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The effects of cortisol administration on approach–avoidance behavior: An event-related potential study

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Abstract

We investigated the effects of cortisol administration (50 mg) on approach and avoidance tendencies in low and high trait avoidant healthy young men. Event-related brain potentials (ERPs) were measured during a reaction time task, in which participants evaluated the emotional expression of photographs of happy and angry faces by making an approaching (flexion) or avoiding (extension) arm movement. The task consisted of an affect-congruent (approach happy faces and avoid angry faces) and an affect-incongruent (reversed instruction) condition. Behavioral and ERP analyses showed that cortisol enhanced congruency effects for angry faces in highly avoidant individuals only. The ERP effects involved an increase of both early (P150) and late (P3) positive amplitudes, indicative of increased processing of the angry faces in high avoidant subjects after cortisol administration. Together, these results suggest a context-specific effect of cortisol on processing of, and adaptive responses to, motivationally significant threat stimuli, particularly in participants highly sensitive to threat signals.

Keywords: Cortisol; Approach–avoidance; Facial expression; Action tendencies; Event-related potentials; Behavioral Inhibition Scale

Activity of the hypothalamus–pituitary–adrenal (HPA) axis is important in the regulation of adaptive stress responses such as the generation of active avoidance reactions (see Sapolsky et al., 2000). Stress leads to activation of the HPA system, resulting in the release of endogenous glucocorticoids such as cortisol. Particularly when measured in social situations, elevated cortisol levels have been found to be related to the manifestation of social submissiveness and avoidance behavior (Sapolsky, 1990). Despite the extensive literature on the relation between HPA-axis activity and avoidance behavior in animals, little is known about the role of cortisol in the generation of human avoidance behavior. In this study, we examined the effect of cortisol administration on avoidance reactions to threatening social stimuli (angry faces) in human participants. In addition, to gain more insight in the brain processes underlying these reactions, we measured event-related brain potentials (ERPs) during performance of an approach–avoidance task, specifically focusing on positive components related to emotional face processing.

The generation of active avoidance responses depends on a motivational network that involves various brain regions (see LeDoux, 2002; Rolls, 2000). When threat stimuli are processed by the amygdala, direct autonomic responses and primary motor reactions such as freezing are activated via connections to the brainstem. Moreover, motivational systems are activated that guide instrumental responses based on past learning or instantaneous decisions. The hippocampus and prefrontal cortex (PFC) play an important role in these motivational systems. The PFC is thought to integrate information on arousal (from brainstem centers) with context-relevant information (from the hippocampus) and with temporary contents of working memory (from PFC areas) in controlling motor

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responses (via connections with the motor cortex). The anterior cingulate (ACC) and orbitofrontal (OFC) regions of the PFC in particular are involved in these motivational systems, which enable approach and avoidance reactions to emotional stimuli (see LeDoux, 2002; Roelofs et al., in preparation; Rolls, 2000).

Rolls (2000) stressed the importance of processing of facial expressions by these motivational systems. Emotion has a communicative function, and faces constitute important signals of threat or appeasement in the social environment. In a series of lesion studies, Hornak et al. (2003) showed that in human participants both the OFC and the ACC are involved in emotion processing, including the identification of facial expression, social behavior, and subjective emotional state.

Angry facial expressions are commonly used as social threat stimuli in human research on threat processing. Neuroimaging studies have shown that viewing angry faces activates large parts of the above-mentioned motivational network, with the ACC, OFC, and amygdala in particular (for an overview see Adolphs, 2002; McClure et al., 2004; Strauss et al., 2005). In addition, transcranial magnetic stimulation of the medial PFC/ACC has been found to disrupt the processing of angry facial expressions (Harmer et al., 2001). Adolphs (2002) argued that whereas activation of the amygdala appears to depend on relatively passive or implicit processing of the emotion (such as in passive viewing paradigms), prefrontal regions may be activated more when participants are engaged in a cognitive task requiring explicit identification of the emotion, which in turn may inhibit the amygdala's activation.

ERP studies have also indicated that prefrontal motivational networks are involved in the processing of facial expressions. An enhanced positivity in response to emotional relative to neutral faces has been found over prefrontal areas as early as 120 ms after stimulus presentation (Eimer and Holmes, 2002) or between 160 and 215 ms (Eimer et al., 2003). This suggests that cortical circuits involved in the detection of emotionally significant events can be triggered rapidly by emotional facial expressions (Eimer et al., 2003; Pizzagalli et al., 1999; Sato et al., 2001). In addition, a more broadly distributed positivity (over parietal as well as frontal and central areas) has been observed beyond 300 ms (Eimer et al., 2003). In particular faces signaling threat (i.e. fearful or angry faces as opposed to happy or neutral faces) have been found to show these enhanced amplitudes in both early (e.g. 50–250 ms: Ashley et al., 2004; Bar-Haim et al., 2005; Schupp et al., 2004; Williams et al., 2006) and late positive components (300–500 ms: Schupp et al., 2004; Williams et al., 2006). Interestingly, recent studies reported the ERP effects of emotional expressions to be attention dependent (Eimer et al., 2003; Krolak-Salmon et al., 2001), suggesting they may reflect a greater allocation of attention to motivationally relevant input (Cuthbert et al., 2000).

In sum, a frontolimbic motivational network is involved in the processing of social threat stimuli and the generation of avoidance behavior. In the next section we explore how the stress hormone cortisol, which is thought to be important in the generation of adaptive stress responses (e.g. Sapolsky et al., 2000), may affect this network and, consequently, approach and avoidance behavior. It is well established that not only the hippocampus but also the PFC is a target structure for cortisol (e.g. Meaney and Aitken, 1985; Radley et al., 2004). Exogenously administered cortisol has been shown to affect prefrontal functions, such as working memory, in humans (for a review see Wolf, 2003). In addition, there is increasing evidence from animal studies that PFC mediated avoidance behavior and fearful temperament are positively correlated with high levels of cortisol (see e.g. Kalin et al., 1998a,b, 2000). De Kloet et al. (1999) emphasized that glucocorticoids influence information-processing systems conditionally, so that specific internal and external stimuli are more likely to elicit responses in the appropriate context. In this way, information processing is biased towards adaptive behavior that is most relevant to the situation.

Human studies on the relation between cortisol, the processing of social threat stimuli and avoidance behavior are scarce, but a recent study by Putman et al. (2007) suggested that acute (25 mg) cortisol administration enhanced preferential processing of angry faces in healthy young men. The results of this study showed a significant increase in memory bias for angry faces (i.e. enhanced spatial working memory performance compared to neutral faces) after cortisol administration compared to placebo. No such memory bias was found for happy faces. In addition, a study by Van Honk et al. (1998) in which angry and neutral faces were presented in a Stroop paradigm indicated that increased basal cortisol levels were associated with faster responses to angry faces, which was interpreted as reflecting (adaptive) avoidance. However, no studies so far have addressed the effects of cortisol administration on overt avoidance behavior.

A systematic and objective method to study human avoidance behavior was provided by Solarz (1960) and Chen and Bargh (1999), consisting of a reaction time task in which individuals evaluate the emotional valence of positive and negative word stimuli by making arm movements (arm flexion or extension) that are either congruent or incongruent with their intuitive action tendencies. Rotteveel and Phaf (2004) extended this paradigm to the nonverbal domain, using pictures of happy and angry faces (the approach–avoidance (AA) task). Affect-congruent movements involve arm flexion (approach) in response to a positive stimulus (happy face) and arm extension (avoidance) in response to a negative stimulus (angry face). Affect-incongruent movements involve reversed mapping instructions (from stimulus valence to arm movement) that conflict with participants' intuitive action tendencies (i.e. to approach positive and avoid negative stimuli). With this paradigm a congruency effect is typically found, indicating faster responses for affect-congruent arm movements compared to affect-incongruent arm movements (see also Chen and Bargh, 1999; Markman and Brendl, 2005; Solarz, 1960).

Using this AA task, Roelofs et al. (2005) found an effect of stress-induced cortisol responses on the congruency effects. Participants with relatively high stress-induced cortisol responses (high CR) showed increased AA congruency effects when tested in baseline conditions, but no significant congruency effects during stress. In contrast, for low CR participants the congruency effects were only significant during and not before stress. Thus, the results of this study showed a significant