Psychoneuroendocrinology (2014) 40, 10—16

Available online at www.sciencedirect.com

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

Dissecting the impact of sleep and stress on the cortisol awakening response in young adults

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Received 28 June 2013; received in revised form 18 October 2013; accepted 18 October 2013

KEYWORDS
Salivary cortisol;
Cortisol awakening response;
Life stress;
Sleep diary

Summary Cortisol rises precipitously upon awakening, in what has been called the cortisol awakening response (CAR). Atypical CARs have been linked to a number of negative health outcomes. Yet, our understanding of the possible mechanisms creating these associations remains unclear. Both stress and sleep can influence CAR, and may potentially explain its links to health. However, these factors also impact each other, and their influence on CAR has rarely been studied simultaneously. In order to differentiate their effects, this study examined the impact of daily life hassles, anticipatory stress, and subjectively reported sleep on CAR among 58 college students. Self-reported stress and sleep, as well as salivary cortisol (collected during the first hour after awakening) were obtained across two consecutive days. Total sleep time predicted CAR magnitude, but daily hassles and anticipatory stress did not after accounting for the effect of sleep. Lower total sleep time was associated with lower awakening cortisol and greater CAR. These results provide further evidence for the impact of sleep insufficiency on CAR, and suggest future efforts to use CAR as a stress biomarker should take the impact of sleep into consideration.
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1. Introduction

The cortisol awakening response (CAR) is a sudden increase in cortisol that occurs immediately following awakening (Pruessner et al., 1997). Despite its growing use in a variety of health research during the past decade (Fries et al., 2009), there is a limited understanding of CAR's fundamental biopsychosocial meaning (Clow et al., 2010). For example, although CAR is commonly viewed as a biomarker of hypothalamic-pituitary-adrenal-axis (HPA-axis) functioning, it varies as a function of multiple individual (e.g., age, sex; Wust et al., 2000; Kudielka and Kirschbaum, 2003) and contextual factors (e.g., stressful events, day of week, sleep patterns; Kunz-Ebrecht et al., 2004; Chida and Steptoe, 2009), suggesting it can also reflect processes beyond basic neuroendocrine functioning. Among these factors, stress and sleep have both been linked to individual and group differences in CAR

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0306-4530/$ — see front matter. Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.psyneuen.2013.10.009

(see Fries et al., 2009 for review). Yet, their impact on CAR is poorly understood, and despite being highly inter-related (Van Reeth et al., 2000), their effects have rarely been examined simultaneously (Elder et al., in press).

While the association between stress and other indices of HPA-axis functioning has been well documented (Tsigos and Chrousos, 2002), the effect of stress on CAR is less clear. Past research has examined different forms of stress independently, leading to various explanations about the potential role of stress on CAR. For example, chronic life stress may sensitize the HPA-axis, thus leading to a greater CAR (Pruessner et al., 2003; Schlotz et al., 2004). In addition, CAR may also orient the body to the demands of the upcoming day and fluctuate as a function of proximal stress. Specifically, previous day stress may impact CAR by modulating regulatory processes in the limbic region that control adrenal sensitivity (Schmidt-Reinwald et al., 1999), or by increasing perceived anticipatory stress to the events of the upcoming day (Eller et al., 2006; Lovell et al., 2011), although, this latter hypothesis has not been empirically tested.

Alternatively, stress may not directly impact CAR, but such link may be explained by the influence of stressful experiences on other processes, such as sleep. That is, stress and sleep have well documented bidirectional effects (Van Reeth et al., 2000), and thus the impact of stress may be a proxy for the effect of sleep on CAR. Not surprisingly, various sleep domains have been linked to CAR (see Elder et al., in press for a recent review). For example, CAR has been found to vary as a function of sleep quantity/quality (Kumari et al., 2009), awakening time (Edwards et al., 2001; Federenko et al., 2004) and nocturnal awakenings (Hatzinger et al., 2008). These effects have been previously attributed to the role of circadian processes (Federenko et al., 2004), and the stress associated with increased sleep debt (McEwen, 2006). Yet, no study has examined the simultaneous effect of sleep difficulties and stress on CAR, and therefore the nature of the associations between these three domains is not clear.

Therefore, the current study examined the specific impact of multiple aspects of stress and sleep on CAR, simultaneously. We assessed the effects of daily life hassles, perceived anticipatory stress, and self-reported indices of sleep on CAR among a sample of non-treatment seeking community participants. Consistent with previous research (Chida and Steptoe, 2009; Kumari et al., 2009), we predicted that greater stress and sleep difficulties would be individually associated with a greater CAR. However, given the impact of stress on sleep (Van Reeth et al., 2000), we predicted that sleep difficulties would account for most of the variance in CAR when examining the combined effect of sleep and stress.

2. Methods

2.1. Participants

Participants included 58 young adults (29 females; M_{age} = 18.7, SD = .91) from the volunteer psychology participant pool at a large research university in the Midwest of the United States. Participants were recruited through an online sign-up procedure and were given course credit points for their participation. Specific data regarding ethnicity was not collected; however, the sample was likely representative of the ethnic diversity of the university psychology participant pool more generally (68% Caucasian, 15% Asian, 4% African American, 3% Hispanic). The Institutional Review Board at the university approved the study, and participants completed written informed consent.

2.2. Measures

2.2.1. Self-reported stress

A revised version of the Hassles and Uplifts Scale (DeLongis et al., 1982) was used to assess daily hassles or stress (DeLongis et al., 1988). The revised scale contained 53-items, and asked participants to rate on a four-point Likert scale to what extent (0 = none or not applicable; 3 = a great deal) an item was a hassle for them that day. Examples of items on this scale included, "family-related obligations", "enough money for necessities", and "meeting deadlines or goals on the job". The total daily hassles score was equal to the sum across all 53 ratings. Only the daily hassles score was used in the current study. This measure has been shown to be significantly associated with health status (DeLongis et al., 1982), and has been validated for use in repeated measures (DeLongis et al., 1988). Anticipatory stress was assessed each morning by asking participants to rate on an eight-point Likert scale, "how stressful you expect today to be."

2.2.2. Sleep dairy

The Core Consensus Sleep Diary (Core CSD; Carney et al., 2012), developed by a committee of sleep research experts at the Pittsburgh Assessment Conference, is a nine-item self-report measure used to collect information about daily sleep patterns. The diary asked participants to report each day the time they attempted to fall asleep, how long it took them to fall asleep, the number and duration of awakenings experienced, and the final time of awakening (waketime). The Core CSD also asked participants to rate on a five-point Likert scale their overall sleep quality (i.e., "How would you rate the quality of your sleep?"). The following sleep parameters were used for the current analyses: total sleep time (TST), sleep onset latency, wake after sleep onset (WASO), waketime, and sleep quality. Waketime was the time of their final awakening. TSTwas equal to the difference between the final waketime and the attempted sleep time (in minutes), minus how long it took them to fall asleep (sleep onset latency) and WASO. WASO was the sum of their nocturnal awakenings (in minutes). Sleep diaries are a widely used self-report measure of daily sleep patterns, and have been shown to be highly correlated with objective reports of sleep (Monk et al., 1994; Wilson et al., 1998).

2.2.3. Covariates

In order to control for the influence other factors may have on individual differences in morning cortisol (Elder et al., in press), a number of covariates were also examined. Specifically, the impact of factors such as age, sex, contraceptive use, medication use, habitual sleep patterns, waketime, difference between typical waketime and actual waketime (wakediff), and depressive symptomatology were assessed in the current sample. Specifically, participants completed a brief general information sheet that asked questions regarding basic demographics, including medication and