Stress May Not Impair Higher Cognitive Functions Via Depleted Cognitive Resources

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Research Article

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Abstract

Whether stress impairs available cognitive resources and affects multiple cognitive functions is under debate. The current study used a relatively direct measure of available cognitive resources (i.e., the cognitive control capacity) to test the effect of acute stress and found that cognitive control capacity did not differ between conditions (stress and control) by using both the *p*-value and Bayes factor as indicators. We argue that stress might not impair higher cognitive functions through depleted cognitive resources after checking the effectiveness of the manipulations. The results potentially contribute to understanding the psychological consequence of stress-related disorders.

Full Text

Individuals with stress-related disorders such as major depressive disorder (Kuehl et al., 2019) and posttraumatic stress disorder (Sumner et al., 2017) tend to perform worse in tasks requiring multiple cognitive functions. Studies have examined the effect of stress on cognitive functions based on assumptions that stress occupies cognitive resources (on a psychological basis) or impairs prefrontal cortex-dependent cognitive functions (on a physiological basis) (Plessow, Schade & Kirschbaum, 2017). For example, acute stress can hinder reinforcement learning (Otto et al., 2013), top-down control (Sanger et al., 2014), working memory, and cognitive flexibility by occupying cognitive resources (Shields, Sazma & Yonelinas, 2016). A review (Shansky & Lipps, 2013) found that stress impaired the prefrontal cortex function, resulting in working memory deficits. Note that acute stress is often used as an operational definition of stress in these studies because it is difficult and unethical to manipulate chronic stress in human subjects (Shields, Sazma & Yonelinas, 2016).

However, there is evidence that stress has no or even a positive effect on such cognitive functions. Boselie, Vancleef, and Peters (2016) reported that acute stress induced by the cold pressor test (CPT) did not affect subsequent 2-back task performance. Similar results have been obtained in related studies using various stressors (Loeber et al., 2020; Quinn and Joormann, 2015). Moreover, acute stress induced by the socially evaluated CPT enhanced response inhibition in the stop-signal task in Schwabe et al.'s (2013) sample. These inconsistent results make it difficult to conclude whether acute stress occupies available cognitive resources or the processing capacity of the prefrontal cortex.

The studies mentioned above inferred cognitive resource occupation from changes in reaction time (RT) and accuracy. Nevertheless, alternative factors may account for task performance. For instance, Steinhauser, Maier, and Hübner (2007) argued that the cognitive system could adapt to depleted resources by adopting less capacity-demanding strategies, which allows individuals to maintain better task performance with fewer cognitive resources. A more direct measure of cognitive resources or the processing capacity of the prefrontal cortex should be used to provide more robust evidence. One candidate for such a measurement is the capacity of cognitive control (CCC).

Cognitive control, the ability to coordinate thoughts and actions under conditions of cognitive uncertainty (Mackie et al., 2013; Fan et al., 2014; Chen et al., 2019), serves as the “controller” of the cognitive system. It selects information from lower-level (automatic) processing (e.g., sensory encoding) and prioritizes information that will reach higher-level (conscious) processing (e.g., working memory), thus enabling a person to pursue goal-directed behavior (Mackie et al., 2013; Wu et al., 2016). However, its capacity is limited by the anterior insular cortex (Wu et al., 2019), making it the bottleneck of cognitive functions when there is competition for limited cognitive resources. The CCC has been estimated as 3 to 4 bits per second (bps) in healthy adults (Wu et al., 2016; Chen et al., 2020).

The current study aims to provide a robust measure of available cognitive resources (i.e., the CCC) and test whether it is affected by acute stress induced by the CPT. The obtained results might provide a better answer to whether stress influences various cognitive functions via depleted cognitive resources.

Method

Sample

Thirty healthy adults were recruited to participate in the study. One subject was excluded from the analysis because less than 95% of his responses were valid. The final sample size was 29 (15 females and 14 males; mean age: 21.07 years, *SD*: 2.68, range: 19 - 26 years).

Measures

Positive and Negative Affect Schedule (PANAS)

The PANAS (Watson, Clark, & Tellegen, 1988) was used to measure the positive and negative affect of the subjects during the experiment. Participants were required to rate their current mood on a 5-point scale (1 = very slightly or not at all, 5 = extremely). The Cronbach’s α coefficient (average across administrations) of the PNANS in this study is .91 for the positive affect subscale and .83 for the negative affect subscale.

CPT

The CPT (Velasco et al., 1997) was applied to induce acute stress in this study, in which subjects submerged one hand (up to the wrist) in ice water (mean temperature: 0.91 °C, range: 0-3.6 °C in this study) for 3 minutes. The ice water was replaced by water at room temperature (mean: 22.56 °C, range: 20.3-23.6 °C) in the control condition. The CPT activated thermal and nociceptor afferents and in turn increased the activity of the sympathetic nervous system and the hypothalamic-pituitary-adrenal axis. A vast number of studies have shown that CPT elicits acute stress (Loeber et al., 2020; Feldmanhall et al., 2015; Errico et al., 1993) without causing lasting psychological effects related to other stressors (McRae et al., 2006).

Backward Masking Majority Function Task (MFT-M)

A modified version of the MFT-M (Chen et al., 2019; Chen et al., 2020) was used to measure CCC. In each trial, five arrows appeared simultaneously at eight possible locations on the screen, and each arrow pointed in one horizontal direction (either left or right). Arrows appeared with different exposure times (0.25, 0.5, 1 or 2 s) and different ratios between the majority and minority directions (5:0, 4:1 or 3:2). Participants were required to indicate the direction of the majority of arrows through a button press. The periods and their durations in a single trial are illustrated in Figure 1. By manipulating exposure time and arrow ratio, the information rates that participants processed cognitive control in each trial could be quantified based on the group searching algorithm (Fan et al., 2008; Fan, 2014). The task constantly challenged the upper limit of the information rate that cognitive control processes and estimated capacity (see details in Wu et al. [2016]). The MFT-M included 12 blocks, corresponding to 12 possible combinations of conditions (3 arrow ratios × 4 exposure time). Each block contains 36 trials. It took approximately 40 minutes for each subject to finish the MFT-M.

Procedure

Upon arrival, participants signed informed consent forms and were provided 10 minutes to relax and complete the PANAS. After that, participants underwent either the stress manipulation (CPT) or control manipulation. They were then required to fill the PANAS a second time and were provided instructions about the MFT-M. Participants wore an infrared pulse oximeter on the middle finger of their left hand, practiced 36 trials, and finished the MFT-M. The average heart rate during the MFT-M was recorded. Participants completed the PANAS a third time after they finished the task. All individuals participated in both the stress and the control condition 5 to 14 days apart, with the order balanced between subjects. The whole procedure is shown in Figure 1.

The materials and procedures of this study were approved by the Institutional Review Board of the university with which the first author is affiliated. Participants were told their rights about anonymity and the right to withdraw at any time. They received 60 RMB (approximately $8.95) after completing all the tasks.

Analysis

To ensure that the task-induced stress was valid, we compared the positive and negative affects between the stress and control conditions for the three administrations (upon arrival, before the task, and after the task) separately. The between-condition differences in heart rate were also analyzed.

A paired sample *t*-test (two sides) was then applied to examine whether the CCC measured by MFT-M differed between stress and control conditions. Since no significant difference was found in CCC between the two conditions, we further calculated the Bayes factor to test whether the data support the null hypothesis (CCC under stress condition = CCC under control condition). The Bayes factor used in this study (BF_{01}) quantified evidence for the null hypothesis relative to the two-sided alternative hypothesis (CCC under stress condition ≠ CCC under control condition) by comparing marginal likelihoods (Rouder et al., 2009). $BF_{01} \geq 3$ indicated evidence for the null hypothesis, and $BF_{01} \leq 1/3$ indicated evidence for the alternative hypothesis (van Doorn et al., 2019). We also examined whether the accuracy or RT of each block differed between stress conditions to rule out the possibility that the effect of acute stress covered only the first few blocks but not the whole MFT-M. All analyses were performed using JASP software (Version 0.13.1; JASP Team, 2020).

Results

Effectiveness of the Stress Manipulation

The negative affect differed significantly before the task (mean ± *SD*; 16.14 ± 4.47 for the stress condition; 14.35 ± 4.72 for the control condition), $t(28) = 3.039$, $p = .005$, and Cohen's $d = 0.564$. No significant difference in negative affect was found at other time points, $ts \leq 1.814$, $ps \geq .080$. The positive affect did not differ between conditions in the three administrations, $ts \leq 1.540$, $ps \geq .135$. The average heart rate during the task in the stress condition (mean ± *SD*; 85.62 ± 12.70 beats per minute) was significantly higher than that in the control condition (80.97 ± 11.33 beats per minute), $t(28) = 2.412$, $p = .023$, and Cohen's $d = 0.448$. The results were similar to those of a previous study using CPT to induce acute stress (Henckens et al., 2009). These results indicated that the stress manipulation was effective.

Influence of Acute Stress on CCC

Descriptive statistics for CCC under stress (mean ± *SD*; 3.73 ± 0.66 bps) and control conditions (3.68 ± 0.57 bps) are shown in Figure 2. The CCC did not differ between conditions, $t(28) = 0.628$, $p = .535$, and Cohen's $d = 0.117$. Bayesian paired samples *t*-tests showed moderate evidence for the null hypothesis, $BF_{01} = 4.227$. These results indicated that acute stress did not affect the CCC in our sample.

The average accuracy (mean ± *SD*; .86 ± .03 for stress condition; .85 ± .03 for control condition) and RT (645.17 ± 130.44 ms for stress condition; 647.56 ± 142.72 ms for control condition) of the MFT-M did not differ between stress or control conditions, $t(28) = 0.402$, $p = .691$, Cohen's $d = 0.075$, $BF_{01} = 4.702$ for accuracy, and $t(28) = 0.121$, $p = .905$, Cohen's $d = 0.023$, $BF_{01} = 4.954$ for RT. In addition, the accuracy and RT did not differ between conditions in any blocks of the task, $ts(28) \leq 1.447$, $ps \geq .159$ for accuracy, and $ts(28) \leq 1.369$, $ps \geq .182$ for RT. The results indicated that acute stress did not have an effect on the accuracy or RT of the MFT-M, and the the negative result are not due to acute stress decaying over time.

Discussion

The current study provides a more direct measure (i.e., the CCC) of cognitive resources and found that acute stress did not impair the CCC in our sample. Both emotion indicators and the heart rate support valid stress induction in this study. By using the same task and estimation procedure, previous studies have found that the CCC estimated from the MFT-M is related to various cognitive functions (Chen et al., 2019; He et al., 2019) and the processing capacity of the anterior insular cortex (Wu et al., 2019). Moreover, the developmental curve of CCC has been studied, and the results shows that CCC reaches 3.87 bps at age 21 (Chen et al., 2020), which is similar to the results of our sample (mean age: 21.07 years; mean ± *SD*: 3.73 ± 0.66 bps for stress condition and 3.68 ± 0.57 bps for control condition). This evidence supports an effective manipulation of stress and the valid measurement of CCC in this study.

One possible explanation is that acute stress does not affect available cognitive resources. Both accuracy and RT do not differ between stress conditions, indicating that subjects do not trade RT for accuracy in this study. Previous studies have proposed several explanations other than strategy adoption; for example, Boselie, Vancleef, and Peters (2016) hold that CPT impairs concurrent but not subsequent working memory. Schwabe et al. (2013) concluded that these different results are due to different stress intensities. Another explanation is that acute stress does influence cognitive resources but is not reflected in the variation in CCC. Vogel (2016) suggested that cognitive resources would be prioritized to higher cognitive processes (especially those that relied on the PFC and hippocampus) to handle stress situations. The CCC is based on PFC activity (Wu et al., 2019) and is related to the working memory process, which is based on the hippocampus (Chen et al., 2019). Therefore, higher cognitive functions such as the CCC and working memory may not be impaired by depleted cognitive resources.

The results potentially contribute to psychopathology in understanding the psychological consequence of stress-related disorders. Using higher cognitive functions to assess the effects of stress may not be ideal, as individuals may be able to maintain or even enhance some higher cognitive function by reallocating cognitive resources. However, only one cognitive function is measured in this study, leaving assumptions, such as resource redistribution, untested. A more elaborate design should be used in future studies discussing the association between cognitive functions and stress-related disorders.

Conclusion

The current study found that acute stress did not influence the CCC as a relatively direct measure of cognitive resources. We argued that stress might not impair higher cognitive processes by depleting cognitive resources. The results may contribute to a better understanding of the psychological consequence of stress-related disorders.

Declarations

Author Note

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Figures

Figure 1

Procedure of the experiment and periods in a single trial of the MFT-M

Note. The periods and their duration are shown below the black arrow (to the lower left of the center). Stress manipulation is illustrated in the square box connected to the CPT period. The periods and their duration in a single trial of the MFT-M are presented above the black arrow (the upper right and center of the figure), and the arrow ratio and exposure time are illustrated in the square box link to the arrow set period.

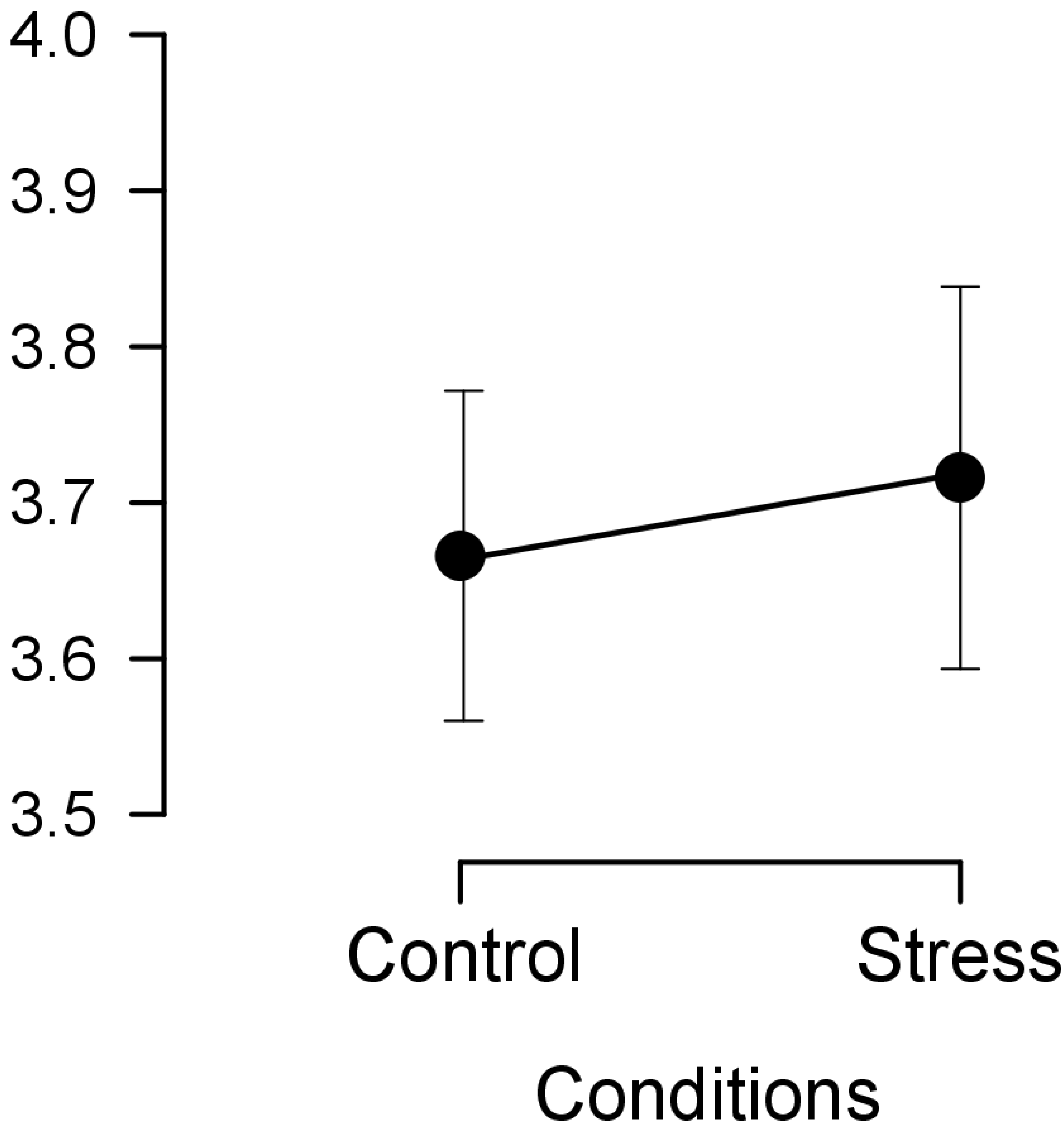

Figure 2

Descriptive statistics for the CCC under stress and control conditions

Note. The y-axis shows the estimated CCC, and the x-axis shows the stress conditions (i.e., control condition and stress condition). Error bars display the standard errors.