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The time course of psychological stress as revealed by event-related potentials

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HIGHLIGHTS

- ► Psychological stress was induced by a mental arithmetic task.
- ► Stress/anxiety level in the stress task was higher than in the control task.
- ► Salivary cortisol increased significantly 10 min after the stress task.
- ► The amplitude of N1 in the stress task was more positive than in the control task.
- ► The latency of P2 in the stress task was faster than in the control task.

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ABSTRACT

Psychological stress is common in everyday life and is believed to affect emotion, cognition and health. Previous brain imaging studies have been able to identify the brain regions involved in the stress response. However, our understanding of the temporal neurological response to psychological stress is limited. The present work aims to investigate the time course of psychological stress induced by a mental arithmetic task, utilizing event-related potentials (ERPs). The elicitation of stress was verified by self-reports of stress and increases in salivary cortisol levels. The subjective and physiological data showed that the stress-elicitation paradigm successfully induced a mild-to-moderate level of psychological stress. The electrophysiological data showed that the amplitude of occipital N1 was more negative in the control task than in the stress task, and the latency of frontal P2 was shorter in the stress task than in the control task. Our results provide electrophysiological evidence that psychological stress occurs primarily at the early stage of cognitive processing.

1. Introduction

Psychological stress is common in everyday life, and can affect one's emotional state, cognitive processing capabilities, and physical health. As a key biomarker of body's response to psychological stress, physiological cascade of the hypothalamus–pituitary–adrenal (HPA) axis is an important link between stress exposure and health outcomes [5]. With the development of neuroscience, the brain is now recognized as playing a central role in the physiological adaptation to the effects of stress, as well as being a target of stress and related behaviors [11]. Processing within the brain determines what is threatening and therefore potentially stressful, and initiates behavioral and physiological responses to the stressors, which can be either adaptive or detrimental.

Two paradigms that have been used effectively to investigate brain activation during psychological stress in functional magnetic resonance imaging (fMRI) studies include: the Montreal imaging stress task (MIST) [2], and a serial subtraction paradigm [23,24]. Both tasks reliably induce a significant HPA stress response in participants. The tasks have also provided evidence for the regulatory roles of the hippocampus, amygdala, and prefrontal cortex areas in response to psychological stressors [23,24,3]. Although brain imaging studies can reveal the specific brain regions involved in the stress response (i.e., they have good spatial resolution), they are limited in terms of temporal resolution; they are unable to provide precise, accurate information regarding the temporal structure of neural responses to psychological stress.

Studies utilizing event-related potentials (ERPs) may be able to elucidate this issue. ERPs are voltage fluctuations associated with the occurrence of some physical or mental event. Unlike fMRI, they provide extremely high temporal resolution, in the range of one millisecond [13]. For example, stress has been found to potentiate early and attenuate the late stages of visual processing [20]. In addition, inhalation of stress sweat has been found to enhance neural

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responses to neutral faces [19], However, to the best of our knowledge, there has only been one study that has investigated the time course of psychological stress itself [12]. In this study, the effect of stress induced by the novelty of a situation was evaluated using ERPs. ERPs recorded in the first session of the experiment were compared with those recorded at least 40 min later; the early waves and P200 components indicated an increased responsiveness during the initial sessions. However, it should be noted that the novelty of the situation is a factor that may mask individual differences in the stress response [14]. Findings suggest that other psychological stressors which play a major role in provoking a cortisol stress response include: the presence of a social evaluative threat, and the perception of uncontrollability and unpredictability [4].

The visual N1 component is a visual evoked potential, which has a typical negative "peak" around 150–200 ms post-stimulus. Both the anterior and posterior N1 peaks are larger for attended-location stimuli than for unattended-location stimuli; however, the lateral occipital N1 attention effect is suggested to reflect the application of a discriminative process to attended-location stimuli; a larger peak is suggested to be associated with the discriminative process [8]. The P2 component is a positive peak occurring about 200 ms post-stimulus and is related to perceptual analysis and attentional allocation [21]. The peak latency of frontal P2 is taken as an indication of the time required for perceptual analysis [26]; a shorter latency is suggested to indicate quicker orienting and processing of visual information at a relatively early stage [10].

In the present study, we employ ERP techniques to investigate the temporal structure of psychological stress processing induced by the performance of a difficult mental arithmetic task (compared to an easy mental arithmetic task) under time pressure. As participants in the stress condition will experience a sense of uncontrollability, they are likely to find it difficult to make discriminations that are dependent on the form of the stimulus; we therefore expect that the lateral occipital N1 will be more positive in the stress task than in the control task. Furthermore, as participants in the stress condition will be vigilant, and are likely to orient and process visual information quickly, we expect that the latency of P2 would be shorter in the stress task than in the control task over the frontal–central region.

2. Materials and methods

2.1. Subjects

Fourteen healthy young individuals were recruited from the local university (6 males, mean age = 21.7 ± 1.8 years) and were compensated for their participation. Participants with a history of depression [1] or head injury (assessed via subjective self-reports) were excluded. All participants were right-handed, and had normal or corrected-to-normal vision. All participants indicated that they understood the procedures involved, and a written consent to participate was provided.

2.2. Procedure

The protocol consisted of four experimental blocks wherein ERP data were collected, and a rest block, with each block lasting 10 min (Fig. 1). The first and the fourth block were baseline blocks, in which a two-decimal number (for e.g., "2.11") was presented on the screen and participants were asked to focus on the number without reaction. During the second and the third block, subjects were instructed to perform the easy (control) and difficult (stress) mental arithmetic tasks, respectively. In the fifth block, there was no task at all and participants were asked to rest. The control and stress blocks were conducted in a fixed order to eliminate contamination of the control condition with increased emotional reactivity elicited by the high stress task.

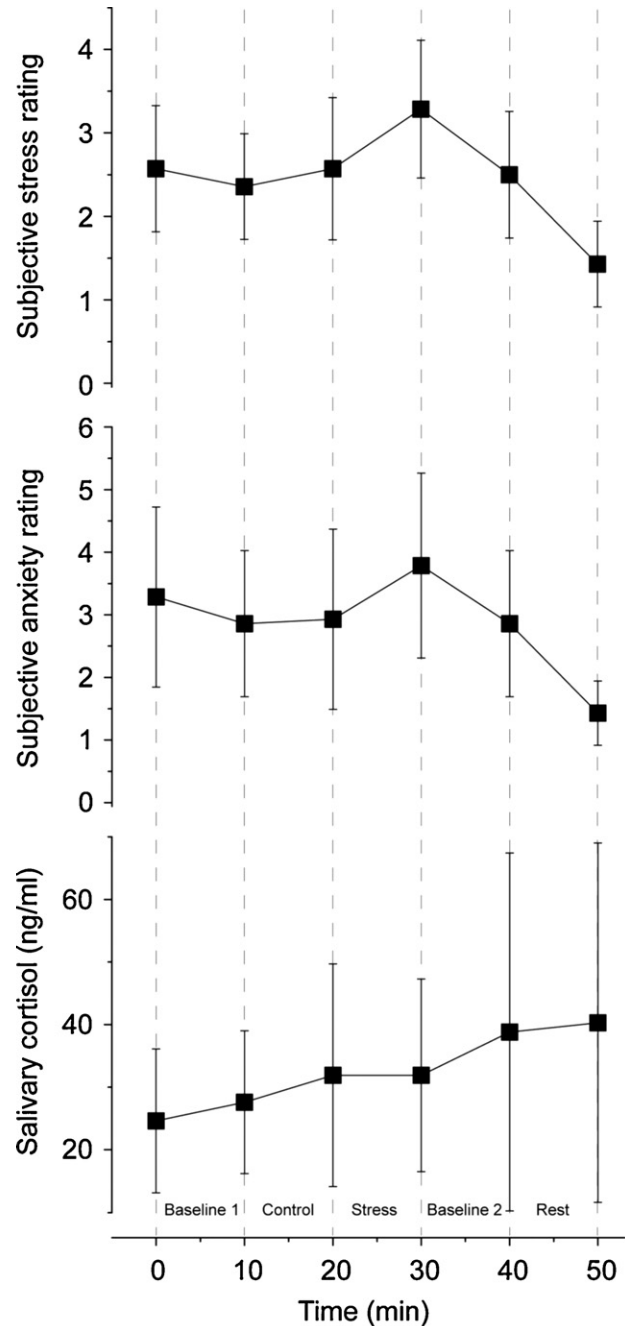

Fig. 1. Average subjective ratings of stress and anxiety, and salivary-cortisol levels during the time course of the experiment (the error bars indicate the standard deviation). Illustrations show that self-reported levels of stress and anxiety were increased during the stress task compared to the control task, and that levels of cortisol were highest 20 min following the stress task.

For the mental arithmetic task, participants were asked to estimate whether the multiplication of 2 two-decimal numbers was above 10 or not, and were given 3200 ms to respond. A time limit was enforced for each trial and the elapsed time was indicated by red dots which progressed from the left to the right of the computer screen. Based on a pilot study, the control condition included 120 "easy" trials (e.g., 1.23×0.54), which allowed subjects to respond quickly and accurately (data from the pilot study revealed that mean reaction time (RT) for easy trials was 781 ms, mean accuracy was 96%). The stress condition included more difficult trials and it was not immediately obvious whether the answer was above or