Acute stress impairs target enhancement but not disrtractor suppression in attention selection: Evidence from the N2pc and Pd

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Abstract: Acute stress has a profound effect on attention selection, however, it remains unclear how acute stress affects target enhancement and distractor suppression in attention selection. The current study aimed to investigated the acute stress effect on target enhancement and distractor suppression in a visual search task by using ERP. The stress response was successfully induced as indexed by the activation of HPA and the subjective affect rating. Crucially, acute stress group showed significant smaller N2pc than the control group in the high-salience distractor condition, no significant differences of Pd was observed, which indicated that actue stress disrupts the target enhancement rather than the distractor suppression in attention selection. The detrimental effects might attribute to the impairing function of prefrontal cortex. The current study provide clear evidences of the impairment of target enhancement under acute stress, and reveal the cognitive mechanism of acute stress effects on attention selection.

Keywords: acute stress, attention selection, target enhancement, distractor suppression, N2pc

Statement of Relevance

In ever-changing environment, we have developed the selective attention to focus on what is important (target enhancement) while blocking out the rest (distractor suppression). Acute stress is ubiquitous in modern day-to-day life and previous studies have found that it profoundly impacts attention selection. However, how acute stress affects target enhancement and distractor suppression in selective attention is unknown. Here, participants experience stress or control situation and then performed a visual search task isolating target enhancement and distractor suppression. Combining behavioral and ERP results, we found that stressful participants showed smaller N2pc than non-stressful participants in the target enhancement condition when the distractor salience was high, whereas no significant difference was observed for the Pd in the distractor suppression condition. These findings reveal the detrimental effect of acute stress on selective attention attribute to the impairment of target enhancement rather than distractor suppression, and highlight the importance of distractor salience.

1. Introduction

Acute stress has a profound impact on attention processing because of the activation of the hypothalamus-pituitaryadrenal (HPA) axis and sympathetic nervous system (SNS) (Arnsten, 2009; Luo et al., 2020; Plessow et al., 2011; Sänger et al., 2014). Recent models of visual attention selection implement target enhancement (or target facilitation, directly boosting relevant information) and distractor suppression (suppressing irrelevant information) as independent processes that resolve the competition of simultaneously presented stimuli for attentional resources (Liesefeld & Müller, 2019; Wyble et al., 2020). However, it remains unclear how acute stress affects the target enhancement and distractor suppression in attention selection.

Acute stress is a physiological and psychological reactions when the environmental demand exceeds the natural regulatory capacity of an organism, in particular situations that include unpredictability and uncontrollability(Koolhaas et al., 2011). Acute stress activates the sympathetic nervous system (SNS) and the hypothalamus-pituitaryadrenal axis (HPA), releasing glucocorticoids and catecholamines (Ulrich-Lai & Herman, 2009) which has profound impacts on the brain regions (e.g., prefrontal cortex, amygdala, hippocampus) related to attention (Arnsten, 2009; Liston et al., 2009). For example, Liston et. al. (2009) found that psychosocial stress selectively impaired attentional control and disrupted functional connectivity within a frontoparietal network that mediates attention shifts.

Attention selection refers to the neural filtering processes of prioritizing relevant objects over irrelevant distractions, which has been shown to invoke a combination of target enhancement and distractor suppression. The relevant features can be enhanced to facilitate target processing(Desimone & Duncan, 1995; Wolfe, 2001) while irrelevant features can be suppressed below baseline to reduce distraction(Chang & Egeth, 2019; Feldmann-Wüstefeld et al., 2019, 2021; Gaspelin et al., 2015). Those attention selection processes have been shown originated from prefrontal, posterior parietal and visual cortex regions (T. Z. Luo & Maunsell, 2019; Xie et al., 2020, 2022; Rubia et al., 2019; Gilbert & Li, 2013; Semedo et al., 2022; Hopf et al., 2000; Luck et al., 1997; Ghosh & Maunsell, 2022; Zhou et al., 2022; Park & Serences, 2022; Adam & Serences, 2021; Giesbrecht et al., 2003). For example, Giesbrecht et al. (2003) found that the frontal–parietal network was more activated in response to target-related cues, suggesting that subregions of the frontal–parietal network are highly specific for controlling spatial selective attention. Furthermore, one of the

important factors affecting attention selection is the salience of distractor. Previous studies have shown that salient stimuli can capture attention in a bottom-up manner(Gaspar & McDonald, 2014; Gaspelin & Luck, 2018, 2019; Sawaki et al., 2012; Sawaki & Luck, 2010), if limited attentional resources are focused on a high salient distracting stimulus, which results in unavailability of additional resources to direct toward the current target.

The acute stress has been shown to affect sub-processes of attention selection (Brüne et al., 2013; Kan et al., 2019, 2021; Macatee et al., 2017), for example, the distractor suppression(Hoskin et al., 2014; Sato et al., 2012; Tiferet-Dweck et al., 2016). Previous studies found that stress consumes attentional resources and reduce the ability to filter distractions, thereby increasing the interference of irrelevant information and thus damaging attention selection(Braunstein-bercovitz, 2003; Henckens et al., 2012; Olver et al., 2015). For example, Xu et. al.(2017) asked participants to performed a visual search task under social stress (social exclusion) , they found that social stress impaired distractor suppression, reflected as smaller distractor-positivity (Pd) amplitudes for the exclusion group compared to the inclusion group, suggests that the stressful participants are more susceptible to the interference of distractor stimuli (Xu et al., 2017). However, Wirz and Schwabe (2020) found that acute stress facilitated attentional disengagement toward negative facial expression not related to the task goal, which might indicate that the distractor suppression was facilitated(Wirz & Schwabe, 2020). Though previous studies provide some indirect evidence about the influence of acute stress on attention selection, to our best knowledge, no study was directly investigated the acute stress effects on both the target enhancement and distractor suppression of attention selection for neutral stimuli. Furthermore, researchers have yet to consider the salience of distractors that might moderate the acute stress effect on selective attention. In a word, the current study investigates how acute stress affect target enhancement and distractor suppression under differential distractor salience. The current study will reveal the cognitive mechanism of acute stress effect on attention selection.

To this end, participants were required to perform a visual search task measuring target enhancement and distractor suppression while the EEG was recorded. In the visual search task, the position of target and distractor was manipulated to isolate target enhancement and distractor suppression(Gaspar et al., 2016; Gaspar & McDonald, 2014). In an ERP study, target enhancement is related to N2pc component

reflecting fast attention reallocation towards task-relevant information(Eimer, 1996; Luck & Hillyard, 1994). Distractor suppression is related to Pd component, typically elicited by irrelevant but salient and potentially distracting stimuli (Burra & Kerzel, 2014; Feldmann-Wüstefeld & Schubö, 2013; Gaspelin & Luck, 2018; Hickey et al., 2009; Sawaki & Luck, 2013). Based on those findings of acute stress on frontoparietal network, and the social stress effect on distractor suppression (Xu et al., 2017), we hypothesized that acute stress would impair both target enhancement and distractor suppression for neutral stimuli, which would manifest as a smaller N2pc and Pd in the stressful participants than in the non-stressful participants.

2.Method

2.1 Participants

Participants were recruited through advertisements posted on university campuses. To minimize the potential effect of sex hormones on cortisol measurement, all women participants were tested during the luteal phase of the menstrual cycle(Duchesne & Pruessner, 2013). Participants were screened before their participation and reported (a) no history of a diagnosed psychiatric disorder, habitual smoking, faint or epileptic seizure; (b) no current endocrine, autoimmune, cardiovascular, respiratory, or dermatological disorders; (c) subjectively not oversensitive to cutaneous sensation (to minimize negative reaction to cold water stress); (d) no medication use that could affect cortisol response (e.g., β-blockers); and (e) not suffering from severe sleep disturbance or fatigue. Participants were asked to refrain from vigorous exercise, alcohol, and caffeine for three hours and to abstain from eating for one hour before testing. All participants were native Chinese-language speakers.

To determine sample size, a priori power analysis(Test family: F tests, Statistical test: ANOVA: Fixed effects, special main effects and interactions, Numerator df = 2, Number of groups = 4,) was conducted based on a medium effect size (Effect size f =0.35), which indicated that 82 participants were required to detect the hypothesized effect at α = 0.05 and β = 0.80(Gaspar et al., 2016; Gaspar & McDonald, 2018; Xu et al., 2017). A total of 87 participants were recruited. Seven participants were excluded from the final analysis because more than 30 % of trials were rejected in the ERP data. The final sample consisted of 80 right-handed healthy participants (Age: 20.95±1.96 years; BMI: 20.97±3.09; 45 women, 35 men).

The study protocol was approved by the local ethics committee and conducted in

accordance with the Declaration of Helsinki. Participants given written informed consent before the experiment. They received ￥30 per hour as compensation for participating.

2.2 Experimental design

A full factorial 2×2 between-subject design was used, with stress (stress, control) and distractor salience (high, low) as between-subject factors manipulated in the experiment. Participants were randomly assign to the Stress (n = 41, women is 23) and Control (No stress, n = 39, womenis 22) groups. After completing the Maastricht Acute Stress Test (MAST) procedure, participants were randomly allocated to either the high-salience distractor (Stress: n =20,12 female; Control: n =17, 11 female) or low-salience distractor condition (Stress: n =21, 11 female; Control: n =22, 11 female). No significant difference was observed at trait anxiety scores across four groups, ps>0.05.

2.3 General Procedure

The experiment was conducted between 13:30 and 18:30. After arrival, the participants were taken to the behavioral laboratory by one experimenter dressed in white laboratory coats acting in a reserved manner (stress group) or friendly experimenter wearing normal casual clothing (control group). Next, participants were required to rest for 10 minutes, then completed two questionnaires including the Positive and Negative Affect Schedule (PANAS)(Watson et al., 1988) and State-Trait Anxiety Inventory(STAI-T, STAI-S;(Spielberger et al., 1970)) and the first saliva sample was collected by using the Salivette collection tubes (Sarstedt, Germany). Participants were asked to chewed the cotton gently in their mouths to collect enough saliva. After that, they were sat on a comfortable chair for the preparation of the EEG equipment in about 30 minutes, followed by the second questionnaires and saliva sample collection. And then, the MAST (a stress or control task) was manipulated in 15 minutes followed by the third questionnaires and saliva sample collection.

Next, participants were performed a visual search task while the EEG was recording. The task was continued about 60 minutes, with four blocks. There was a 5 minutes break between the second and third bolck, during which the fourth questionnaires and saliva sample were collected. The firth questionnaires and saliva sample were collected immediately after the EEG recording, meanwhile, participants were additionally required to fill in the Beck Depression Inventory (BDI) to assess

their current mental health.

2.4 Stress induction

The Maastricht Acute Stress Test (MAST) was used to induce stress or control (non-stress) condition. The MAST is an established method to induce stress by asking participants to immerse one hands into ice water and perform mental arithmetic in a setting of unpredictability, uncontrollable, and social evaluation (i.e., negative feedback)(Smeets et al., 2012) . Participants started with a 5-minutes preparation phase followed by a 10-minutes acute stress phase. In the preparation phase, participants were seated in front of a computer and were instructed about the upcoming task. In the stress group, participants were explicitly informed that their facial expressions are recorded and that they need to immerse their hand in ice-cold water (2.89 ± 0.32°C, range from 1.9 to 3.4 °C) for a random time across 60 to 90 seconds multiple times. In between hand immersion trials participants had to count backwards from 2043 in steps of 17 as fast and accurate as possible. When they made a mistake, they received negative feedback from the experimenter and had to start over at 2043. They were told to continue with the mental arithmetic until the computer would signal the start of the next hand immersion trial, which would take at least 45 s. For the exact sequence and duration of hand immersion trials (HIT) and mental arithmetic (MA) backward counting intervals was: HIT-90 s, MA-45 s, HIT-60 s, MA-60 s, HIT-60 s, MA-90 s, HIT-90s, MA-45s, HIT-60 s. Participants in the control condition immersed their hand in body temperature (i.e. 37.58 ± 0.51°C, range from 36.5 to 38.6 °C) water and counted backwards from 2000 in steps of 10 at a speed of their own choosing, no feedback was given and no facial expressions was recorded.

The saliva samples for cortisol and subjective affect rating were collected at five-time points throughout the experiment: After rest for 10 min (T1, −55 min), immediately after preparation for the EEG measurement (T2, −20 min), immediately after the MAST/control-MAST (T3, 0 min), after half of the visual search task (T4, 35 min), and after the visual search task is completed (T5, 70 min). The salivary cortisol samples were frozen at −20 °C within 1 hour of collection until assay. Cortisol was assayed by centrifuged at 3,000 rpm for 10 minutes to remove particulate matter. Salivary cortisol concentrations were determined by electrochemiluminescence immunoassay (Cobas e 601, Roche Diagnostics, Numbrecht, Germany). The lower limit of sensitivity was 1.5 nmol/L.

2.5 Visual Search Task

In the visual search task, stimuli were presented using PsychToolbox (http://psychtoolbox.org/) on a 24.5-inch, 144-Hz AOC-AG251FX LCD monitor with a black (RGB: 0, 0, 0) background that was placed at a viewing distance of 57 cm.

As shown in Fig. 1, each visual search display contained 10 unfilled circles presented equidistant (9.2°) from a central fixation point. Each circle was 3.4° in diameter with a 0.3° thick outline. There were two trials type, in the distractor-present tirals, eight of the circles were uniformly colored non-targets, one was a target color singleton, another circle was a distractor color singleton. In the distractor-absent trials, nine of the circles were uniformly colored non-targets, one was a target color singleton.The target was yellow (RGB: 255,255,0), the nontarget circle was either green (RGB: 0,255,0) or orange(RGB: 255,182,75) and the distractor was either red (RGB: 255,0,0) or blue (RGB: 0,0,255). A randomly oriented vertical or horizontal gray line (RGB:100,100,100) was contained within each of the circles.

In each trial, a search display was presented after an 800~1,200-ms fixation period, during which only a central fixation point was visible. Next, the search display was presented, participants were instructed to maintain fixation on the central point and to identify the orientation(vertical or horizontal) of the gray line inside the target singleton by pressing one of two response buttons as quickly and accurately as possible within 2,000-ms. Response buttons was balanced between subject. The next trial began after a response or no response within 2,000-ms (see Fig. 1a).

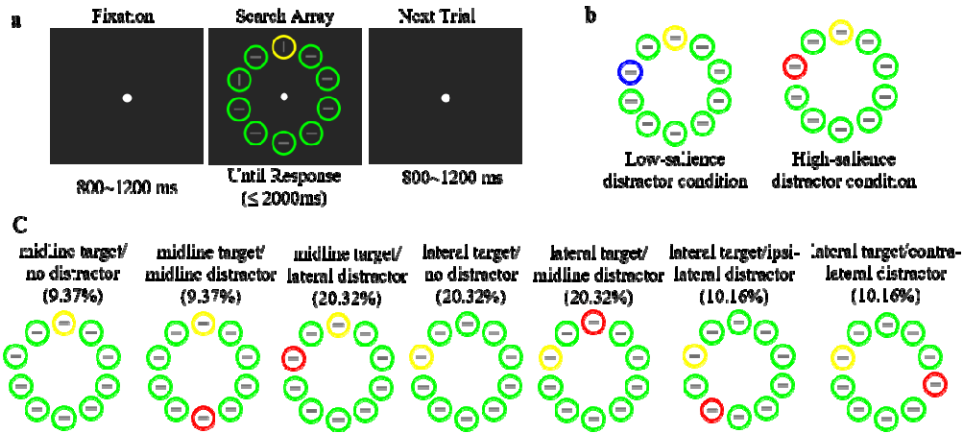

Fig.1. (a) Example trial from the visual search task,(b) example of low-salience distractor and high-salience distractor condition,(c) examples of the seven display configurations used in the present study. In each trial, Participants were instructed identify the orientation of the gray line

inside the yellow target singleton.

The experiment consists of 4 blocks, for a total of 1,260 trials per participant. Each experimental block comprised 315 trials, with a 5-s break after every 45 trials. At the end of the block, participants were given a minimum 5-s rest period and could begin the subsequent block when ready. To note, the salience of distractor was manipulated as a between subject factor to avoid excessive fatigue interfering with the experiment. At least 36 practice trials were given to each participant before the start of the experiment. Feedback about compliance with instructions was provided between blocks.

The search displays contained a target was the only singleton in the array on 29.68 % of trials (distractor-absent trials). On the remaining 70.32% of trials, the target singleton and one distractor singleton (distractor-present trials) presented in the search display. In the distractor-present trials, the distractor salience was defined in terms of the local contrast between the nontargets color and distractor or target color singleton(Gaspar et al., 2016; Gaspar & McDonald, 2014).the high salience distractor condition that is the distance in chromaticity space between the distractor singleton and the nontargets(i.e., red distractor vs. green nontargets) was greater than the distance between the target singleton color and the nontargets color(i.e., yellow target v.s. green nontargets), and the another is low salience distractor condition, that is the distance in chromaticity space between the distractor singleton and the nontargets(i.e., blue distractor vs. green nontargets) was close the distance between the target singleton color and the nontargets color(i.e., yellow target v.s. green nontargets). Participants need to completed distractor absent trials and distractor present trials.

Target and distractor locations were varied to produce the following display configurations (see Fig. 1b) (Gaspar et al., 2016; Gaspar & McDonald, 2014, 2018): lateral target/no distractor (20.32% , 256/1260); midline target/no distractor (9.37% , 118/1260); lateral target/midline distractor (20.32% , 256/1260); lateral target/ipsilateral distractor (10.16% , 128/1260); lateral target/contralateral distractor (10.16%, 128/1260); midline target/lateral distractor (20.32% , 256/1260); midline target/midline distractor (9.37%, 118/1260). These display configurations were randomly intermixed across trials.

2.6 Electrophysiological Recording and preprocessing

The EEG was recorded using an electrode cap (Neuroscan, Herndon, VA, USA) with 64 Ag/AgCl scalp sites according to the International 10/20 system. The ground

electrode was placed between FPz and Fz. The online reference electrode was located between Cz and CPz. To detect eye movements and blinks, the vertical electrooculograms (EOGs) were recorded supra-orbitally and infra-orbitally relative to the left eye; and the horizontal EOG was recorded as the difference in activity of the right vs. the left orbital rim. The impedance of all electrodes were kept below 5 KΩ. All signals were recorded in DC mode using a Neuroscan SynAmps2 amplifier and Curry recording software. The EEG was amplified with a low-pass filter at 100 Hz with no high-pass filters applied and then digitized with a 1000-Hz sampling rate.

All analysis after data acquisition were conducted using EEGLAB Toolbox (Delorme & Makeig, 2004) and ERPLAB Toolbox (Lopez-Calderon & Luck, 2014). The EEG signals were referenced to the average of the left and right mastoids, and the four EOG signals were referenced using bipolar vertical and horizontal EOG derivations. All the signals were bandpass filtered (noncausal Butterworth impulse response function, half-amplitude cutoffs at 0.1 and 30 Hz, 12 dB/oct roll-off) and resampled at 500 Hz. Portions of EEG containing large muscle artifacts or extreme voltage offsets (identified by visual inspection) were removed. Independent component analysis (ICA) was then performed on the scalp EEG for each subject to identify and remove components that were associated with blinks (Jung et al., 2000) and eye movements (Drisdelle et al., 2017). The ICA-corrected EEG data were segmented for each trial from −100 to +500 ms relative to the onset of the search array. The baseline correction was based on the pre-stimulus time interval (−100 to 0 ms). Trials with incorrect responses and blinks or saccades between 0 ms and 400 ms were excluded from analysis.

Blinks were defined by using Moving Window Peak-to-Peak Threshold (Test period:0~400 ms; Moving Windows Full Width: 200 ms; Window step:100 ms, Voltage Threshold: 80) detection an absolute amplitude of the vertical EOG exceeding 80 μV. Saccades were defined by using Step-like artifacts(Test period: 0~400 ms; Moving Windows Full Width:200 ms; Window step: 50 ms; Voltage Threshold: 40 μV) detection an amplitude of the horizontal EOG of difference more than 40 μV. Additionally, segments were excluded from further analysis on an individual-channel basis when the absolute voltage exceeded 100 μV. Data from 7 participants for whom more than 30 % of trials were rejected because of artifacts or incorrect responses or too quickly (RT < 300 ms), or too slowly (RT > 1,500 ms) therefore excluded from the analyses.

2.7 Data Analysis

Data were analyzed with JASP (2022, version 0.16.3.0). JASP is a freely accessible, open-source package for statistical analyses. We report appropriate corrections in case of analysis-specific violations of assumptions.

Data and analyses script have been made publicly available via the Science Data Bank（ScienceDB）and can be accessed at: http://cstr.cn/31253.11.sciencedb.02116.

2.7.1 Stress response

Two measures of cortisol output were quantified. First, the area under the cortisol curve with respect to the ground (AUCg) was calculated as the total cortisol concentration over the duration of the experiment. Second, the cortisol concentration specifically related to the increase due to the stress induction (AUCi) was calculated by subtracting the baseline from the AUCg. All calculations followed the trapezoid integration method as recommended by pevious study (Pruessner et al., 2003).

To test for successful stress induction, three separates repeated-measures analysis of variance (ANOVA) were performed on salivary cortisol and subjective affect rating scores, with group(stress, control) as between subject factor and time (T1, T2, T3, T4, T5) as within subject factor. ANOVAs with more than two levels of a factor used the Greenhouse–Geisser correction for nonsphericity, and only the corrected *p* values are reported.

2.7.2 Behavioral Performance

Trials on which the participant responded incorrectly, too quickly (RT < 300 ms), or too slowly (RT > 1,500 ms) were excluded from all behavioral and ERP analyses (with the exception of accuracy analyses, which included incorrect trials). Trials contaminated by blinks or eye movements were also rejected from the behavioral analysis. After artifact rejection, the mean RTs were averaged across participants separately for each display configurations. Mean RTs was compared between the group and distractor salience using a 2(group: stress, control) ×2 (distractor salience: high, low) analysis of variance (ANOVA) on mean RT in lateral target/middle distractor; lateral target/contralateral distractor and midline target/ lateral distractor condition.

2.7.3 ERP amplitude

According to the aim of the present study, only the distractor-present trails were analyzed. The lateralized ERP waveforms were created for each condition for the

following display configurations: lateral target/midline distractor; lateral target/contralateral distractor and midline target/ lateral distractor. ERPs of these search displays were created by collapsing across left and right visual hemifields and left and right electrodes (PO7 and PO8) to produce waveforms recorded ipsilateral and contralateral to target or distractor stimuli. Lateralized ERP difference waveforms were then derived by subtracting the ipsilateral waveform from the corresponding contralateral waveform. All ERP statistics were computed using contralateral minus ipsilateral difference values (Hickey et al., 2009; Woodman & Luck, 2003).

Pd and N2pc magnitudes were measured using a mean-amplitude approach. By convention, we selected electrodes and time windows based on existing studies that measured mean amplitudes. Both components were measured at lateral occipital electrodes PO7 and PO8, as in most previous paper(Gaspar et al., 2016; Gaspar & McDonald, 2014, 2018; Gaspelin & Luck, 2018; Xu et al., 2017). In lateral target, middle distractor and lateral target, contralateral distractor trial, the N2pc window was in the time window of 260~310 ms, whereas in midline target, lateral distractor trial, the Pd window was in the time window of 110~160 ms (Early Pd) and 280~330 ms (Late Pd). N2pc and Pd mean-amplitude was compared between the group and distractor salience by using a 2(group: stress, control) ×2 (distractor salience: high, low) analysis of variance (ANOVA), the corrected *p* values are reported. In order to further explore the effects of acute stress on target enhancement and distractor suppression, the correlation between AUCg, AUCi of cortisol and Mean Amplitute of Pd, N2pc was analyzed.

To minimize biases from the choice of measurement windows, we also used a signed-area approach from Sawaki et al. (2012): N2pc amplitude was quantified as the negative area between 200~350 ms in the lateral target/middle distractor and lateral target/contralateral distractor tiral; Pd amplitude was quantified as the positive area between 100~200 ms (Early Pd) and 260~360 ms (Late Pd), in the midline target/ lateral distractor trial. Note that in N2pc component, we measured the negative area over a broad time window, ignoring any periods of positive voltage. In Pd component, we measured the positive area over a broad time window, ignoring any periods of negative voltage. Because signed area is naturally biased away from zero, we could not use traditional statistical approaches to determine whether the area was greater than expected by chance (such as a one-sample *t* test comparing the mean to zero). We therefore used the nonparametric permutation approach (Sawaki et al., 2012), in

which random permutations of the data are used to estimate the distribution of signed area values that would be expected by noise alone. We simulated a lack of difference between the contralateral and ipsilateral voltages by randomizing the labels (event codes) indicating which side contained the singleton in the single-trial EEG data. If there is no real difference between the contralateral and ipsilateral voltages, then it should not matter which side is labeled as containing the singleton. Consequently, we can estimate the positive area that would occur by chance in the absence of a true difference by randomizing the labels, averaging the data, and computing the negative/positive area. If we did this once, the randomization might not produce a representative value, so this procedure is repeated many times to obtain a probability distribution, which reflects the likelihood of obtaining a given negative/positive area if the null hypothesis is true (i.e., if there is no true difference between the contralateral and ipsilateral sites).

Because this is a nonparametric test, it can be performed by measuring the negative/positive area of the N2pc/Pd difference waveform from grand averages across participants (as in the well-validated jack-knife technique, which improves statistical power without inflating Type I error rates;(Miller et al., 1998). We performed 1000 iterations in which we permuted the data and measured the positive area to provide a robust estimate of the distribution of negative/positive area values that would be expected if there was no reliable lateralized activity. We compared the observed positive area measured from the actual grand average ERP waveform to these randomly permuted values. The *p* value can then be estimated with the following equation: p = (number of permuted negative/positive areas $\geq$ observed negative/positive area) /total number of simulated permutations. For example, imagine that our null distribution of 1000 values contains 5 values that were greater than or equal to the observed positive area. The *p* value would be 5/1000 or .005. The observed negative/positive (indicated by red lines in the supplementary materials) were both statistically significant (in the top 5% of values that would be expected from chance: indicated by yellow areas in the supplementary materials). Thus, the probability that the observed responses were due to random variation was very low, and we can be confident that these effects were real physiological responses.

3.Results

3.1 Stress measurement

Salivary cortisol: As shown in Fig. 2a, the results showed a main effect of group[$F(1,78) = 5.74$, $p = 0.02$, $\eta^2p = 0.07$], and a main effect of time[$F(4,312) = 4.21$, $p = 0.01$, $\eta^2p = 0.05$]. Crucially, there was a significant interaction[$F(4,312) = 12.27$, $p < 0.01$, $\eta^2p = 0.14$] between group and time. Subsequent comparisons showed that the stress group had significantly higher cortisol levels than the control group at T3[stress: 5.83±4.50 nmol/L v.s. control: 2.46±1.48 nmol/L, $t = 4.75$, $p < 0.01$, *Cohen's d* =1.06] and T4[stress: 5.38±4.85 nmol/L v.s. control: 2.16±1.57 nmol/L, $t = 4.52$, $p < 0.01$, *Cohen's d* =1.01], no significant difference was observed between the two groups at the rest time points:T1 and T2 (*p*s > 0.05). Within the stress group, a significant higher crotisol level was observed at T3 (5.83±4.50 nmol/L) and T4(5.38±4.85 nmol/L) comparing to T2(2.94±2.43 nmol/L) and T1 (3.59±3.22 nmol/L)[T3 v.s. T1, $t = -4.30$, $p < 0.01$, *Cohen's d* =-0.71; T3 v.s. T2, $t = -5.56$, $p < 0.01$, *Cohen's d* =-0.91; T4 v.s. T1, $t = -3.42$, $p = 0.02$, *Cohen's d* =-0.56; T4 v.s. T2, $t = -4.68$, $p < 0.01$, *Cohen's d* =-0.77], indicated that the stress level was significantly increased in the stress group.

State Anxiety: The state anxiety results are illustrated in Fig. 2b. The ANOVA revealed no significant main effect of group[$F(1,78) = 3.05$, $p = 0.09$], but a significant main effect of time[$F(4,312) = 30.59$, $p < 0.01$, $\eta^2p = 0.28$], the interaction of group by time was significant[$F(4,312) = 19.87$, $p < 0.01$, $\eta^2p = 0.20$], the post-hoc analysis showed that the stress group had significantly higher state anxiety scores than the control group at T3[stress: 46.51±8.39 v.s. control: 35.56±7.16, $t = 6.33$, $p < 0.01$, *Cohen's d =1.42*]. No significant difference between the two groups was observed at T1 and T2 (*ps* > 0.05). Within the stress group, a significant higher state anxiety scores was observed at T3 (46.51±8.39) comparing to T2(36.12±8.61) and T1 (33.78±7.11) [T3 v.s. T1, $t = -12.03$, $p < 0.01$, *Cohen's d* =-1.65; T3 v.s. T2, $t = -9.81$, $p < 0.01$, *Cohen's d* =-1.34], indicated that the state anxiety scores was significantly increased in the stress group.

Negative Emotion: The negative emotion results are illustrated in Fig. 2d. The ANOVA revealed significant main effect of group[$F(1,78) = 6.02$, $p = 0.02$, $\eta^2p = 0.07$], and significant main effect of time[$F(4,312) = 18.88$, $p < 0.01$, $\eta^2p = 0.20$], the

interaction of group by time was significant[$F(4,312) = 22.88$, $p < 0.01$, $\eta^2p = 0.23$], the post-hoc analysis showed that the stress group had significantly higher negative emotion scores than the control group at T3[stress: 21.12±3.61 v.s. control: 14.26±3.63, $t = 7.44$, $p < 0.01$, *Cohen's d* =1.66]. No significant difference between the two groups was observed at T1 and T2 (*ps* > 0.05). Within the stress group, a significant higher negative emotion scores was observed at T3 (21.11±3.61) comparing to T2(15.98±4.75) and T1 (16.68±3.99) [T3 v.s. T1, $t = -7.55$, $p < 0.01$, *Cohen's d* =-1.08; T3 v.s. T2, $t = -8.75$, $p < 0.01$, *Cohen's d* =-1.25], indicated that the negative emotion scores was significantly increased in the stress group.

Positive Emotion: As shown in Fig. 2c, the results showed no significant main effect of group[$F(1,78) = 0.73$, $p = 0.40$], and a main effect of time[$F(4,312) = 34.96$, $p < 0.01$, $\eta^2p = 0.31$]. Crucially, there was significant interaction[$F(4,312) = 4.62$, $p = 0.004$, $\eta^2p = 0.06$] between group and time. However, subsequent comparisons showed that no differences of positive emotion scores were observed between stress and control group at T3[stress: 27.85±6.79 v.s. control: 31.77±7.18, $t = -2.26$, $p = 0.08$]. Within the stress group, a significant lower positive emotion scores was observed at T3 (27.85±6.79) comparing to T2(31.71±8.61) and T1 (32.95±7.41) [T3 v.s. T1, $t = 6.87$, $p < 0.01$, *Cohen's d* =0.66; T3 v.s. T2, $t = 5.20$, $p < 0.01$, *Cohen's d* =0.50], indicated that the positive emotion scores was significantly reduced in stress group.

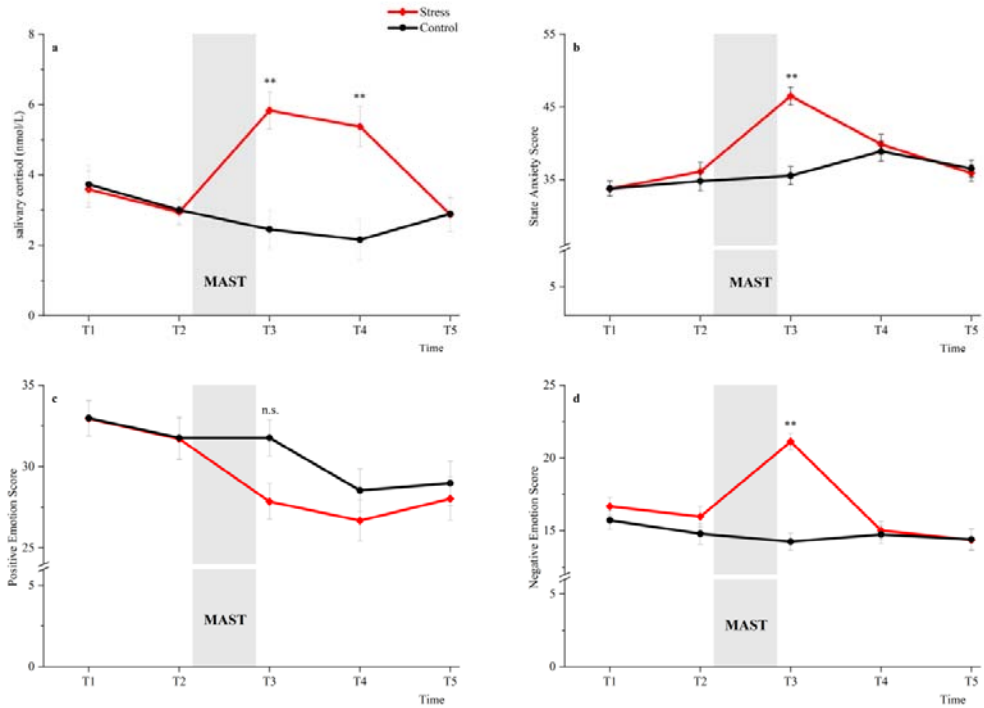

Fig. 2. Means and SEs of salivary cortisol levels(a), state anxiety score(b), positive emotion scores (c), Fig. 2c shows that and negative emotion score (d) in the stress group and control group during the experiment. Fig. 2a shows that the stress group had significantly higher cortisol levels than the control group at T3 and T4, Fig. 2b shows that the stress group had significantly higher state anxiety scores than the control group at T3, Fig. 2d shows that the stress group had significantly higher negative emotions scores than the control group at T3,**p*<0.05, ***p*<0.01.

3.2 Behavioral Results

The results of midline target/lateral distractor condition were illustrated in the Fig. 3a.The ANOVA revealed a significant main effect of distractor salience[$F(1,76) = 6.02$, $p = 0.03$, $\eta^2 p = 0.06$], subsequent comparisons showed that the high-salience distractor condition had significantly longer response time than the low-salience distractor condition[high-salience distractor: 823.99±87.53 ms v.s. low-salience distractor: 782.36±877.94 ms, $t = -2.20$, $p = 0.03$, *Cohen's d* = -0.49]. Neither significant main effect of group nor interaction of group by distractor salience were observed，*ps* > 0.05. The ANOVAs revealed neither significant main effect of group, distractor salience, nor interaction of group by distractor salience for the lateral target/midline distractor condition (*ps* > 0.05) and for the lateral target/contralateral distractor condition (*ps* > 0.05).

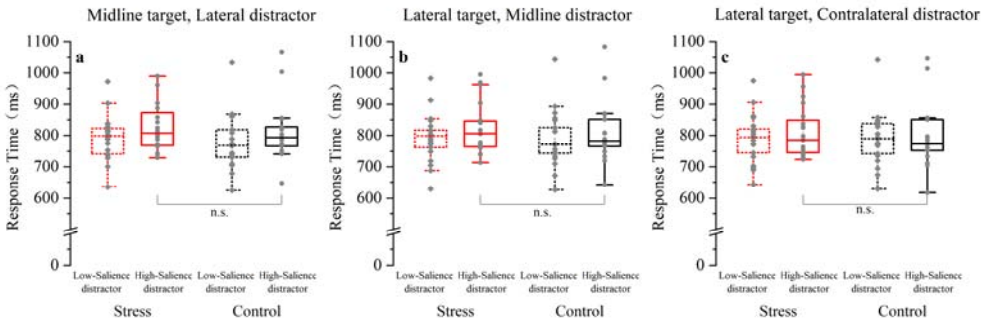

Fig. 3. Behavioral results from visual search task. Mean RT on the visual search task by middle target,later distractor(a), lateral target,middle distractor(b) and later target, contralateral distractor(c).

3.3 Electrophysiological Results: ERP Components

Midline target, lateral distractor

Early Pd: The results of early Pd (110~160 ms) are illustrated in the Fig. 4b, there was a significant main effect of distractor salience[$F(1,76) = 4.79$, $p = 0.03$, $\eta^2p = 0.06$], a larger early Pd amplitude in the high-salience distractor condition than in the low-salience distractor condition[0.48±0.41 μV v.s. 0.29±0.38 μV, $t = -2.19$,$p = 0.03$, *Cohen's d* = -0.49]. No other significant main effect or interaction of group by distractor salience was observed , *ps* > 0.05.

The non-parameters test showed that there were early Pd for all conditions in the time window of 100~200 ms, $ps<0.05$ (see supplementary materials S.Fig. 1). However, there was no significant differences across conditions, $ps>0.05$ (see supplementary materials S.Fig. 2).

Late Pd: As shown in the Fig. 4d, the results of late Pd (280~330ms) showed neither significant main effect of group, distractor salience, nor interaction of group by distractor salience, *ps* > 0.05.

The non-parameters test showed that there were late Pd for all conditions in the time window of 260~360ms, $ps<0.05$ (see supplementary materials S.Fig. 3). However, there was no significant differences across conditions, $ps>0.05$ (see supplementary materials S.Fig.4).

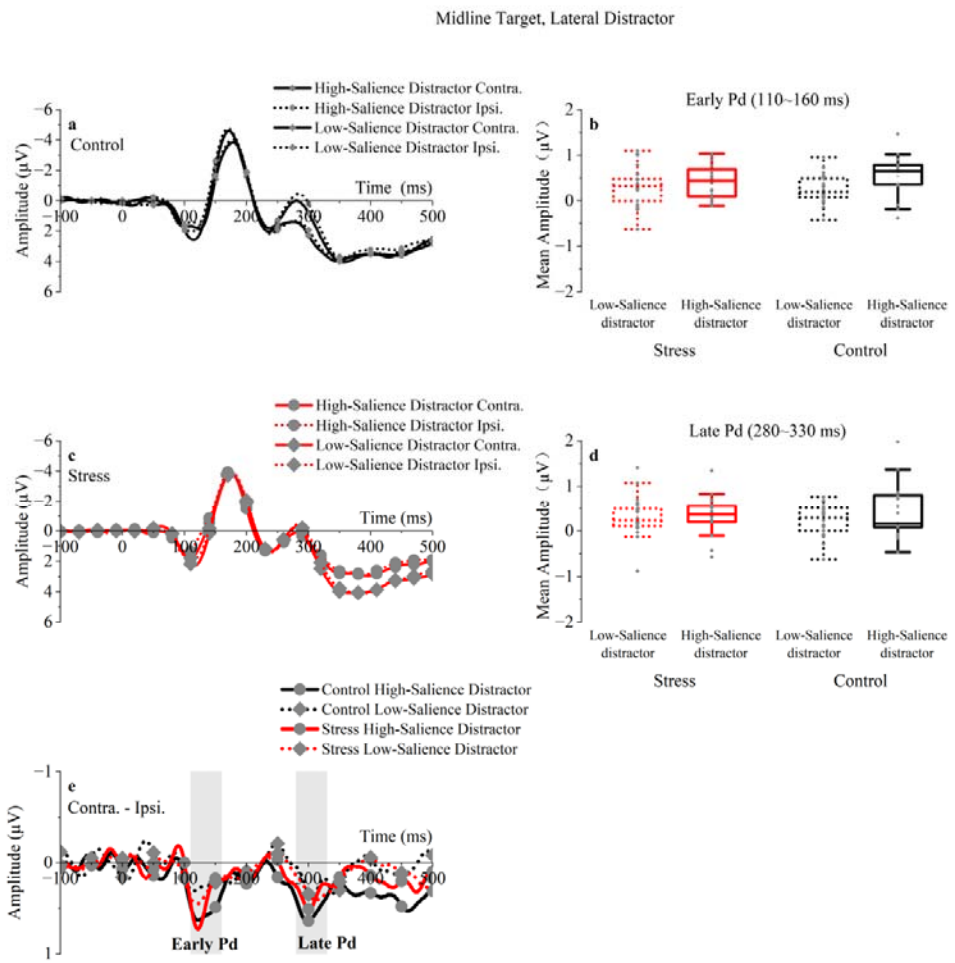

Fig. 4. Electrophysiological results from midline target, lateral distractor trials. There was no significant differences in early Pd and late Pd across conditions between stress group and control group.

Lateral target, midline distractor

N2pc: As shown in Fig. 5b and 5d, the results of N2pc (260~310 ms) showed neither significant main effect of group nor distractor salience, *ps*>0.05. Crucially, there was a significant interaction[$F(1,76) = 5.47$, $p = 0.02$, $\eta^2p = 0.07$], between group and distractor salience. The post-hoc analysis showed that the N2pc in the stress group was significantly smaller (more positive) than in the control group at the high-salience distractor condition[stress: -1.35±0.82 μV v.s. control: -2.57±1.68 μV, $t = 2.95$, $p = 0.03$, Cohen's d = -0.49]. No significant results was observed in the low-salience condition (*p*s > 0.05).

The non-parameters test showed that there were N2pc for all conditions in the time window of 200~350 ms, *ps <0.05* (see supplementary materials S.Fig. 5). Crucially, the N2pc area was significantly larger in the control group than in the stress group at high-salience distractor condition, *p <0.05*, which was similar with the results of mean amplitude. No other significant effect was found, *ps >0.05* (see supplementary materials S.Fig. 6).

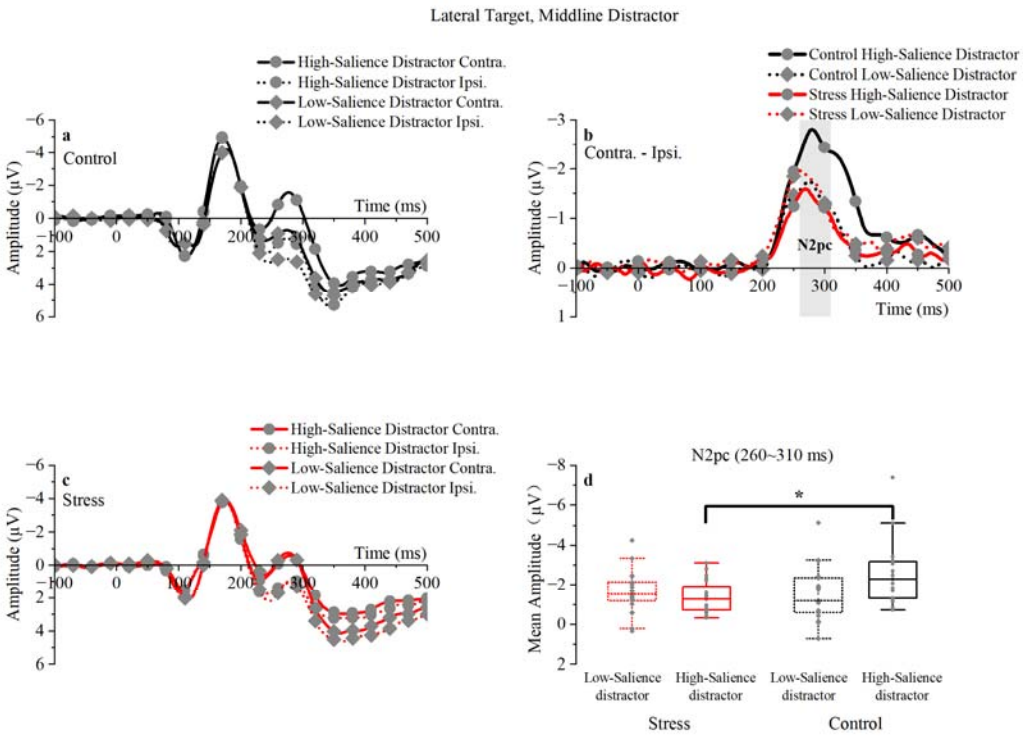

Fig. 5. Electrophysiological results from Lateral target, midline distractor trials. **p*<0.05. Fig. 5d shows that the N2pc was significantly smaller (more positive) in the stress group than in the control group at the high-salience distractor condition.

Lateral target, contralateral distractor

N2pc: As shown in Fig. 6b and 6d, the results of N2pc (260~310 ms) showed neither significant main effect of group nor distractor salience, *ps*>0.05. There was a significant interaction[$F(1,76) = 5.34$, $p = 0.024$, $\eta^2p = 0.066$] between group and distractor salience. The post-hoc analysis showed that the amplitude of N2pc was significantly smaller (more positive) in the stress group than in the control group at high-salience distractor condition[stress: -1.40±0.86 μV v.s. control: -2.50±1.59 μV, $t = 2.67$,$p = 0.056$,*Cohen's d* = 0.88]. In the control group, the amplitude of N2pc was

smaller in the low-salience condition than in the high-salience condition [-1.31±1.34 μV v.s. -2.50±1.59 μV, t = 2.97, p = 0.024, *Cohen's d* = 0.96].

The non-parameters test showed that there were N2pc area for all conditions in the time window of 200~350 ms, *ps <0.05* (see supplementary materials S.Fig. 7), the N2pc area was significantly smaller in the stress group than in the control group at high-salience distractor condition, *p <0.05*, which was similar with the results of mean amplitude. No other significant effect was found, *ps >0.05* (see supplementary materials S.Fig. 8).

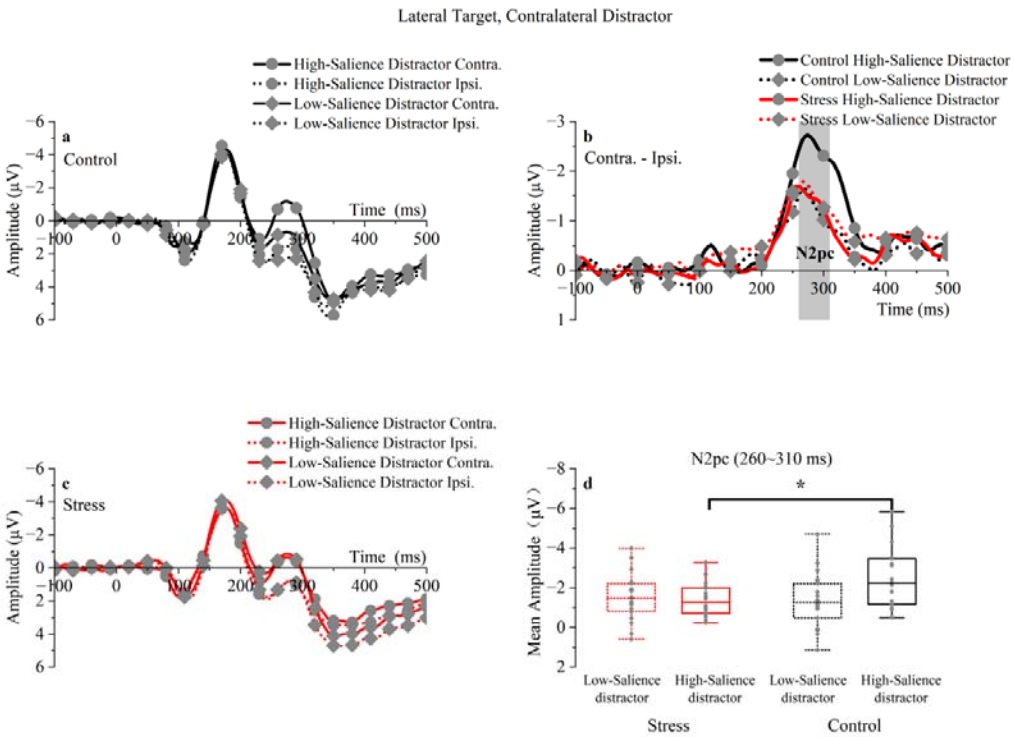

Fig. 6. Electrophysiological results from Lateral target, contralateral distractor trials, *p<0.05. Fig. 6d shows that the N2pc was significantly smaller (more positive) in the stress group than in the control group at the high-salience distractor condition

3.4 Correlational Results

The Spearman's rank order correlations revealed that AUCi of cortisol was negatively correlated with N2pc amplitude at the lateral target/midline distractor[rs = -0.21, p = 0.03] and at the lateral target/contralateral distractor condition[rs = -0.19, p = 0.04], but not correlated with early Pd [rs = -0.06, p = 0.29] and late Pd [rs = -0.04, p = 0.37] amplitude at midline target/lateral distractor. No other significant correlation was found, ps>0.05.

4. Disscussion

The current study investigated how acute stress affects target enhancement and distractor suppression in attention selection. The MAST was successfully induced stress response as indexed by the higher salivary cortisol, state anxiety, and negative emotion in the stress group than in the control group. Acute stress impairs the target enhancement rather than the distractor suppression indexed by a smaller N2pc in the stress group than in the control group under high-salience distractor condition, no significant difference was observed for the Pd. The impairment of target enhancement might due to the detrimental effect of acute stress on the prefrontal cortex (PFC). The current study provides clear evidences for how acute stress alternates attention selection, and the moderate role of distractor salience. These results reveal the cognitive mechanism of acute stress on attention selection for the first time.

Behaviorally, we found no significant effect of acute stress on the reaction times, suggesting that stressful individuals performed as well on the task as their non-stress counterparts. The result consistent with previous studies show that trait anxiety did not affect behavioral response in a visual search task (Gaspar & McDonald, 2018). It is possible that behavioral response are the output of complex multiple processes, whereas EEG measures reflect more direct processing. We found that participants respond slowly in the high-salience condition than in low-salience condition, which indicates that salience of distractor was manipulated successfully. Previous study has shown that high-salience distractor would capture attention and leading to slow response to target(Anderson et al., 2011; Gaspar et al., 2016; Gaspar & McDonald, 2014).

Crucially, we found a smaller N2pc in the stress group than in the control group under high-salience condition, whereas no difference was found for the Pd. These results suggest that acute stress impairs target enhancement rather than distractor suppression, because the N2pc is an established marker for target enhancement (Hickey et al., 2009; Woodman & Luck, 2003). This results are in line with previous study shows that sleep deprivation (a kind of stress) attenuates attentional direction/orientation processing (Song et al., 2022). Acute stress impairs target enhancement could attribute to the detrimental effect of acute stress on the PFC. Previous studies have shown that target enhancement is a PFC dependent cognitive process. For example, Ort et. al.(2019) found that the frontoparietal control network was more activated, compared only one of the targets was available, in response to selected one of two possible targets presented among distractors (Ort et al., 2019). As

is known to all, acute stress down regulate the activity of PFC and thus impairs related function (Arnsten, 2009; Larra et al., 2022; Qin et al., 2009). This point of view also supported by the correlation results revealed that the more activation of HPA the stronger detrimental effect showed.

Furthermore, we found that target enhancement was impaired only when the distractor is a salient color. This result is in line with that stress impaired selective attention under high perceptual load (Kawahara et al., 2011; Sato et al., 2012). This selectively impairment effect is highly possible due to that PFC engaged more in the high-salience condition than in the low-salience condition. The existing work indicates that the involvement of PFC in top-down attentional control was increased when task-irrelevant(e.g. salience, task-relatedness, emotionality) information can effectively compete for priority in processing(Milham et al., 2003), suggesting that the phases of target processing on high salient distractor condition are highly dependent on the PFC and thus more susceptible to stress (Hermans et al., 2014). Contrarily, less competition was involved when the distractor is not salient(Kerzel & Huynh Cong, 2022; Wolf et al., 2019). There is less PFC engaged when competition is not strong(Ligneul et al., 2016; Snyder et al., 2014), the target enhancement keeps intact under acute stress situation. However, the current study did not directly measure the brain activation, the further study should test this explanation by using fMRI.

Contrary to our expectation, we did not found significant effect of acute stress on distractor suppression. This result is contrary to the existing studies showed that social exclusion(Xu et al., 2017) and trait anxiety(Gaspar & McDonald, 2018) impair distractor suppression in a visual search task. However, the current results is consistent with our previous data showed that state anxiety has no effect on distarctor filtering in a working memory task which is closely related to attention process (Luo et al., 2021). On the one hand, the different effect of acute stress on target enhancement and distractor suppression is inline with the theory that target facilitation and distractor inhibition are controlled by distinct cognitive mechanisms(Noonan et al., 2016; Xie et al., 2020). Specially, flexible top-down mechanisms of cognitive control are specialized for target-related attention, whereas distractor suppression only emerges when the predictive information can be derived directly from experience. On the other hand, it is possible that social exclusion and trait anxiety is an emotional state which have strong effect on the visual cortex(Cacioppo et al., 2009; Pourtois et al., 2013; Pourtois & Vuilleumier, 2006; Schulz et al., 2022), whereas the acute stress

effect mainly due to the activation of HPA targeting on the prefrontal cortex, a recent meta-analysis study found that the visual cortex is unlikely to be involved in stress processing(Berretz et al., 2021). Previous studies have shown that suppression of simple perceptual distracted stimuli(e.g., red circle) may have been completed in the visual cortex and does not require the involvement of brain regions (e.g., PFC) with higher cognitive functions (Adam & Serences, 2021; Hopf et al., 2000; Park & Serences, 2022; Westerberg & Schall, 2021; Zhang et al., 2022). Taken together, no stress effect on distractor suppression suggests that acute stress impacts cognitive function related to PFC.

5. Conclusion

To conclude, the current study reveals that acute stress affect attention selection does not driven by distractor suppression difficulties, but by impairments in goal-directed target enhancement in presence of high-salience distractor. This impairment might caused by the acute stress effects on the PFC but not on the visual cortex. The current study provide clear evidence for alterations in attention selection caused by acute stress and reveal the cognitive mechanism of acute stress effect on attention selection.

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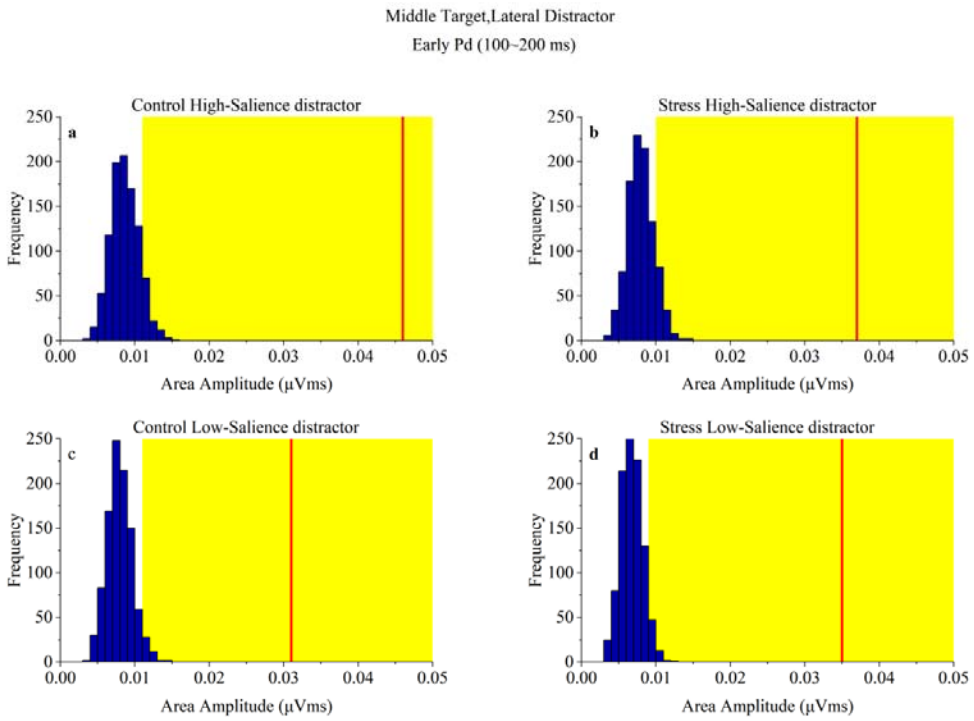
Supplementary Materials: Acute stress impairs target enhancement but not distractor suppression in attention selection: Evidence from the N2pc and Pd

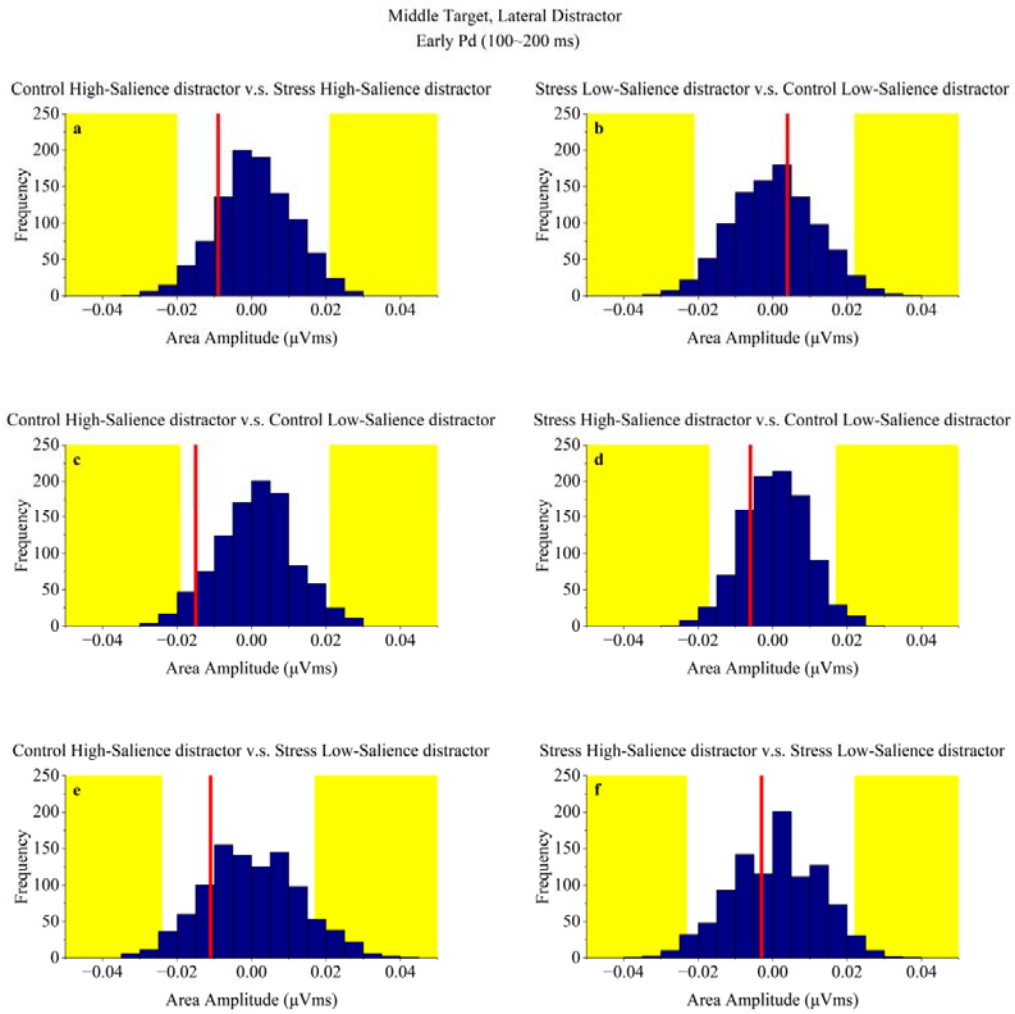
1. Permutation Tests results of Pd and N2pc Waveforms (Signed-area approach)

1.1 Midline target, lateral distractor

Early Pd(100~200 ms):We tested whether the area of the Early Pd component was significantly greater than chance for each trial type by using a permutation test (as described in the above). Permutation tests showed that a significant Pd was present for stress group and control group at high-salience distractor and low-salience distractor(**see S.Fig. 1**). However the Early Pd area did not significantly differ between stress group and control group at high-salience distractor and low-salience distractor(**see S.Fig. 2**).



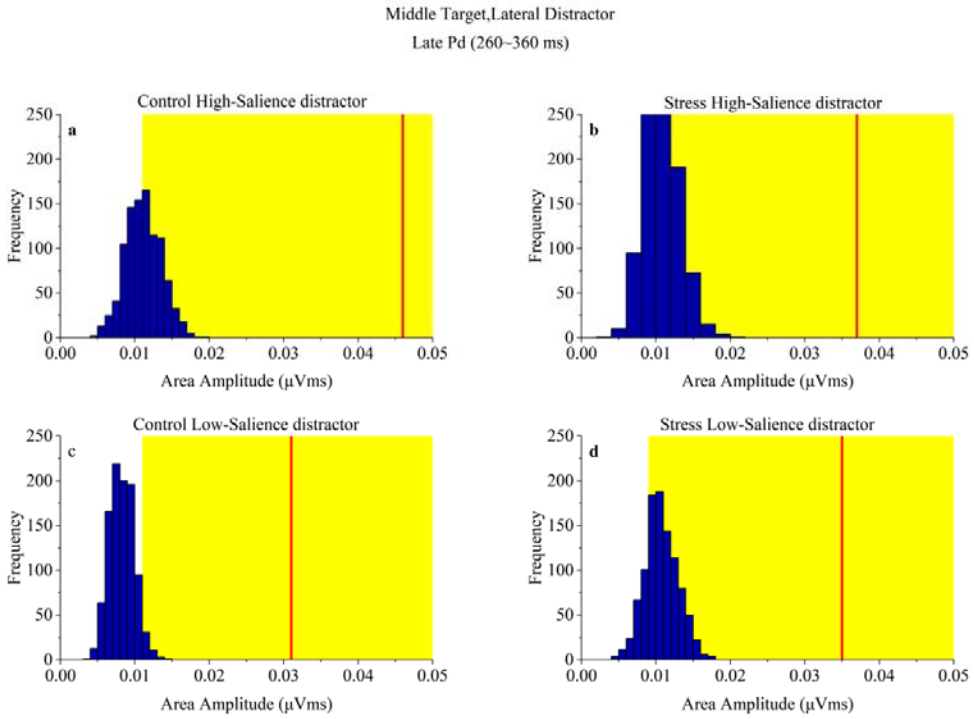
S.Fig. 1. Permutation tests of the positive areas from 100 to 200 ms. The blue bars indicate the estimated null distribution from 1000 permutations. The red lines represent the observed values of the positive areas (early Pd) from the grand average waveforms. The yellow areas indicate the top 5% of the permutation distribution. Because the red lines fall within the yellow regions the observed values are significantly greater than would be expected by chance.



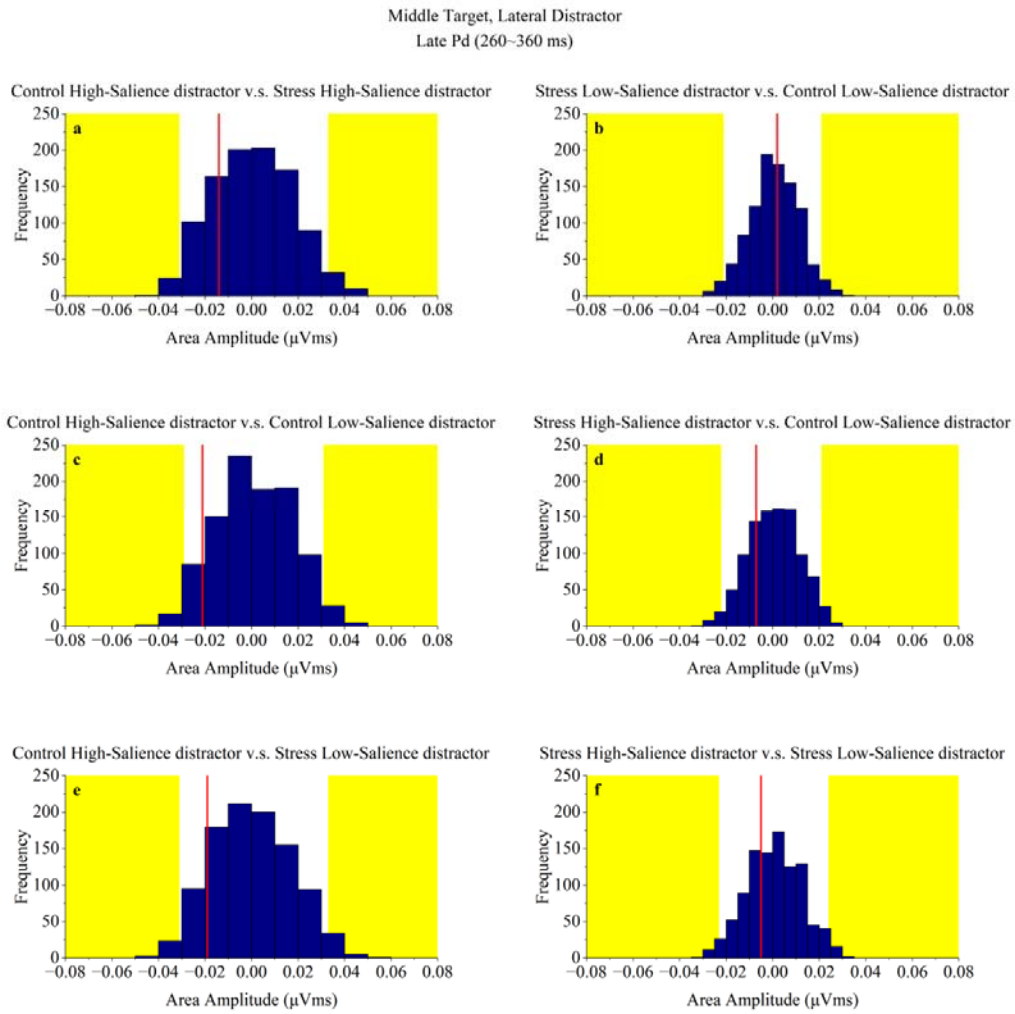
S.Fig. 2. Permutation tests of the difference of positive areas from 100 to 200 ms in between stress group and control group at high-salience distractor and low-salience distractor. The blue bars indicate the estimated null distribution from 1000 permutations. The red lines represent the observed values of the difference of positive areas (early Pd) from the grand average waveforms. The yellow areas indicate the top 2.5% of the permutation distribution. Because the red lines fall within the yellow regions, the observed values are significantly greater than would be expected by chance.

Late Pd(260~360 ms):We tested whether the area of the late Pd component was significantly greater than chance for each trial type by using a permutation test (as described in the above). Permutation tests showed that a significant Pd was present for stress group and control group at high-salience distractor and low-salience distractor(**see S.Fig. 3**). However the late Pd area did not significantly differ between stress group and control group at high-salience distractor and low-salience

distractor(**see S.Fig. 4**).



S.Fig. 3. Permutation tests of the positive areas from 260 to 360 ms. The blue bars indicate the estimated null distribution from 1000 permutations. The red lines represent the observed values of the positive areas (late Pd) from the grand average waveforms. The yellow areas indicate the top 5% of the permutation distribution. Because the red lines fall within the yellow regions the observed values are significantly greater than would be expected by chance.

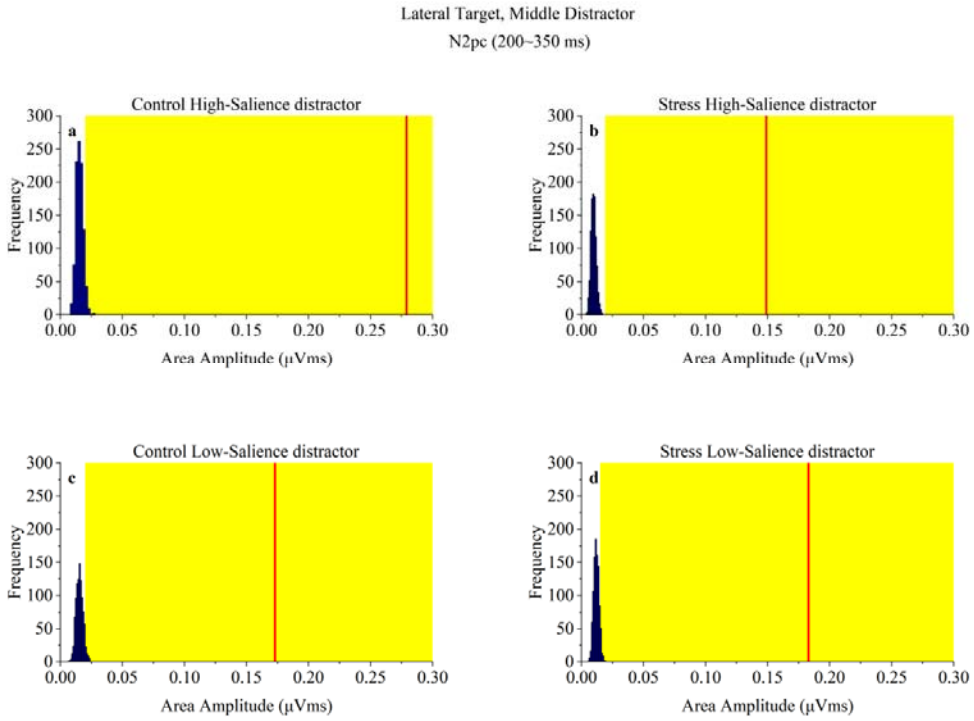


S.Fig. 4. Permutation tests of the difference of positive areas from 260 to 360 ms in between stress group and control group at high-salience distractor and low-salience distractor. The blue bars indicate the estimated null distribution from 1000 permutations. The red lines represent the observed values of the difference of positive areas (late Pd) from the grand average waveforms. The yellow areas indicate the top 2.5% of the permutation distribution. Because the red lines fall within the yellow regions, the observed values are significantly greater than would be expected by chance.

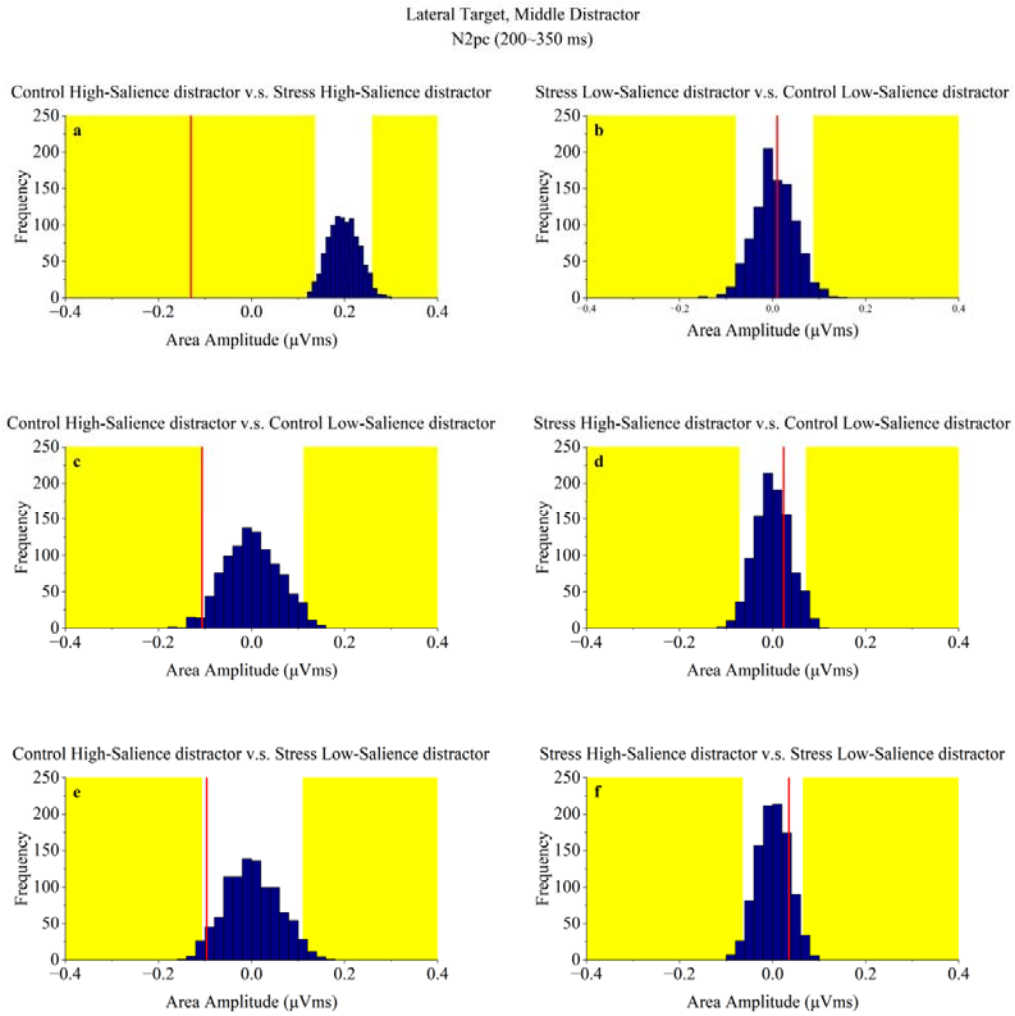
Lateral target, middle distractor

N2pc(200~350 ms): We tested whether the area of the N2pc component was significantly greater than chance for each trial type by using a permutation test (as described in the above). Permutation tests showed that a significant N2pc was present for stress group and control group at high-salience distractor and low-salience

distractor(**see S.Fig. 5**), and N2pc area was significantly larger between stress and control group at high-salience distractor condition. However, the N2pc area did not significantly differ between others condition(**see S.Fig. 6**).



S.Fig. 5. Permutation tests of the negative areas from 200 to 350 ms. The blue bars indicate the estimated null distribution from 100 permutations. The red lines represent the observed values of the negative areas (N2pc) from the grand average waveforms. The yellow areas indicate the top 5% of the permutation distribution. Because the red lines fall within the yellow regions, the observed values are significantly greater than would be expected by chance.

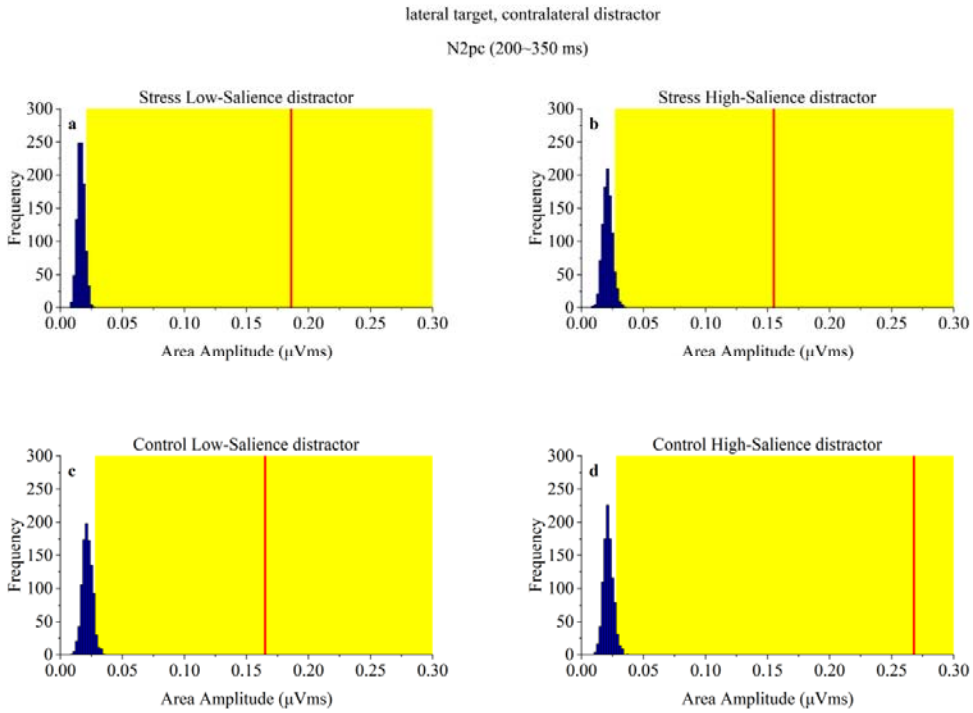


S.Fig. 6. Permutation tests of the difference of negative areas from 200 to 350 ms in between stress group and control group at high-salience distractor and low-salience distractor. The blue bars indicate the estimated null distribution from 1000 permutations. The red lines represent the observed values of the difference of negative areas (N2pc) from the grand average waveforms. The yellow areas indicate the top 2.5% of the permutation distribution. Because the red lines fall within the yellow regions, the observed values are significantly greater than would be expected by chance.

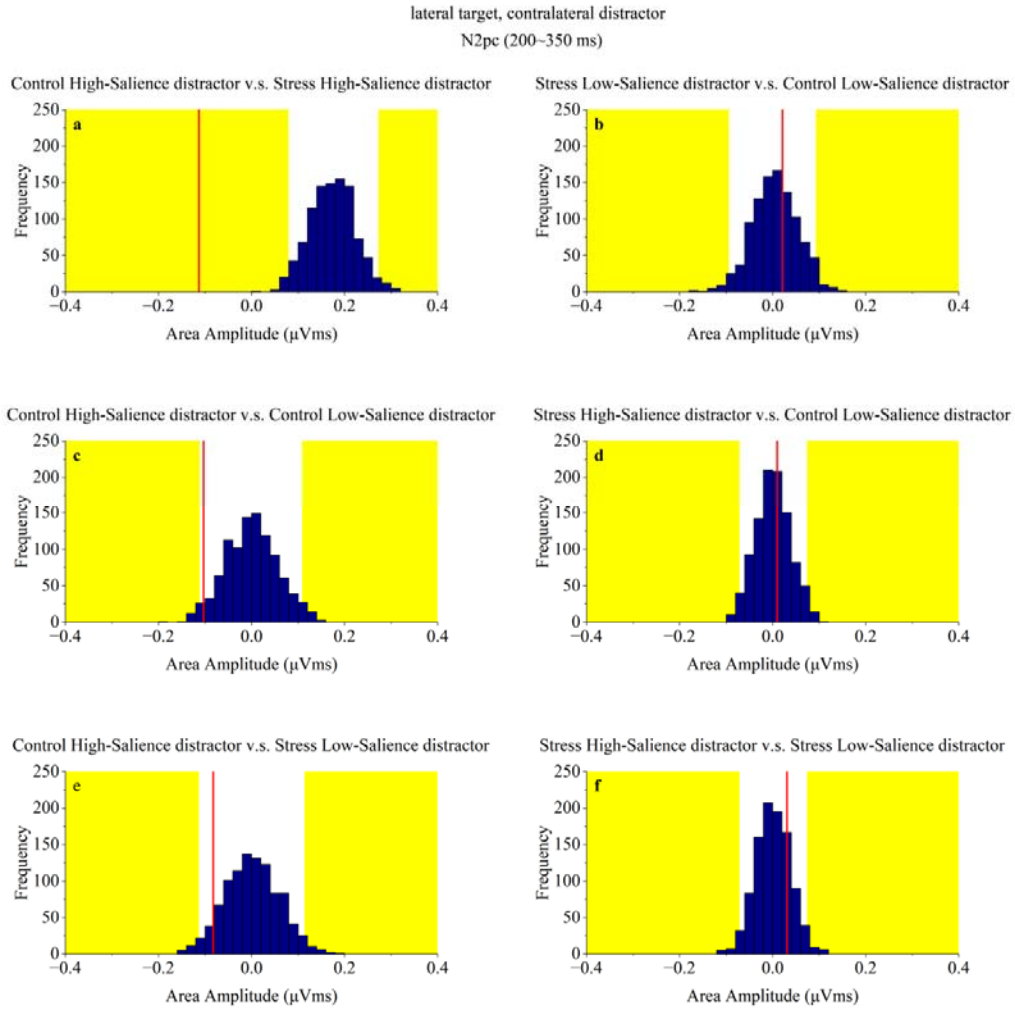
Lateral target, contralateral distractor

N2pc(200~350 ms): We tested whether the area of the N2pc component was significantly greater than chance for each trial type by using a permutation test (as described in the above). Permutation tests showed that a significant N2pc was present

for stress group and control group at high-salience distractor and low-salience distractor(**see S.Fig. 7**), and N2pc area was significantly larger between stress and control group at high-salience distractor condition. However, the N2pc area did not significantly differ between others condition(**see S.Fig. 8**).



S.Fig. 7. Permutation tests of the negative and positive areas from 200 to 350 ms. The blue bars indicate the estimated null distribution from 1000 permutations. The red lines represent the observed values of the negative and positive areas (N2pc) from the grand average waveforms. The yellow areas indicate the top 5% of the permutation distribution. Because the red lines fall within the yellow regions, the observed values are significantly greater than would be expected by chance.



S.Fig. 8. Permutation tests of the difference of negative areas from 200 to 350 ms in between stress group and control group at high-salience distractor and low-salience distractor. The blue bars indicate the estimated null distribution from 1000 permutations. The red lines represent the observed values of the difference of negative areas (N2pc) from the grand average waveforms. The yellow areas indicate the top 2.5% of the permutation distribution. Because the red lines fall within the yellow regions, the observed values are significantly greater than would be expected by chance.