., 2014; Zhou et al., 2014). A study using transcranial direct current stimulation (tDCS) found that increasing activation in the right dlPFC resulted in higher acceptance rate in the UG (Speitel et al., 2019). Moreover, since UG involves the processing of violations of social fairness and moral norms, brain regions related to morality and fairness, such as the left middle temporal gyrus (lMTG), may also contribute to understanding the allocation process and making final decisions (Boccia et al., 2017; Diveica et al., 2021; Etzel et al., 2016; Garrigan et al., 2016; Li et al., 2023).

Acute stress can affect the activation of brain regions associated with decision-making during the UG. Previous studies have demonstrated the susceptibility of PFC to stress, with acute psychosocial stress resulting in the suppression of PFC activation (Arnsten, 2009; Datta and Arnsten, 2019). This suppression may impair cognitive control processes in the UG, potentially affecting the evaluation of options and the final decision tendency. Furthermore, exposure to acute stress has been found to increase the activation level of rTPJ (Ashare et al., 2016; Kogler et al., 2015), and this activation has shown a significant positive correlation with stress-induced cortisol increase (Hernaus et al., 2018). In the context of the UG, heightened activation in the rTPJ may indicate an enhanced of unfair allocation by the responder (Ogawa et al., 2023; Wu et al., 2023). Overall, the involvement of the frontal and temporal cortex is crucial for the processing and decision-making in the UG, and stress exerts a significant impact on these regions.

Functional near-infrared spectroscopy (fNIRS) is a non-invasive optical technique used to monitor cerebral hemodynamics in the brain (Highton et al., 2023; Scholkmann et al., 2013). Compared to other neuroimaging techniques (such as EEG), fNIRS is more tolerant of movement artifacts. This allows for more natural engagement in social decision-making tasks, significantly enhancing the ecological validity of our research (Cui et al., 2011; Maier et al., 2019). Therefore, in the current study, fNIRS was used to investigate the neural mechanisms underlying the UG under acute psychosocial stress, with a specific focus on the activations of the frontal and temporal cortex.

1.3. *Trait coping style as a modulating factor*

Previous studies have indicated that individual differences such as anxiety, neuroticism, repressive coping style, and others can influence physiological responses and task performance under stressful conditions (Degroote et al., 2020; Jezova et al., 2004; Oskis et al., 2019; Verschoor and Markus, 2011). Specifically, trait coping style, which encompasses the cognitive and behavioral strategies individuals adopt when confronted with uncontrollable situations or events beyond their control (Folkman et al., 1986; Jiang and Zhu, 1999), has found to be influential. Individual differences in trait coping styles are crucial for responding to acute psychosocial stress, as they can influence the cortisol response (Oskis et al., 2019; Sladek et al., 2017) and predict subsequent behavioral performance (Anshel and Anderson, 2002). Jiang and Zhu (1999) categorized coping styles into positive and negative dimensions and developed the Trait Coping Style Questionnaire (TCSQ). Positive coping (PC) involves the adaptive use of positive cognitive strategies to reframe negative events or employ problem-solving behaviors to cope with situations, leading to enhanced subjective well-being, decreased depression, and reduced social anxiety (Wu and Zheng, 2020; Yang et al., 2021; Zhu et al., 2022). Therefore, positive adaptation in response to stress exposure, facilitated by PC, may serve to attenuate the impact of acute psychosocial stress on subsequent unfairness decision-making. On the other hand, negative coping (NC) includes maladaptive coping behaviors centered around emotional generation, rumination, and avoidance, which can have detrimental effects on individuals' physical and mental health, as well as their social adaptation (Han et al., 2023; Yang et al., 2021; Zhou et al., 2016). These coping mechanisms could potentially intensify the negative emotional responses triggered by inequitable propositions in the UG, leading to an increased tendency to reject unfair offers. Although trait coping styles may influence individuals' responses to acute psychosocial stress, subsequently affecting different cognitive processes and decision-making behaviors (Cavanagh and Obasi, 2021; Deniz, 2006; Folkman et al., 1986), conclusive evidence in this regard remains limited. Thus, the present study employed the TCSQ to measure trait coping styles and investigate whether these styles can modulate the relationship between acute psychosocial stress and the behavioral and neural mechanisms involved in decision-making regarding unfairness.

1.4. *The effect of acute psychosocial stress on female's unfairness decision-making*

There is a need for increased attention to explore the impact of acute psychosocial stress on female behavior and the underlying brain mechanism. Historically, many stress-related studies have primarily focused on men, resulting in a lack of sufficient research on the impact of stress specifically on females (Zhang et al., 2021). Contrasting with the typical "fight or flight" response observed in males, the females under acute psychosocial stress often exhibit a "tend and befriend" pattern (Taylor et al., 2000), characterized by notably rich prosocial behaviors. This distinct response is biologically rooted in elevated oxytocin levels in females, leading to unique psychological processes and mechanisms of social interaction under stress, which differ significantly from those in males (Campbell, 2008; Cecile et al., 2022; Taylor et al., 2000). Oxytocin prompts females to engage in more affiliative behaviors during stress situations, actively seeking additional social support and resources within their potential social networks. This tendency toward enhanced social interaction plays a critical role in ensuring not only their personal well-being but also the survival and safety of their offspring (Cecile et al., 2022; Riem et al., 2020; Taylor, 2006; Youssef et al., 2018). However, the effect of acute stress on females' decision behavior in the UG cannot be adequately understood solely through the rejection rate and the "tend and befriend" pattern. Both accepting and rejecting unfair allocations can be seen as prosocial behavior. Accepting implies friendliness and cooperation towards the current interaction partner (Prasad et al., 2017; Taylor et al., 2000; Youssef et al., 2018), while rejecting signifies sacrificing personal benefits to maintain social fairness, in-group social norms, and the order (Fehr and Gachter, 2002; Youssef et al., 2018). Although computational modeling can provide a more comprehensive representation of the behavioral mechanisms of decision-making through more indicators, previous studies on stress and unfairness decision-making have not adopted this method widely. Therefore, our study incorporates additional behavioral indicators by employing computational models, and investigates the underlying brain mechanisms. The goal is to understand the mechanism underlying the impact of acute psychosocial stress on females' unfairness decision-making, providing further evidence on how stress influences female behavior.

1.5. The present study

In this study, our main goal was to investigate how acute psychosocial stress influences young females' unfairness decision-making and its underlying neural mechanisms. In our study, we formulated three specific predictions. Firstly, considering the known sensitivity of key brain regions in the UG, such as rTPJ and PFC, to stress exposure (Ashare et al., 2016; Cheng et al., 2022; Datta and Arnsten, 2019; Ogawa and Kameda, 2020; Speer and Boksem, 2019), we anticipated observing notable differences in activation within these brain regions measured using fNIRS. Secondly, given the documented influence of trait coping styles on post-stress behaviors, particularly the escalation of negative emotions and rumination associated with NC (Han et al., 2023; Jiang and Zhu, 1999; Yang et al., 2021; Zhou et al., 2016), we hypothesized that these coping styles would significantly modulate the interplay between acute psychosocial stress, decision-making in the UG, and corresponding brain activity. Lastly, considering the prosocial and antisocial connotations of both acceptance and rejection behaviors in the UG (Fehr and Gachter, 2002; Prasad et al., 2017; Youssef et al., 2018; Zhu et al., 2019), coupled with the tendency of females to exhibit prosocial behavior under stress (Taylor et al., 2000), we posited that female responses in the context of unfairness decision-making might be more nuanced. Therefore, while refraining from explicit hypotheses regarding acceptance rates, we predicted that acute psychosocial stress might amplify maladaptive behaviors in females, such as increased randomness in responses, as revealed through computational modeling.

2. Method

2.1. Participants

This study recruited 49 right-handed college students as participants, with normal or corrected-to-normal vision, and without history of mental illness. All participants self-reported as female. To minimize the potential impact of negative emotions associated with menstrual cycles or proximity to menstruation, participants were required to take part in the experiment after the second day following the end of their menses (the second week of the follicular phase). Participants were randomly assigned to either the control group or the stress group. Data from 5 participants were excluded from the analysis for the following reasons: 1 participant did not complete the experiment, 1 participant had an acceptance rate below 0.7 under fair allocation conditions, 1 participant had an excessive number of undecided trials (9 trials undecided), and 2 participants' behavioral data were lost due to equipment failure. Finally, the control group included 23 participants (21.26 ± 2.80 years) and the stress group included 21 participants (20.67 ± 3.02 years). All participants provided informed consent and received 100 yuan as compensation upon completion of the experiment. This study was approved by the Institutional Review Board of East China Normal University (HR 020–2017).

2.2. Tasks and procedures

The experimental procedure, illustrated in Fig. 1A, commenced with participants arriving at the laboratory and providing their informed consent. Following this, they were given a 30-min period of rest in a quite preparation room where they completed the Trait Coping Style Questionnaire (TCSQ). Subsequently, participants underwent the Trier Social Stress Test (TSST) in a separate room. After the TSST, participants were guided to the fNIRS operation room where experimenter equipped them with the fNIRS. The ultimatum game (UG) was then conducted, lasting about 15 min. Subjective indicators of stress were measured by having participants complete the Multidimensional Mood State Questionnaire (MDMQ) before and after the TSST (T1 & T2), as well as after the UG (T3). Additionally, the experimenter used a wrist blood pressure monitor (PHILIPS, Holland) to measure the participants' systolic blood pressure (SP), diastolic blood pressure (DP), and heart rate (HR) as physiological indicators. Physiological measurements were taken 3 times at each time point, and the mean of the measurements was used as the result for that particular sampling time. Experimental stimuli were presented using E-prime 2.0 software, and the behavioral data were collected during the session. The entire experiment had a total duration of approximately 80 min.

2.2.1. Trier Social Stress Test (TSST)

The Trier Social Stress Test (TSST) consists of three stages (Kirschbaum et al., 1993): preparation (3 min), speech (5 min), and a mental arithmetic task (5 min). This paradigm is widely recognized as an effective method for inducing acute psychosocial stress, as it elicits stable stress-related physiological responses. It has been extensively used in stress-related laboratory research (Linares et al., 2020). The TSST procedure used in this study followed the protocol used in a previous study conducted in our laboratory (Li et al., 2014). Participants assigned to the stress group were asked to prepare for a job interview and stood in front of two professionally trained interviewers to deliver their speech. Following the speech, they were required to quickly and accurately complete a demanding mental arithmetic, continuously subtracting 17 from 2043, while providing the results out loud. During both the speech and arithmetic tasks, participant's facial expressions were recorded by a camera and displayed in real-time on a 23-inch monitor. In contrast, participants in the control group were asked to give a speech on their most recent trip and complete a simple mental arithmetic task involving the continuous addition of 5 to 0. There were no interviewers, cameras, or displays in the control group. After the completion of whole experiment, participants in the stress group returned to the TSST room, where the experimenter provided a debriefing about the TSST to help alleviate their stress.

2.2.2. The ultimatum game (UG)

After the TSST, participants were informed that they would be engaging in a money allocation task with other participants, known as the ultimatum game (UG) (Zheng et al., 2017). Before starting the UG, the experimenter asked the participant to recall and describe a memorable experience of unfair treatment, aiming to evoke their sense of unfairness (3 min). Then, participant began the one-shot UG task. In

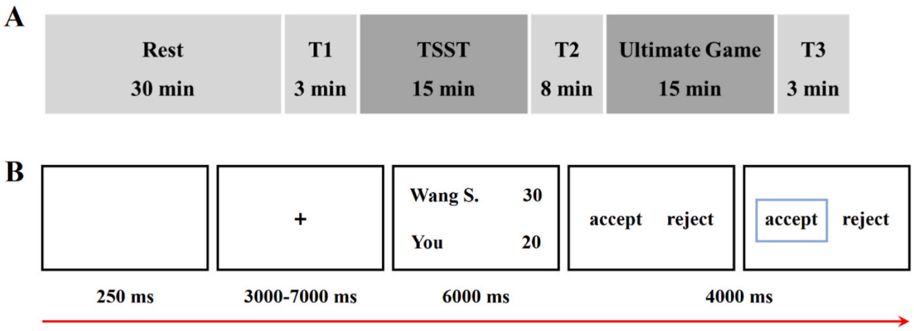

Fig. 1. Experimental design. (A) Experimental procedure. During the resting period, participants completed the TCSQ. Participants were asked to complete the MDMQ and have their systolic and diastolic blood pressure and heart rate measured three times before the TSST (T1), after the TSST (T2), and after the UG task (T3). After the measurement of T2, the experimenter attached the fNIRS equipment to the participant. (B) UG procedure. Each trial consisted of three stages: presentation of the allocation scheme, decision-making, and feedback. During the presentation stage, the virtual proposer's name abbreviation (e.g. Wang S.) and the amount they allocated to themselves (e.g. 30 yuan) are displayed at the top of the screen, and "You" (i.e., the participant) and the amount allocated by the proposer to the responder (e.g. 20 yuan) are displayed at the bottom. The decision-making and feedback stages lasted for a total of 4000 ms.

each trial, participants, acting as responders, had to divide 50 yuan with a new proposer. The proposers' name was displayed using random initials without indicating their gender. Each trial started with a 250 ms blank screen, followed by a random fixation point lasting between 3 and 7 s. The allocation scheme was then presented, offering the responder the opportunity to be allocated with 25, 20, 15, 10, or 5 yuan. Each offer appeared 10 times in a random order. After the allocation scheme was presented for 6 s, participants had to make an accept or reject decision within 4 s by pressing a button. If a response was made, the selected option was highlighted as feedback. In cases where no response was given, the decision screen remained visible until the end of the trial. If the participant (responder) accepted the allocation scheme, both the responder and proposer received money according to the offer. However, if participants rejected the allocation, neither the participant (responder) nor the proposer received any money (Fig. 1B).

2.2.3. *Subjective questionnaires*

2.2.3.1. Multidimensional Mood State Questionnaire (MDMQ). To assess participants' subjective stress levels, the MDMQ (http://www.metheval.uni-jena.de/mdbf.php) was used, which is derived from the German Mehrdimensionale Befindlichkeitsfragebogen (MDBF) (Steyer et al., 1997). This questionnaire consists of 3 dimensions: good-bad mood, alertness-tiredness, and calmness-nervousness, each consisting of 10 items. Participants responded to the MDMQ uses a 6-point Likert scale, ranging from 1 ("not at all") to 6 ("extremely"). Higher scores on each dimension indicate greater levels of pleasure, alertness, and calmness, respectively.

2.2.3.2. Trait Coping Style Questionnaire (TCSQ). The TCSQ measures coping styles along two dimensions: positive coping (PC) and negative coping (NC) (Jiang and Zhu, 1999). Each dimension consists of 10 items. Participants rate their responses on a 5-point Likert scale, ranging from 1 ("never") to 5 ("always").

2.3. *Behavioral data preprocessing*

2.3.1. *Acceptance rate*

The allocation schemes in the UG were classified into 3 allocation conditions: Fair (F; offer = 25 yuan), Moderately Unfair (MU; offer = 20 or 15 yuan), and Very Unfair (VU; offer = 10 or 5 yuan) (Duek et al., 2014; Lois et al., 2020). For each participant, the acceptance rate was calculated separately for each type of allocation scheme. Additionally, the acceptance rate was calculated across all 5 offer amounts to align with the computational models used to analyze participants' decision-making in the UG (see details in the next section).

2.3.2. *Computational modeling*

We performed computational modeling using the "hBayesDM" package in R-4.2.3 (Ahn et al., 2017). Two computational models, derived from previous studies (Gu et al., 2015; Morasse et al., 2023; Xiang et al., 2013; Yang et al., 2022), were adopted. Both models assume that the internal fairness norm is a function of the observed offer, but they differ in their updating rules (Gu et al., 2015).

Bayesian observer (BO) model. This model treats participants as Bayesian observers who perform the Bayesian update to change their expected offer distribution with each UG trial (Xiang et al., 2013). To simulate participants' decision-making in the UG, the BO model combines the inequality aversion model (Fehr and Schmidt, 1999) and the norm-based utility function (Bicchieri, 2006), and represents the decision utility of offer x_t as:

$$U(x_t) = x_t - \alpha \cdot \max(f_t - x_t, 0) - \beta \cdot \max(x_t - f_t, 0),$$

in which f_t represents the expected offer at trial t, α ($0 < \alpha < 20$) represents the sensitivity to the negative norm prediction errors (envy), while β ($0 < \beta < 10$) represents the sensitivity to the positive norm prediction errors (guilt). Thus, the probability of accepting offer x_t can be represented as:

$$P_{\text{accept}} = \frac{e^{U(x_t)/\tau}}{1 + e^{U(x_t)/\tau}},$$

where τ ($0 < \tau < 10$) represents the inverse temperature, also known as decision noise. A higher τ indicates that the participant's decision-making is more deterministic, while a lower τ indicates more random. In our UG task, the proposers always allocated 50 yuan, so we set the initial fairness expectation f_0 to 25 (Zhu et al., 2019).

Rescorla-Wagner (RW) norm adaptation model. The RW model does not consider β, i.e., the degree of aversion to the positive norm prediction errors, which is more in line with the UG paradigm we used. In terms of updating rule, this model is based on temporal difference learning and uses the RW rule (Rescorla and Wagner, 1972), assuming the participant's update of internal fairness (f_t) during the UG task follows the following function:

$$f_t = f_{t-1} + \varepsilon(x_t - f_{i-1}),$$

where ε ($0 < \varepsilon < 1$) is the norm adaptation rate, indicating the degree to f_t is influenced by the offer in the previous allocation. A higher ε means a greater influence of offers on internal norms of fairness, while a lower ε means an unwillingness to adapt. The two models use the same method to estimate acceptance rates. Likewise, the RW model outputs three parameters: α, τ, and ε. Similar to the BO model, in the RW model, f_0 is set to 25.

After model fitting, the leave-one-out information criterion (LOOIC) and the widely applicable information criterion (WAIC) were used for model comparison (Ahn et al., 2017). The parameters of the better model were extracted as the indicators for comparing differences between the two groups and the subsequent correlation analysis.

2.4. *fNIRS data acquisition and preprocessing*

During the UG task, functional near-infrared spectroscopy (fNIRS) data were continuously recorded using the Hitachi ETG-7100 Optical Topography System (Hitachi Medical Corporation, Japan). The fNIRS system employed two wavelengths of 695 and 830 nm, with a sampling rate of 10 Hz. Two patches of 3 × 5 were symmetrically placed on the left and right hemispheres horizontally. The second channel of the bottom row, corresponding to F7 and F8 in accordance with the 10–20 electrode placement system, was placed near the forehead. Each patch consisted of 8 emitters and 7 detectors, forming 22 channels. The distance between optode probes was 3 cm. A 3D digitizer was used to determine the locations of the optodes and channels, and the corresponding Brodmann areas (BA) were identified as reference regions for region-of-interest (ROI) analysis. Our ROIs, including PFC, rTPJ, and lMTG, play integral roles in cognitive control (Servaas et al., 2015; Speer and Boksem, 2019), mentalization (Ogawa and Kameda, 2020; Wu et al., 2023), and the processing of moral information (Diveica et al., 2021; Etzel et al., 2016), during decision-making in the face of perceived unfairness. The real coordinates were then transformed into the Montreal Neurological Institute (MNI) space using a virtual registration approach (Singh et al., 2005). Brain visualizations were performed using BrainNet Viewer (Xia et al., 2013) (Fig. 2). The concentrations of HbO and HbR were calculated using the modified Beer-Lambert law. HbO was selected as the indicator of brain activity during the task, as it has a higher signal-to-noise ratio and greater sensitivity for measuring cerebral blood flow than HbR (Hoshi, 2003; Zhang et al., 2021). Channels with poor signal quality were manually identified and excluded from statistical analysis. The proportion of excluded channels across all participants and channels (44 participants × 44 channels) was 0.98%.

The fNIRS data preprocessing was performed using MATLAB R2021b. We used correlation-based signal improvement (CBSI) to improve signal quality (Cui et al., 2010). The wavelet-based method was used to remove motion artifacts (Molavi and Dumont, 2012). A sixth-order Butterworth bandpass filter (0.01–0.1 Hz) was then used to remove physiological noise, such as cardiac and respiratory activity (Henze et al., 2023). In each trial, the starting point of the allocation scheme was used as the onset time, and a period of 12.5 s was extracted for the HbO time series. The HbO time series for each trial were transformed into z-scores, with the HbO values from the 0.5 s period prior to the onset time serving as the baseline. The mean z-score time series for the channels within each ROI were then calculated, and the maximum z-score value (HbO peak) within each trial was extracted. Finally, the mean peak value for each ROI was calculated across the 3 allocation conditions (Fair, Moderately Unfair, and Very Unfair), serving as an indicator for subsequent statistical analysis (Yokoyama et al., 2019).

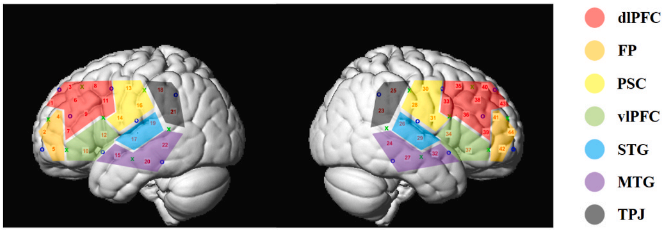

Fig. 2. Channel position and ROI construction. Blue "○" indicate emitters, green " × " indicate detectors, and red numbers indicate channels. Channel 10 corresponds to F7 according to the 10–20 electrode placement system, while channel 37 corresponds to F8. The seven colored blocks cover the channels corresponding to 7 ROIs in each hemisphere, including the dorsolateral prefrontal cortex (dlPFC), frontopolar cortex (FP), primary somatosensory cortex (PSC), ventrolateral prefrontal cortex (vlPFC), superior temporal gyrus (STG), middle temporal gyrus (MTG), and temporoparietal junction (TPJ).

2.5. *Statistical analysis*

Statistical analyses were performed using SPSS 23.0 software. To validate the manipulation of acute psychosocial stress, a mixed-design analysis of variance (ANOVA) was employed. The ANOVA included a between-participants variable of group (control vs. stress) and a within-participants variable of time (T1/T2/T3). This analysis was applied to examine physiological indicators (SP, DP, HR) and subjective measures (MDMQ scores) related to stress.

For the behavioral data, Wilcoxon signed-rank test was used to examine differences in acceptance rates between the Fair (F), Moderately Unfair (MU), and Very Unfair (VU) conditions. These tests were performed separately for the control and stress groups. Additionally, Mann-Whitney *U* test was used to compare acceptance rates between groups (control vs. stress) under the 3 allocation conditions. For the computational model parameters, the LOOIC and WAIC were first used to determine the better-fitting model. Subsequently, an independent sample *t*-test was conducted to examine the differences in model parameters between the two groups.

For the fNIRS data, a 2 (group: control vs. stress) × 3 (allocation condition: F vs. MU vs. VU) mixed-design ANOVA was conducted. This design allowed for the examination of potential differences in the peak values of HbO within the ROIs. The stress condition served as the between-participants variable, while the allocation condition was the within-participants variable.

Following that, a series of Pearson correlation analyses were performed. First, correlation coefficients were computed to examine the relationship between computational model parameters and the HbO peak values within each ROI under each allocation condition. Corresponding correlation analyses were then conducted separately for the control and stress groups, aiming to investigate the association between brain activity and behavior during unfairness decision-making, as well as any potential differences between the groups. A web-based tool (https://www.psychometrica.de/correlation.html) was used to assess the significance of correlational differences between the two groups. The Fisher's z transformation was used to convert the correlation coefficient (r) into z-scores, expressed as $z_{diff} = (z_1 - z_2)/SE$. This facilitates the comparison of differences between two groups. Next, within the stress group, correlation analyses were conducted between stress-related indicators at T2, the model parameters, and HbO peaks within the ROIs that exhibited significant group differences. These analyses aimed to provide further insights into the potential mechanisms underlying the impact of stress on behavior and brain activity. Furthermore, correlations were computed between the TCSQ scores and the HbO peaks within each ROI under the 3 allocation conditions, as well as the model parameters, across all participants. Corresponding correlation analyses were also performed for both the control and stress groups, and group differences were compared. Note that before conducting the correlation analyses, independent sample *t*-tests were carried out on the TCSQ scores to account for any potential influence of group differences. The Bonferroni correction was applied for multiple comparisons in the correlation analyses. The significance threshold was determined by dividing 0.05 by the total number of correlation analyses performed within each group.

3. Results

3.1. *Stress manipulation check*

The blood pressure and HR data for one participant in the stress group at T3 were not available. Consequently, we decided to exclude this participant from the statistical analysis concerning physiological measures. Regarding SP, the ANOVA revealed a significant interaction effect of stress condition and time, $F(2, 82) = 3.73$, $p = 0.033$, $\eta_p^2 = 0.08$. Post-hoc tests showed that SP was significantly higher at T2 ($p = 0.001$) and T3 ($p < 0.001$) compared to T1 in the stress group, and there was no significant difference between T2 and T3 ($p = 0.087$). In the control group, no significant difference in SP across the three time points was found (Fig. 3A). There were no significant interaction effects for DP or HR.

MDMQ scores at T3 of one participant in the control group had missing and was excluded from the statistical analysis of subjective measures. There was a significant interaction effects of stress condition and time for good-bad mood and calmness-nervousness dimension, $F_{good\text{-}bad}(2, 82) = 5.16$, $p = 0.015$, $\eta_p^2 = 0.11$; $F_{calm\text{-}nervous}(2, 82) = 7.47$, $p = 0.003$, $\eta_p^2 = 0.15$ (Fig. 3B and C). Post-hoc tests showed that only at T2, the control group had significantly higher scores on the good-bad mood dimension ($p = 0.002$) and calmness-nervousness dimension ($p = 0.002$) compared to the stress group. There was no significant interaction for the alertness-tiredness dimension.

Taken together, the stress group showed a significant increase in SP after the TSST, alongside reporting higher levels of negative emotions and nervousness compared to the control group. These findings suggest that the manipulation of acute psychosocial stress was valid according to both physiological and subjective stress indicators.

3.2. Behavioral results

3.2.1. Acceptance rate

Wilcoxon signed-rank test showed that the acceptance rate decreased as the level of inequality increased, with significant differences between each pair of conditions, $z_{F\text{-}MU} = -4.03$, $p < 0.001$; $z_{F\text{-}VU} = -5.58$, $p < 0.001$; $z_{MU\text{-}VU} = -5.52$, $p < 0.001$ (Fig. 4A). These results were observed in both the control and stress groups (Table 1). Mann-Whitney *U* test showed no significant differences between the two groups under any of the allocation conditions, $U_F = 241.50$, $z_F = 0.00$, $p = 1.000$; $U_{MU} = 186.50$, $z_{MU} = -1.40$, $p = 0.162$; $U_{VU} = 224.00$, $z_{VU} = -0.429$, $p = 0.668$.

3.2.2. Computational modeling

All of the $\widehat{R}$ for latent variables were less than 1.01, indicating that all chains converged (Ahn et al., 2017; Zhu et al., 2019). The LOOIC and WAIC of the RW model were lower than those of the BO model for both the control and stress groups (Table 2), thus, RW model fitted better. Independent sample *t*-test was conducted to compare the model parameters (α, τ, and ε) between the two groups. The results showed that the control group had significantly higher τ values ($t = -3.02$, $p = 0.005$) and ε values ($t = -38.43$, $p < 0.001$) compared to the stress group (Fig. 4C and D). In other words, the stress group had higher decision noise and lower fair adaptation rate than the control group.

3.3. fNIRS results

For the HbO peak in the 3 allocation conditions within each ROI, ANOVA showed a significant interaction between stress and allocation in the right temporoparietal junction (rTPJ), $F(2, 84) = 6.69$, $p = 0.003$, $\eta_p^2 = 0.14$ (Fig. 5A). Post-hoc test revealed that under the MU condition, the stress group had significantly higher HbO peak compared to the control group ($p = 0.002$). Within the stress group, the *z*-score under the MU condition was significantly higher than that of the F ($p = 0.021$) and VU conditions ($p = 0.001$). Meanwhile, in the left middle temporal gyrus (lMTG), there was a significant interaction between stress and allocation, $F(2, 84) = 5.52$, $p = 0.009$, $\eta_p^2 = 0.12$ (Fig. 5B). Post-hoc test revealed that under the MU condition, the control group had significantly higher HbO peak compared to the stress group ($p = 0.008$). Within the control group, the HbO peak under the MU condition was significantly higher than that of the VU condition ($p = 0.032$). Other main and interaction effects were not significant.

In addition, we acknowledge the critical role of the prefrontal cortex (PFC) in decision-making and stress response. Accordingly, we conducted post-hoc analyses on the PFC-related ROIs. We observed a tendency for reduced HbO peaks in the left dlPFC ($M \pm SD$: Stress = 33.20 ± 86.12; Control = 34.90 ± 45.77), left vlPFC ($M \pm SD$: Stress = 25.21 ± 33.26; Control = 37.10 ± 54.30), and right vlPFC ($M \pm SD$: Stress = 19.84 ± 27.77; Control = 27.79 ± 44.18) under the stress condition. Notably, under the MU condition, the stress group exhibited a significantly lower HbO peak in the left vlPFC ($M = 17.04$, $SD = 23.48$) compared to the control group ($M = 51.48$, $SD = 73.57$; $p = 0.047$), indicating partial support for the inhibition of PFC activation by stress.

3.4. Correlation analysis results

3.4.1. Correlation between behavioral and fNIRS data

Using Pearson correlation analysis, we calculated the correlation coefficients between the RW model parameters of all participants and the HbO peak values in each ROI under 3 allocation conditions. Each group went through the same analyses and compared the differences in correlation coefficients between the two groups. The results showed that α and the HbO peak in rTPJ under the MU condition did not significantly correlate among all participants ($r = -0.04$, $p = 0.796$) and in the stress group ($r = -0.19$, $p = 0.422$). In contrast, there was a significant correlation in the control group ($r = 0.47$, $p = 0.023$), as well as with a significant difference between the two groups ($z = 2.15$, $p = 0.016$) (Fig. 6A). It is worth mention that we noted that there might be extreme values in the stress group. After removing the extreme values, the correlation in the stress group was still not significant ($r = -0.227$, $p = 0.336$), and the correlation coefficients between the two groups remained significantly different ($z = 2.25$, $p = 0.012$); therefore, we still included the participant in our analysis. It should be noted that significant correlations observed in the control group did not remain significant after multiple comparison. The significant correlations between HbO peak in other ROIs and RW model parameters with differences

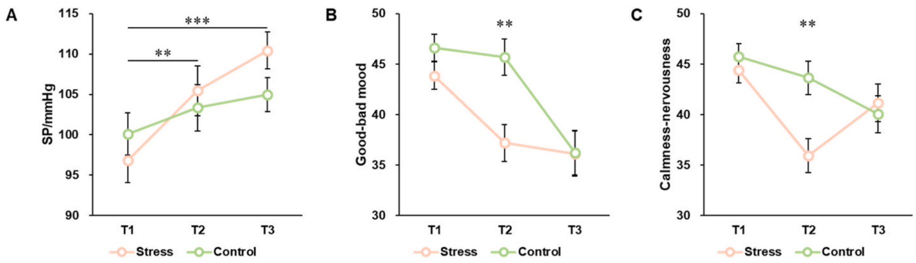

Fig. 3. Physiological and subjective stress indicators. (A) Systolic blood pressure (SP), (B) MDMQ (Multidimensional Mood State Questionnaire) good-bad mood score, (C) MDMQ calmness-nervousness score. T1: before the TSST, T2: after the TSST, T3: after the UG. **$p < 0.01$, ***$p < 0.001$. Error bars represent standard error (*SE*).

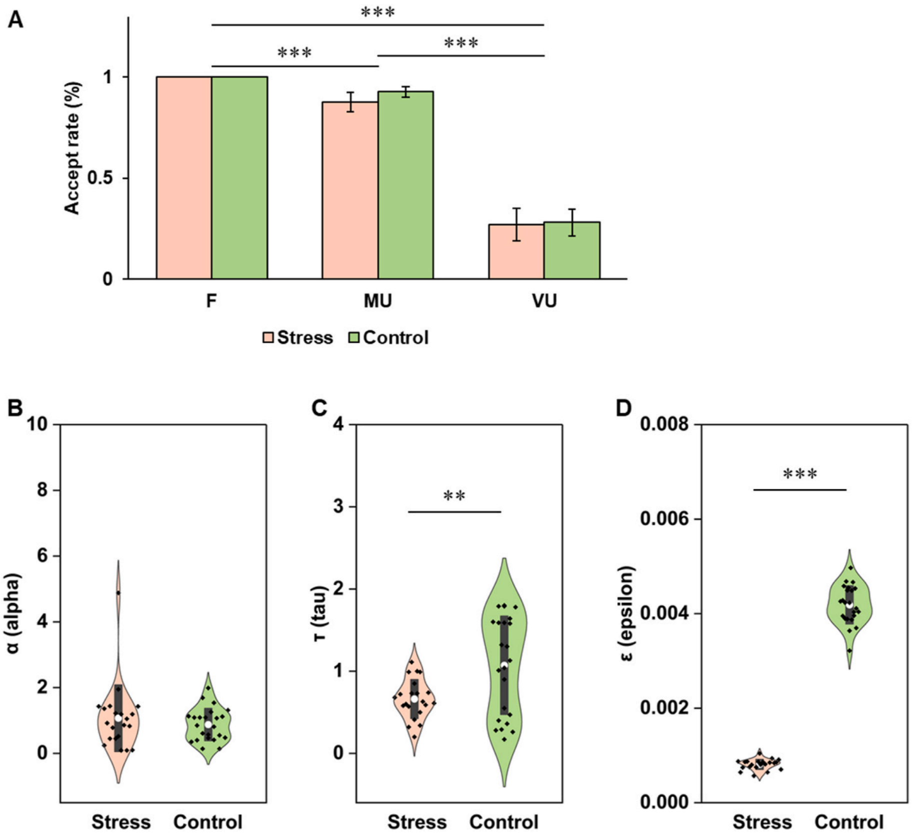

Fig. 4. Behavioral results in the UG. (A) Acceptance rate. (B) α (the sensitivity to the negative norm prediction errors). (C) τ (inverse temperature). (D) ε (norm adaptation rate). $^{**}p < 0.01$, $^{***}p < 0.001$. Error bars represent *SE*. In the violin plots, the black "⋄" represent data points, the white "○" represent means (*M*), and the upper and lower boundaries of the boxes represent $M \pm 1$ *SD*.

Table 1
The differences of acceptance rates between allocation conditions.

	F vs. MU		F vs. VU		MU vs. VU	
	z	*p*	*z*	*p*	*z*	*p*
Stress	−3.19**	0.001	−3.89***	<0.001	−3.83***	<0.001
Control	−2.53*	0.012	−4.05***	<0.001	−4.02***	<0.001
Total	−4.03***	<0.001	−5.58***	<0.001	−5.52***	<0.001

Note: F: fair, MU: moderately unfair, VU: very unfair; $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 2
Model fitting.

	LOOIC	WAIC
BO-Stress	429.94	406.39
BO-Control	368.05	342.28
RW-Stress	313.00	292.20
RW-Control	318.09	296.58

Note: A smaller value of LOOIC and WAIC indicates a better model fit. LOOIC: leave-one-out information criterion. WAIC: widely applicable information criterion. BO: Bayesian observer model. RW: Rescorla-Wagner norm adaptation model.

between the two groups are shown in Table 3.

3.4.2. *Effects of stress indicators on behavior and brain activation*

We calculated the Pearson correlation coefficients between the stress indicators at T2, RW model parameters, and HbO peak in lMTG and rTPJ under the MU condition for the stress group (Fig. 7). The results showed that the alertness-tiredness score was significantly positively correlated with ε ($r = 0.59$, $p = 0.005$). The calmness-nervousness score was significantly negatively correlated with α ($r = -0.44$, $p = 0.049$) and significantly positively correlated with ε ($r = 0.44$, $p = 0.046$). After removing the extreme value of α, the correlation was still significant ($r = -0.47$, $p = 0.039$). The good-bad mood score was significantly positively correlated with ε ($r = 0.48$, $p = 0.027$). These correlations were not significant after multiple comparison.

3.4.3. *The moderation effects of coping styles*

3.4.3.1. Effects of coping styles on behavior. Independent sample *t*-test showed that there was no significant difference between the two groups in the scores of PC ($M_{\text{Stress}} = 34.90$, $SD_{\text{Stress}} = 4.31$; $M_{\text{Control}} = 34.39$, $SD_{\text{Control}} = 5.37$; $t = 0.35$, $p = 0.730$) and NC ($M_{\text{Stress}} = 30.29$, $SD_{\text{Stress}} = 4.96$; $M_{\text{Control}} = 31.39$, $SD_{\text{Control}} = 5.26$; $t = -0.72$, $p = 0.478$). We then calculated the Pearson correlation coefficients between the TCSQ dimensions and the RW model parameters in all participants, control group, and stress group. Significant differences in correlation coefficients between the two groups were reported. The results showed that NC and τ did not significantly correlate among all participants ($r = 0.17$, $p = 0.258$) and in the control group ($r = -0.02$, $p = 0.931$), while there was a significant positive correlation in the stress group ($r = 0.66$, $p = 0.001$), with a significant difference between the two groups ($z = -2.48$, $p = 0.007$) (Fig. 6B). Significant correlations observed in the stress group remained significant even after multiple comparison.

3.4.3.2. Effects of coping styles on brain activation. We calculated the Pearson correlation coefficients between the TCSQ dimensions and the HbO peak in each ROI under 3 allocation conditions and reported the results of the significant differences in correlation coefficients between the two groups. We did not find any differences between the two groups

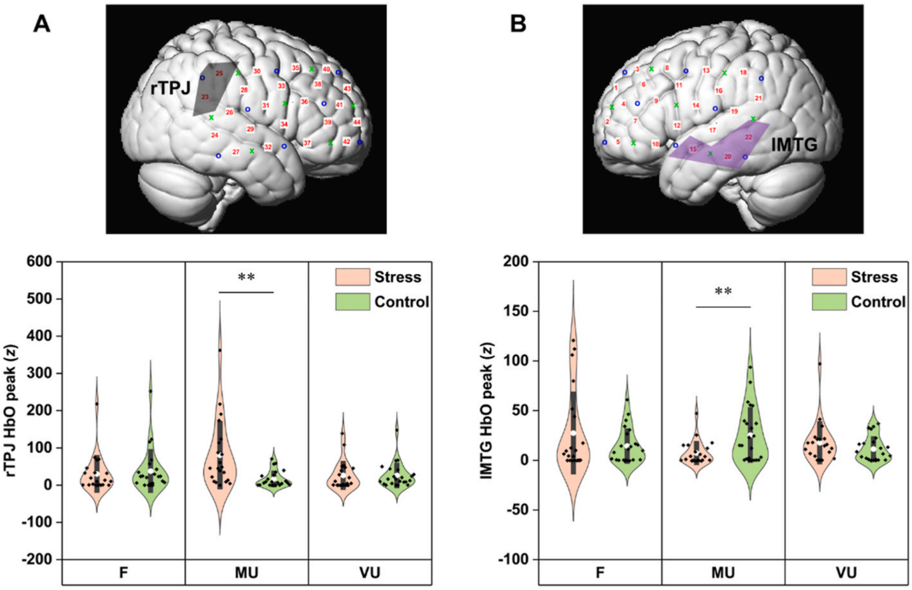

Fig. 5. HbO peak (*z*-score) during the UG. (A) Right temporoparietal junction (rTPJ). (B) Left middle temporal gyrus (lMTG). In the violin plots, the black "⬦" represent data points, the white "○" represent *M*, and the upper and lower boundaries of the boxes represent *M* ± 1 *SD*. F: fair; MU: moderately unfair; VU: very unfair. $^{**}p < 0.01$.

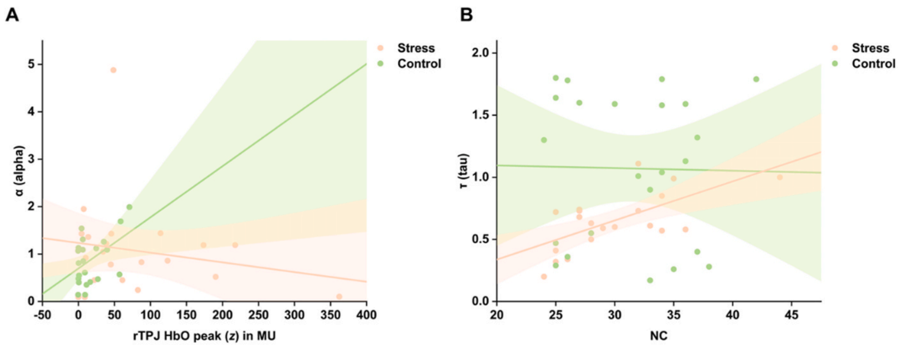

Fig. 6. The inter-group differences of correlations. (A) In the control group, α was significantly positively correlated with rTPJ HbO peak in MU condition. (B) In the stress group, τ was significantly positively correlated with NC.

Table 3
Correlation between brain activation and model parameters of RW model.

	r in control group	r in stress group	Group comparison	
			z	p
F				
lSTG & τ	0.06	−0.65**	2.55	0.005
MU				
rTPJ & α	0.47*	−0.19	2.15	0.016
lvlPFC & ε	−0.35	0.44*	−2.55	0.005
rvlPFC & α	−0.38	0.68**	−3.73	<0.001
VU				
rdlPFC & τ	0.32	−0.45**	2.49	0.006
lvlPFC & ε	0.14	−0.46*	1.92	0.028

Note: F: fair; MU: moderately unfair; VU: very unfair. $^{*}p < 0.05$, $^{**}p < 0.01$.

in the correlations between HbO peak in lMTG, rTPJ, and coping styles. The significant correlations between HbO peak in other ROIs and coping styles with differences between the two groups were shown in Table 4.

4. Discussion

In the current study, we used the TSST to induce acute psychosocial stress and investigate its impact on females' unfairness decision-making. The results showed that acute psychosocial stress did not affect acceptance rates in the UG, but it did reduce adaptability to fairness and lead to more random decision-making responses. fNIRS results showed that under the moderately unfair (MU) condition, stress led to a decrease in activation within brain regions associated with fairness and moral processing, while increasing the HbO peak in the rTPJ, which is related to the theory of mind. This finding potentially explains the observed "tend and befriend" pattern from a cognitive neuroscience perspective. Furthermore, we found that under stress, there was a positive correlation between negative coping style and the deterministic of decision-making behavior. In the control group, activation of the rTPJ positively predicted disadvantageous aversion. However, this relationship was not observed under the stress condition.

4.1. Fairness level impacted the acceptance rate

Our findings provide further support for the concept of inequality aversion in unfairness decision-making. In line with the inequality aversion model (Fehr and Schmidt, 1999), individuals exhibit a tendency to reject unfair allocations when acting as responders in unfairness decision-making, even if doing so means punishing the proposer by sacrificing potential benefits the responder could have received. This

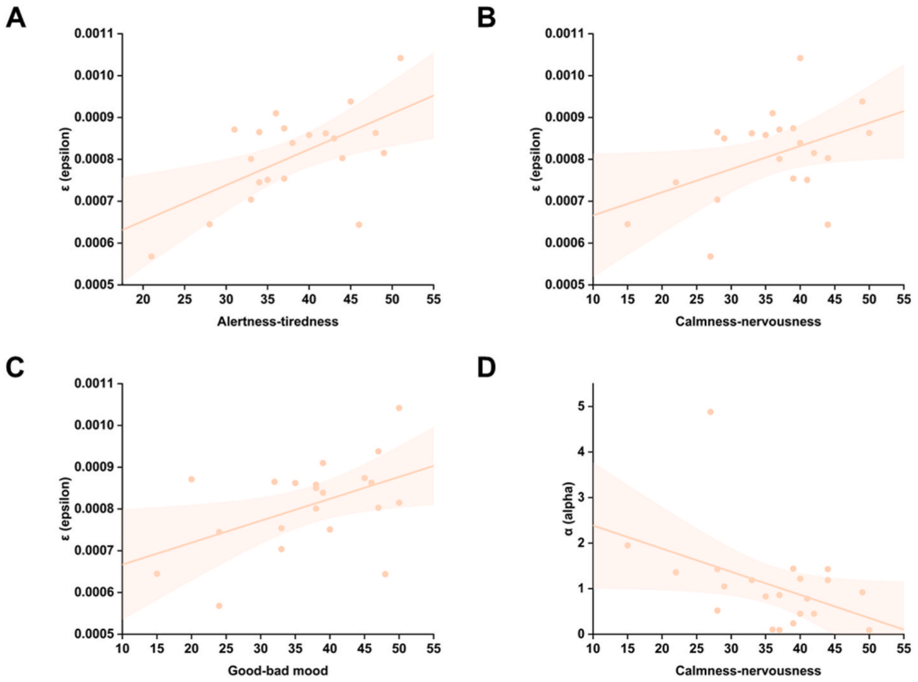

Fig. 7. Correlation between behavioral indicators and subjective stress indicators in the stress group at T2. The ε was significantly positively correlated with the alertness-tiredness (A), calmness-nervousness (B) and good-bad mood (C) scores, while α was significantly negatively correlated with the calmness-nervousness score (D) in the stress group at T2.

Table 4

The correlation between coping styles and brain activation.

	r in control group	*r* in stress group	Group comparison	
			z	*p*
MU				
rdlPFC & NC	0.74***	0.31	1.90	0.029
VU				
rPSC & PC	−0.46*	0.16	−1.97	0.024

Note: MU: moderately unfair; VU: very unfair. *$p < 0.05$, ***$p < 0.001$.

pattern persists unless the proposers allocates all the resources exclusively to themselves (Ogawa et al., 2023; Xu et al., 2023; Youssef et al., 2018). Our observation aligns with previous studies and underscores that as the level of fairness decreases, participants become increasingly inclined to reject the allocations.

4.2. Acute psychosocial stress impacted the decision-making behavior during UG

Acute psychosocial stress increased decision randomness and impaired fairness adaptation of unfairness decision-making behavior. Similar to the previous studies (Nickels et al., 2017; Zhang et al., 2019), acute psychosocial stress did not yield significant differences in acceptance rates among females in the UG. However, through computational modeling, we found that the stress group demonstrated lower adaptability to fairness (lower ε) and higher levels of decision randomness (lower τ). Additionally, higher subjective stress levels were associated with reduced adaptability to fairness and heightened sensitivity to disadvantageous unfairness. Although acute psychosocial stress did not significantly change participants' final decisions within more complex unfairness decision-making tasks involving social situations, it did affect the process of fairness-related judgments. In the UG, both the acceptance and rejection of unfair offers are associated with prosocial and antisocial outcomes (Fehr and Gachter, 2002; Prasad et al., 2017; Youssef et al., 2018; Zhu et al., 2019). This duality renders the decision-making behavior of females more complex, particularly due to the stress-induced bias towards prosocial behavior (Taylor et al., 2000). The resulting internal conflict, stemming from their prosocial inclinations juxtaposed with varied decision-making options in the UG, is likely to increase behavioral unpredictability. Additionally, it is well established that the perception of stress heightens feelings of uncontrollability and unpredictability (Koolhaas et al., 2011), further exacerbating this tendency towards unpredictable behavior. Consequently, these factors collectively contribute not to a marked shift in the overall pattern of outcomes (e.g., acceptance rate), but rather to an increase in the randomness of responses.

Moreover, these non-adaptive responses align with the dysfunctional strategy use and insufficient adjustment from automatic responses (Starcke and Brand, 2012). On one hand, while it is important to consider various alternatives comprehensively during decision-making, premature closure induced by stress can result in an incomplete evaluation of all available options (Janis and Mann, 1977), resulting in maladaptive and dysfunctional decision-making processes, such as a preference for immediate benefits without considering future risks (Cano-Lopez et al., 2016). On the other hand, stress impairs individuals' ability to implement controllable modifications in their behavior (Kassam et al., 2009; Starcke and Brand, 2012), specifically, their ability to mobilize cognitive resources for the regulation and modification of ongoing behavior. In essence, acute stress exposure may deplete available cognitive resources (Datta and Arnsten, 2019; Dimenichi et al., 2018; Chu et al., 2023; Lin et al., 2020), impairing responders' capabilities to fully process and consider essential social interaction information within the current context, such as the fairness of allocation schemes (Kassam et al., 2009; Starcke and Brand, 2012). Consequently, there is an increased tendency to default to habitual decision-making processes (Morgado et al., 2015), leading to decisions that lack suitable adjustments based on situational nuances. This deficiency in regulating automatic response may ultimately lead to increased behavioral randomness and decreased situational adaptability under acute psychosocial stress. Therefore, exploring the effects of stress in relatively complex decision-making tasks requires more than solely examining single behavioral output measures. Even if female participants in the stress group exhibit similar final task choices to those in the control group, they may have undergone more intricate psychological processes.

4.3. *Acute psychosocial stress increased the activation of rTPJ under MU*

The stress group exhibited heightened activation in the rTPJ compared to the control group under the MU condition, suggesting a greater involvement of mentalizing processes. This align with prior research indicating increased rTPJ activation in unfairness decision-making (Guo et al., 2014; Guroglu et al., 2010; Ogawa et al., 2023). The rTPJ is a key brain region involved in mentalization or theory of mind processes, facilitating the understanding of others' behavior and intentions (Blair-West et al., 2018; Molenberghs et al., 2016; Ogawa and Kameda, 2020; Park et al., 2021). Therefore, the significant increase in rTPJ HbO peak under stress suggests that participants engaged in heightened mentalizing processes following acute psychosocial stress. Interestingly, although the rTPJ is implicated in social allocation decisions and processing of unfairness aversion (Kameda et al., 2016; Ogawa et al., 2023; Wu et al., 2023), our study found that the level of rTPJ activation did not affect the final decision of responders to accept or reject unfair allocations in the UG. In fact, rTPJ involvement does not necessarily imply agreement with the proposer's behavior (Blair-West et al., 2018; Speitel et al., 2019). We found that under non-stress conditions, the rTPJ HbO peak could positively predict sensitivity to disadvantageous unfairness, indicating a stronger inclination to reject unfair offers. However, when stress enhanced rTPJ activation, the activation level of the rTPJ no longer exhibited sensitivity to disadvantageous unfairness. This may be due to the complex neurobiology of social decision-making (Blair-West et al., 2018; Jeurissen et al., 2014). In other words, rTPJ involvement merely signifies a deeper processing of the intentions of the proposers, while the understanding of their intentions and subsequent decision-making behavior may be influenced by various additional factors.

Also, the activation of rTPJ under stress provides evidence for the cognitive neuroscience perspective of the "tend and befriend" pattern observed in females experiencing acute psychosocial stress. For a long time, limited research has focused on the impact of stress specifically on females. Meanwhile, the results regarding the acceptance rates in the UG task have not been consistently explained by the concept of "tend and befriend" (Nickels et al., 2017; Prasad et al., 2017; Youssef et al., 2018). This is because both accepting and rejecting unfair offers can be understood as prosocial behavior (Fehr and Gachter, 2002; Speer and Boksem, 2019; Youssef et al., 2018). Our study offers a possible explanation from the perspective of cognitive neuroscience. Under specific unfairness conditions, stress led to greater activation of the rTPJ in female participants.

4.4. *Acute psychosocial stress decreased the activation of lMTG under MU*

Furthermore, we found that the stress group exhibited a lower HbO peak in the lMTG compared to the control group under the MU condition. The lMTG has been implicated in encoding information about fairness in social interactions (Etzel et al., 2016). Additionally, extensive research has highlighted the crucial role of the lMTG in moral reasoning, moral decision-making, and moral emotions (Boccia et al., 2017; Diveica et al., 2021; Garrigan et al., 2016; Li et al., 2023). Thus, the reduced activation of lMTG under stress may lead to an incomplete processing of fairness-related information about the interaction partner, as well as an ambiguous understanding of the relationship between current allocation schemes and social moral norms (Diveica et al., 2021; Etzel et al., 2016; Garrigan et al., 2016).

Notably, both the lMTG and rTPJ showed stress-related activation differences in the UG specifically under the MU condition. Previous research has found that response times (RT) in decision-making tasks tend to be longer when participants encounter moderately unfairness conditions compared to fairness and very unfairness conditions (Lois et al., 2020; Youssef et al., 2018). These findings suggest that the MU condition entail a more intricate cognitive processing. It is possible that there is a heightened conflict between maintaining fairness and pursuing self-benefit, as well as a more complicated comprehension of the intentions of others in such circumstances.

4.5. *The activations of PFC under stress were correlated with unfairness decision behavior*

Acute stress has been found to inhibit frontal lobe function in a variety of decision-making and memory tasks (Arnsten, 2009; Datta and Arnsten, 2019). Our post-hoc analysis revealed that stress induction decreased activation in the left vlPFC under the MU condition, confirming the hypothesis that stress inhibits PFC activation during economic decision-making. Moreover, we found that under the MU condition, the activation of the PFC in the stress group exhibited a stronger relationship with sensitivity to disadvantageous unfairness and fairness adaptability. These findings suggest that although acute psychosocial stress enhances mentalizing processes and reactivity in the rTPJ, the monitoring and inhibition of bottom-up emotional reactions by the frontal lobe are still necessary to facilitate behavioral changes in fairness-related decisions (Cheng et al., 2022; Guo et al., 2014; Speer and Boksem, 2019; Speitel et al., 2019).

4.6. *NC modulated the relationship between acute psychosocial stress and deterministic of decision-making*

In the stress group, individuals with higher NC exhibited more deterministic decision-making behavior. No similar relationship was found in the control group. When faced with unfair distributions, acute psychosocial stress may lead to heightened arousal of negative emotions related to unfairness in individuals with high NC, consequently resulting in more convergent behavior, such as rejecting unfair allocations. The insights gained from our findings, particularly regarding the significant activation differences in the rTPJ and lMTG, can substantially enrich our understanding of the psychological underpinnings of decision-making in real-world scenarios (e.g. decision-making in business activities). These insights underscore the importance for managers to foster effective stress coping strategies in professional development programs. Cultivating adaptive coping styles can be instrumental in enhancing critical economic decision-making processes, especially under stress conditions (Yu et al., 2023). Moreover, under acute psychosocial stress, the correlation between coping styles and the peak level of HbO in the rdlPFC and rPSC under unfair conditions was not significant, which differed from the control group. This finding is consistent with previous research indicating that acute psychosocial stress weakens the impact of trait-related factors on physiological and behavioral responses (Ahmad et al., 2021; Puig-Perez et al., 2016; Zunhammer et al., 2013). These results suggest that under acute psychosocial stress, the factors affecting neural activity mainly stem from the stress itself, thereby attenuating the impact of trait-related factors.

4.7. *Limitations*

Finally, despite its strength, this study has several limitations. First, the present study was confined to female participants. While this study provides a preliminary neuroscience explanation for the "tend and befriend" pattern, future studies can investigate gender differences in neural activity induced by stress when facing unfair situations. Second, the processing of unfair situations in the UG involved subcortical regions such as the bilateral anterior insula (AI) and the right amygdala (Bellucci et al., 2018; Gabay et al., 2014; Ouyang et al., 2020; Pan et al., 2022), which cannot be detected using fNIRS due to its insufficient probing depth. Finally, while we collected subjective and physiological stress indicators, we encountered an error during the testing process that rendered our collected saliva samples unusable for cortisol analysis. Consequently, we were unable to report the cortisol-related results. Future studies could delve into the potential role of cortisol in the process of stress affecting female's unfairness decision-making.

5. Conclusion

In summary, this study illuminated the behavioral and neural mechanisms of unfairness decision-making in young females as responders under acute psychosocial stress, and explored the modulating role of coping styles. Acute psychosocial stress leads to lower adaptability to the social fairness norms, and triggers more random decision-making responses. A higher level of negative coping is associated with more deterministic decision-making under stress. The enhanced activation of rTPJ in the unfair condition indicates more involvement of the mentalization, which provides evidences for the “tend and befriend” pattern for females under stress from the perspective of cognitive neuroscience. At the same time, the decrease of lMTG activation may indicate the inhibition of moral processing by stress. These results extend the research on the relationship between stress and unfairness decision-making, and provide a basis for further research on its neurocomputational mechanism.

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CRediT authorship contribution statement

Guangya Wang: Data curation, Formal analysis, Software, Visualization, Writing – original draft, Writing – review & editing. **Jun Tang:** Investigation, Methodology. **Zhouqian Yin:** Software. **Siyu Yu:** Investigation, Methodology. **Xindi Shi:** Writing – original draft. **Xiurong Hao:** Writing – original draft. **Zhudele Zhao:** Writing – original draft. **Yafeng Pan:** Formal analysis, Software, Supervision, Writing – original draft, Writing – review & editing. **Shijia Li:** Conceptualization, Funding acquisition, Methodology, Resources, Software, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

None.

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