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The effect of a naturalistic stressor on frontal EEG asymmetry, stress, and health

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Abstract

The aim of the current study was to investigate the effect of a naturalistic stressor, examination stress, on frontal EEG asymmetry, psychological stress, hormonal stress, and negative health. Forty-nine subjects were tested during periods of low and high examination stress. During the high examination stress period, subjects reported higher levels of stress on the Spielberger State Anxiety Inventory and Cohen's Perceived Stress Scale. However, no change in cortisol was detected across the two sessions. Furthermore, a shift from relatively greater left frontal activity during the low examination session to relatively greater right frontal activity during the high examination session was also found. Moreover, the increasing right frontal activity asymmetry associated with the high exam session compared to the low exam session correlated with increasing reports of negative health. No evidence was found for the prediction that cortisol mediated either the relationship between examination stressor and right frontal asymmetry or between right frontal asymmetry and negative health. In conclusion, while the findings from this study are compelling, the mechanism mediating increases in psychological stress, relatively greater right frontal activity, and increases in negative health from naturally occurring stressors is in need of further investigation.

Keywords: Frontal asymmetry; Stress; Health; EEG

The major tenet of the valence models of hemispheric specialization of emotion (see Davidson et al., 1979 and Tucker, 1981 for a review of foundational studies) states that the left hemisphere is more involved in the processing of positive emotions and approach-related behaviors, whereas the right hemisphere is more involved in the processing of negative emotions and withdrawal behaviors. The model also suggests that the frontal cortex is particularly critical in emotional processing. There is an abundance of evidence supporting this model from prefrontal EEG alpha asymmetry studies (e.g., Davidson et al., 1979; see Davidson, 2003; Coan and Allen, 2004 for recent reviews of the literature). Specifically, positive moods or reactions have been found to predict relatively greater left prefrontal activity (LFA), whereas negative moods or reactions have been found to predict relatively greater right prefrontal activity (RFA).

However, there is some question regarding whether the region of the prefrontal cortex most involved in emotion is also most relevant to EEG asymmetry findings, especially those related to stress and anxiety. More specifically, Davidson (2004) suggests that EEG mostly records activity at the level of the dorsolateral prefrontal cortex. However, a common finding in anxiety and fear studies is higher metabolic activity in the orbitofrontal prefrontal cortex and ventromedial prefrontal cortex rather than the dorsolateral prefrontal cortex (Davidson, 2002; see Murphy et al., 2003 for a review of these issues). Nevertheless, Davidson (2002) also argues that the strong interconnections among the dorsolateral, orbitofrontal and ventromedial prefrontal cortices, allow for an indirect measure of the level of activity in a variety of prefrontal cortical subregions.

Notwithstanding the need for further elucidation of the specific prefrontal regions involved, numerous findings have confirmed a differential role for the two prefrontal cortices in emotional processing. For instance, in a series of studies investigating shifts in prefrontal activity in infants, smiling faces (Davidson and Fox, 1982), sugar on the tongue (Fox and

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Davidson, 1986), and being approached by the mother (Fox and Davidson, 1987) were related to relatively greater LFA. Furthermore, several studies have found that relatively greater RFA is associated with negatively valenced reactions to emotional stimuli (Davidson and Fox, 1982; Fox and Davidson, 1986, 1988; Hagemann et al., 1998; Tomarken et al., 1990; Wheeler et al., 1993). While relatively greater RFA has been demonstrated with a number of distinct negative mood states or behaviors, including depression, fear and withdrawal (see Coan and Allen, 2004), one negative emotion or mood state that has received less attention is stress. Nevertheless, stress has also been empirically related to relatively greater RFA, especially in rodents (e.g., Sullivan, 2004).

Recent studies have also suggested a differential role for the two cerebral hemispheres in immunocompetence and suppression (e.g., Barneoud et al., 1987; Neveu, 1988, 1993; Quaranta et al., 2004). More specifically, while activity of the left hemisphere appears to be related to increased immunocompetence, activity of the right hemisphere appears to be related to increased immunosuppression. Furthermore, similar to the emotional valence studies, there is evidence that the prefrontal cortex is particularly critical in these hemispheric effects (see Sullivan, 2004 for a review of this issue). While few studies have investigated the more complex associations among prefrontal asymmetry, stress, and health, of those that have, there is evidence to suggest that increased activity in the right hemisphere is related to both increased stress and decreased immune functioning (e.g., Davidson et al., 1999; Kang et al., 1991).

With regard to a mechanism by which stress, health and relatively greater RFA may interact, there is emerging evidence that individuals with relatively greater RFA may also have higher cortisol levels (see Kalin et al., 1998 in rhesus monkeys; Schmidt et al., 1999; Tops et al., 2005 in humans). There is also evidence from hemispheric brain damage and hemispheric presentation studies to suggest that the right hemisphere is more involved in the release of cortisol than is the left hemisphere (see Sullivan, 2004; Wittling, 1995 for reviews). However, few studies have reported a direct linear correlation between the two measures (Buss et al., 2003; Rilling et al., 2001). Again, the complex associations among higher cortisol levels, relatively greater RFA, and greater health problems remain unclear. It is intended that studies like the present one will help to better elucidate these issues.

The goal of the present study was to use an examination stressor to elevate cortisol and psychological stress levels and to test the effect of these elevations on frontal asymmetry and health. There is good motivation for using an examination stressor to elevate cortisol levels and psychological stress in studies investigating these complex issues. For example, there is evidence to suggest that the stress of examinations elicits increased activity in the hypothalamic–pituitary–adrenal (HPA) axis and the release of cortisol (Frankenhaeuser et al., 1978; Lovallo et al., 1986; Lacey et al., 2000; Lucini et al., 2002; Malarkey et al., 1995). However, there is some inconsistency in the literature, with other evidence suggesting either no change in cortisol or even decreased release of cortisol in the face of examinations (see Glaser et al., 1994; Vedhara et al., 2000). One explanation for these discrepancies across studies is that elevations in cortisol in response to examination stress are simply less consistent and less robust than are those in response to the laboratory stressors. Indeed, one recent review (Weekes and Lewis, 2006) found that changes in cortisol levels in response to examination stress ranged from a 58% decline in cortisol (Vedhara et al., 2000) to a 95% increase in cortisol (Rohrmann et al., 2003). The average change was a 21% increase. In laboratory stress studies (especially using Trier social stress test or TSST), the average change in cortisol is typically in the range of a 70–80% increase (e.g., Kudielka et al., 2004).

While these findings might suggest that examination stress protocols would be a less effective means for investigating the relationship between stress-related changes in prefrontal asymmetry than would laboratory-based protocols, we suggest that such environmental stressors may better mimic the level of stress encountered in everyday life (Weekes et al., 2006), and therefore make for a more externally valid measure.

In the present study, each subject was tested during both a high and a low examination stress period. Equal numbers of males and females served as participants in this study, as our previous studies have shown sex differences in a number of the factors being measured (Weekes et al., 2005, 2006). Stress was measured through both psychological inventories and hormonal assays for cortisol. Health will be measured through a negative symptom inventory.

Finally, prefrontal asymmetry was measured via EEG alpha asymmetry. As is typical within this literature, asymmetry in brain activity will be inferred from the measurement of alpha band EEG. This inference has been empirically supported by studies demonstrating an inverse relationship between alpha and cerebral perfusion using $H_2{}^{15}O$ with PET (Cook et al., 1998) and BOLD with fMRI (Laufs et al., 2003).

However, it remains unclear which EEG leads are most relevant for measuring emotion related changes in frontal asymmetry. For instance, there is some question regarding whether midline frontal (F3/4) or lateral frontal (F7/8) leads are more sensitive to mood states or individual differences in trait characteristics (see Tops et al., 2005; Rilling et al., 2001 for discussions of this issue). While midline frontal effects are more consistently reported (see Coan and Allen, 2004 for a review of this issue), when lateral effects are included, they are often found as well (Reid et al., 1998; Tops et al., 2005). For this reason, both midline frontal and lateral frontal leads were included in the analyses for this study. Along with this more traditional approach, a full scalp quadrant analysis was also performed in order to better demarcate the extent of any shifts in asymmetry.

It was predicted that the occurrence of examination stress would result in relatively greater RFA, and that greater psychological stress, cortisol levels and negative health would be associated with relatively greater RFA.