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The cortisol awakening response predicts response inhibition in the afternoon of the same day

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ABSTRACT

The cortisol awakening response (CAR) is the rapid increase of cortisol levels 30–45 min after awakening in the morning. Numerous studies have indicated the relationship between the CAR and cognition. However, little is known about daily variation in the CAR and cognitive function in healthy adults. The aim of the present study was to investigate whether the CAR predicted the response inhibition function on the same day in both behaviour and the dynamic time course of brain processing. The saliva samples of 47 healthy men were collected at three time points: immediately on awakening, 30 min and 45 min post-awakening in the morning. Participants performed a Go/NoGo task while electroencephalograms (EEG) were recorded in the afternoon of the same day. The results showed that a greater CAR was associated with a stronger N2. In the sub-group of CAR responders (n = 33) the CAR was negatively related to the false alarm rate of NoGo-trials. Our findings suggested that the CAR was predictive of the function of response inhibition in both the earlier cognitive step (i.e., conflict monitoring) and the behavioural performance of response inhibition on the same day in healthy men.

1. Introduction

The cortisol awakening response (CAR), first established by Pruessner et al. (1997), is the rapid increase of cortisol levels 30–45 min after awakening in the morning. Previous studies have suggested that the daily CAR provides energy in anticipation of upcoming demands (Adam et al., 2006; Fries et al., 2009; Hellhammer et al., 2007; Kudielka and Kirschbaum, 2003). As a kind of neuroendocrine phenomenon superimposed on the circadian rhythm of cortisol, the CAR has been related to a wide range of psychosocial and physical variables (Mangold et al., 2010; Pruessner et al., 2003).

The relationship between CAR magnitude and cognition has been investigated in several studies (Aas et al., 2011; Almela et al., 2012; Evans et al., 2011; Evans et al., 2012). Most studies treated the CAR as a trait biomarker by averaging CAR across several days and focused on patients and older adults. Some studies have found a positive correlation between the CAR and cognition. For example, Aas et al. (2011) found a blunted CAR was related to a deficit in verbal memory and processing speed in patients with first-episode psychosis. Evans et al. (2012) showed that the CAR was positively associated with executive function in older age. In contrast, other studies suggested a negative relationship between the CAR and cognition. For example, Almela et al. (2012) indicated that a greater CAR was associated with poorer declarative performance in older men and women.

Recently, the relationship between daily variation in the CAR and cognitive function in healthy adults has received growing attention. Law et al. (2015) employed a 50-day case study and found that during a day following a greater CAR the participant had better cognitive flexibility, one important aspect of executive functions. A recent study from our lab found a similar positive relationship between the CAR and brain function, that is, a greater CAR predicted higher resting-state intrinsic functional connectivity of the medial prefrontal cortex (mPFC) with the other brain areas in the afternoon of the same day (Wu et al., 2015). The results of Hodyl et al. (2015), however, suggested a negative association between the CAR and the degree of learning and the performance of memory. While Moriarty et al. (2014) found an inverted U-shaped relationship between the CAR and spatial working memory on the same day. The difference between these results could be due to the difference in cognitive functions and the methodology used, such as the time points when the cognitive tasks were performed. There is also a gap in our knowledge as to whether the association between the CAR and cognition on the same day can be extended to other aspects of

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executive functions, such as response inhibition. Moreover, these previous studies generally used behavioural performance as the index of cognition but behaviour is only the final output of information processing. We asked the question of whether the CAR could predict dynamic cognition during information processing and investigated the neural mechanisms underlying the association between the CAR and behaviour on the same day.

Response inhibition is "the ability to suppress behaviours that are inappropriate, unsafe, or no longer required"(Chambers et al., 2009, p. 632). It is assumed that the prefrontal cortex (PFC) plays an important role in inhibition processes (Miller and Cohen, 2001). This is a key area of the brain reportedly involved in both the target of stress, cortisol, (Herman et al., 2005) and the regulation of the hypothalamic-pituitary-adrenal axis (Fries et al., 2009; Ostrander et al., 2003). The event-related potential (ERP) technique has high temporal resolution and could be used to investigate the dynamic steps of information processing. There are two major ERP components of response inhibition, i.e., the NoGo-N2 and the NoGo-P3. The NoGo-N2 may reflect conflict monitoring and recognition of the need for inhibition (Donkers and van Boxtel, 2004; Falkenstein and Hohnsbein, 1999). The NoGo-P3 may represent response evaluation and success of response inhibition (Smith et al., 2008). Previous studies have also reported an association between cortisol and response inhibition (Shields et al., 2015). For example, one study found that acute cortisol administration enhanced inhibitory performance in healthy participants (Schlosser et al., 2013). However, the relationship between the CAR and response inhibition on the same day has not yet been studied.

The aim of the current study was to examine whether the CAR predicted the response inhibition function on the same day applying both behaviour and the dynamic time course using ERP. To avoid the confusion between baseline cortisol and the CAR, the response inhibition task, in this case the Go/NoGo, was performed in the afternoon. In the light of previous studies on the relationship between the CAR and PFC functions (Law et al., 2015; Wu et al., 2015), we hypothesised that a higher CAR would be associated with increased ability for response inhibition as shown by ERP and behaviour results.

2. Methods

2.1. Participants

Forty-nine healthy, right-handed university students were recruited through advertisements posted at universities in Beijing. All participants were male because the CAR differs between men and women (Kudielka and Kirschbaum, 2005; Pruessner et al., 1997; Wright and Steptoe, 2005). Participants were excluded by the following exclusion criteria: (1) Chronic use of any psychiatric, neurological, or endocrine medication; (2) any history of psychiatric, neurological, or endocrine disorder; (3) any history of major chronic physiological disorders; (4) any history of major head injury; (5) any long-term overnight work or irregular day/night patterns; (6) any current acute inflammation; and (7) excessive consumption of alcohol (more than 2 alcoholic drinks a day) or nicotine (more than 5 cigarettes a day). All participants provided written informed consent and were paid for participation. This study was approved by the Ethics Committee of Human Experimentation of the Institute of Psychology, Chinese Academy of Sciences.

2.2. General procedures

Participants came to the laboratory on the first day and first completed the informed consent form and questionnaires including demographic questions, the Symptom Checklist 90 (SCL-90) and the Adolescent Self-Rating Life Events Check List (ASLEC) (Derogatis et al., 1973; Liu et al., 1997). Then they were instructed on how to collect saliva samples in oral form. They were also provided with a pack containing a written version of instructions for saliva collection, MotionWatch 8 (Camntech, UK), the Salivette collection device (Sarstedt, Germany) and MEMS TrackCap containers (MEMS 6 TrackCap Monitor, Aardex Ltd. Switzerland). The MotionWatch 8 recorded sleep and activity to confirm awakening times and the MEMS TrackCap containers recorded the exact time when the participants opened the container to take the saliva Salivettes. All participants used the MEMS caps. Because there were not enough devices, we used a 'mock strategy' with the participants being told that the monitoring strategies were used without the true Motionwatch for some participants (n = 20). Stalder et al. (2016) suggested that this might be one way to obtain reliable data. A standardized message sent by the experimenter in the evening of the first day reminded participants to wake up between 6:00 am and 8:00 am of the second day to balance the effect of wake time. Before going to bed in the evening, participants wore the MotionWatch on their wrist until the end of saliva collection next morning. We also instructed the participants to refrain from intense exercise during the collecting period and the night before the collecting day.

On the second experimental day, participants were asked to collect saliva samples at three time points: immediately on awakening, 30 min and 45 min after awakening in the morning. They were asked to come to the laboratory between 1:30 pm and 2:30 pm. After arrival at the laboratory, the participants rested for half an hour in a quiet room and then prepared for electroencephalogram (EEG) recording. The EEG was collected while the participants performed tasks including the Go/NoGo. Another saliva sample was collected before the Go/NoGo task began to measure the baseline cortisol level before the task.

2.3. Go/NoGo task

One of the most common measures to investigate response inhibition is the classical Go/NoGo task. The procedures followed the protocol of previous studies performed in our laboratory (Ma et al., 2015; Wu et al., 2017; Zhang et al., 2015). The only difference in the current study is that we did not use O/X but the digit 1/9 as the stimulus. Both digits and letters have been commonly used as in Go/NoGo task in literature (Duan et al., 2009; Scholz et al., 2009). Participants viewed a series of digits with a size of 2 cm × 1 cm (either the digit 1 or 9) in the centre of a screen. All stimuli were presented on a 17-inch monitor of a Pentium processor using E-prime software, at a viewing distance of approximately 70 cm. Each stimulus was presented in white on the black screen for 150 milliseconds (ms), with randomly varying interstimulus intervals between 1200 ms and 1500 ms. Participants were explicitly instructed to respond as fast as possible to the appearance of the digit of Go trials by pressing a button on the keyboard with their index finger of the right hand, and to withhold their response for the NoGo trials. The response window was 1000 ms. Response assignments between the two digits and Go/NoGo trials were counterbalanced across participants. Ten practice trials preceded two blocks of 240 trials each, of which 20% were NoGo and 80% were Go trials. After the first block, participants were allowed a rest break for approximately 1 min. Total task duration was about 12 min.

2.4. Questionnaires

We measured the psychological disorder of the participants by the SCL-90. The SCL-90 is a 90-item self-reported scale, and participants were asked to refer to their feelings and behaviour during the last one week. Each item has a 5-point Likert scale (0 for not at all, 4 for extremely). We used the Chinese version, which demonstrated adequate reliability and validity (Wang, 1984). The Adolescent Self-Rating Life Events Check List (ASLEC) was also used to measure life events of the participants (Liu et al., 1997). The ASLEC consisted of 27 life events such as death in the family and having an accident. Participants were asked to indicate whether the event occurred in the previous 12 months. The total score is computed by summing the scores on all the items of whether the event occurred. Higher scores reflect higher levels