Psychoneuroendocrinology (2009) **34**, 1486—1494

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/psyneuen

Cortisol awakening rise in middle-aged women in relation to psychological stress

D.B. O'Connor [a,*], H. Hendrickx [b], T. Dadd [b], T.D. Elliman [a], T.A. Willis [a], D. Talbot [b], A.E. Mayes [b], K. Thethi [b], J. Powell [b], L. Dye [a]

[a] *Institute of Psychological Sciences, University of Leeds, Leeds, UK*
[b] *Unilever Discover, Sharnbrook, UK*

Received 12 March 2009; received in revised form 1 May 2009; accepted 3 May 2009

KEYWORDS
CAR;
Cortisol;
Stress;
Health behaviours;
HPA axis;
Allostatic load

Summary
Objectives: The cortisol awakening rise (CAR) is defined as cortisol secretory activity in the first 45—60 min immediately post-awakening. It has been suggested that psychological factors may disrupt the normal awakening rise. Recent research has shown that psychological stress may influence the magnitude of the CAR, however the findings have been mixed. This study examined the impact of stress on the CAR and the diurnal mean in a sample of middle-aged women.
Method: One hundred and eighteen healthy female participants who reported experiencing high or low stress were recruited. Salivary cortisol levels were measured immediately upon awakening (at 0, 15, 30, and 45 min) and at 3, 6, 9 and 12 h on two consecutive days. A number of metabolic and inflammatory biomarkers were also assessed together with measures of mood disturbance and health behaviour.
Results: The magnitude of the CAR, assessed by the area under the response curve (AURC) estimate, was significantly lower in the high stress group compared to the low stress group indicating that participants who experienced high stress secreted lower levels of cortisol. The effect was largely accounted for by differences 30 min after waking. The diurnal mean was also lower for the high stress group. Although participants in the high stress group had a slightly worse inflammatory profile, only low-density lipoprotein levels were found to be significantly higher, compared to the low stress group. Lifestyle indicators and mood were also found to be significantly poorer in the high stress group.
Conclusions: The results suggest that psychological stress may be associated with a smaller cortisol awakening rise, a lower diurnal mean, poor lifestyle choices and high levels of psychological distress. These findings may have broader implications for future health risk and for an individual's ability to cope with imminent daily stressors and demands.

* Corresponding author. Tel.: +44 113 343 5727; fax: +44 113 343 5749.
E-mail address: d.b.o'connor@leeds.ac.uk (D.B. O'Connor).

0306-4530/$ — see front matter
doi:10.1016/j.psyneuen.2009.05.002

1. Introduction

Psychological stress can affect health not only directly through autonomic and neuroendocrine responses, but also indirectly through changes to health behaviours (Jones and Bright, 2001; O'Connor et al., 2008). One of the central pathways through which stress can exert its negative effects is by way of the hypothalamic-pituitary-adrenal (HPA) axis (McEwen, 1998). When we experience stress, the HPA axis is activated and releases the glucocorticoid cortisol from the adrenal glands. Once released, cortisol has several important functions such as increasing access to energy stores, increasing protein and fat mobilisation, as well as regulating the magnitude and duration of inflammatory responses (Sapolsky et al., 2000). As such, cortisol is the primary effector hormone of the HPA axis and has received extensive empirical investigation. As with other endocrine systems, the HPA axis is regulated by a negative feedback system, whereby the hypothalamus and the pituitary gland have receptors that detect changes in cortisol levels. For example, cortisol secretion will be inhibited when circulating levels rise or it will be stimulated when levels fall. However, if the HPA axis is repeatedly activated the immune, cardiovascular and the endocrine systems are potentially exposed to excessive wear and tear (McEwen, 1998, 2000). Over time, such repetitive activation may contribute to future ill health by placing excessive pressure on various bodily systems. Nonetheless, the precise effects of psychological stress on HPA axis regulation in relation to the diurnal cortisol profile and how this relates to health remains unclear. Moreover, less is known about the biological mechanisms that account for the relationship between psychosocial factors such as stress and coronary heart disease (Brotman et al., 2007; Chandola et al., 2008).

The diurnal pattern of cortisol production is characterised by two distinct components: the peak levels after awakening (i.e., the cortisol awakening rise, CAR) and the diminishing levels throughout the rest of the day (i.e., diurnal levels) (Pruessner et al., 1997; Clow et al., 2004; Fries et al., 2009). A relatively large amount of research has explored the links between daily cortisol levels and health outcomes. For example, cortisol secretory activity has been linked to numerous clinical and psychological end-points such as hypertension, burnout, emotional distress, upper respiratory illness and eating behaviour (e.g., Vedhara et al., 2003; Cohen, 2005; Miller et al., 2007; Newman et al., 2007; Sonnenschein et al., 2007; Wirtz et al., 2007; Bellingrath et al., 2008). A number of previous studies have reported that psychological stress may be associated with alterations in both components of daily cortisol activity with the most inconsistent findings relating to the CAR (e.g., Wust et al., 2000; Buchanan et al., 2004; Schlotz et al., 2004).

Increased CAR, whereby there is a greater secretion of cortisol post-awakening, has been found to be associated with psychological stress in a number of studies. For example, Wust et al. (2000) demonstrated that the CAR was positively associated with higher levels of social stress, worrying and lack of social recognition. Similarly, Schlotz et al. (2004) showed that chronic work overload was also associated with an increased CAR. Moreover, using data from the Whitehall II longitudinal study, Kunz-Ebrecht et al. (2004a) found that psychological job demands were positively associated with the CAR. More recently, De Vugt et al. (2005) compared the CAR of caregivers (high stress) to those of non-caregivers (low stress) and again found a greater CAR in the high stress group.

Conversely, there is growing evidence to suggest that chronic stress may disrupt HPA axis regulation leading to a blunted CAR. Buchanan et al. (2004) and Thorn et al. (2006) both documented evidence of a reduced, blunted CAR in participants experiencing high levels of psychological stress. This is also consistent with an epidemiological study, exploring the impact of chronic economic stress, which found a blunted CAR in participants who reported high levels of economic hardship compared to those experiencing low economic hardship (Ranjit et al., 2005).

Few of the existing studies in this area have explicitly targeted participants who are experiencing high levels of chronic stress. Many studies have been conducted in healthy samples (e.g., Edwards et al., 2001; Hucklebridge et al., 2002; Thorn et al., 2006) or have used participants recruited to other epidemiological, longitudinal studies whereby the impact of psychological stress has been of secondary interest or not measured at all (e.g., Kunz-Ebrecht et al., 2004a, 2004b). Therefore, we set up a new study to examine the relationship between chronic stress and the diurnal cortisol profile. Specifically, we recruited participants on the basis of their reported high and low levels of psychological stress and assessed HPA axis activity (CAR and diurnal levels).

A number of factors may account for the inconsistent findings in relation to stress and the CAR. By explicitly taking these factors into consideration, we aimed to address some of the limitations of previous research. Participant adherence to the sampling protocol is likely to be important (cf., Kudielka et al., 2003; Clow et al., 2004; Thorn et al., 2006; Lasikiewicz et al., 2008). The CAR is heavily influenced by the timing of the first sample upon awakening and whether participants are compliant to the study protocol. It is imperative that this issue is addressed by probing for participant non-compliance. Thorn et al. (2006) have argued that it is possible to detect potentially non-adherent participants in non-clinical samples by identifying individuals who show no rise in cortisol following awakening. This rationale is based on work by Kupper et al. (2005), who have demonstrated, using a recording device, that non-clinical participants who failed to exhibit a rise in cortisol (i.e., presented with negative CARs) following awakening had an actual waking time on average 42 min earlier than they reported. In addition, other studies that have identified non-adherence using alternative strategies have shown that non-adherent participants tend to exhibit flat CARs (e.g., Kudielka et al., 2003; Kunz-Ebrecht et al., 2004b). Taken together these studies indicate that participants who exhibited no rise or a decrease in cortisol after waking were non-adherent to protocol. Therefore, in the current study, we analysed our data including and excluding suspected non-adherent participants to control for the potential impact of this problem.

The CAR has also been found to be linked to central adiposity as indexed by waist/hip ratio. Lasikiewicz et al. (2008) showed that blunted cortisol profiles were associated with a greater waist/hip ratio (see also Steptoe et al., 2004). Nevertheless, this variable often remains uncontrolled. Another factor that may also contribute to the observed inconsistencies relates to the age range of participants stu-