Psychoneuroendocrinology (2013) 38, 2354—2365

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

A day-centered approach to modeling cortisol: Diurnal cortisol profiles and their associations among U.S. adults

Natalia O. Dmitrieva [a,*], David M. Almeida [b], Julia Dmitrieva [c], Eric Loken [b], Carl F. Pieper [a]

[a] Center for the Study of Aging and Human Development, Duke University Medical Center, Durham, NC 27710, USA
[b] Department of Human Development and Family Studies, The Pennsylvania State University, University Park, PA 16801, USA
[c] Department of Psychology, University of Denver, Denver, CO 80208, USA

Received 5 November 2012; received in revised form 7 May 2013; accepted 9 May 2013

KEYWORDS
Aging;
Daily diary;
Diurnal rhythm;
HPA axis;
Latent growth curve modeling;
Mixture modeling;
Salivary cortisol;
Stress

Summary Diurnal cortisol is a marker of HPA-axis activity that may be one of the biological mechanisms linking stressors to age-related health declines. The current study identified day-centered profiles of diurnal cortisol among 1101 adults living in the United States. Participants took part in up to four consecutive days of salivary cortisol collection, assessed at waking, 30 min post-waking, before lunch, and before bedtime. Growth mixture modeling with latent time basis was used to estimate common within-day trajectories of diurnal cortisol among 2894 cortisol days. The 3-class solution provided the best model fit, showing that the majority of study days (73%) were characterized by a Normative cortisol pattern, with a robust cortisol awakening response (CAR), a steep negative diurnal slope, coupled with low awakening and bedtime levels. Relative to this profile, diurnal cortisol on the remainder of days appeared either elevated throughout the day (20% of days) or flattened (7% of days). Relative to the normative trajectory, the elevated trajectory was distinguished by a higher morning cortisol level, whereas the flattened trajectory was characterized by a high bedtime level, with weaker CAR and diurnal slope parameters. Relative to the normative profile, elevated profile membership was associated with older age and cigarette smoking. Greater likelihood of the flattened cortisol pattern was observed among participants who were older, male, smoked cigarettes, used medications that are known to affect cortisol output, and reported poorer health. The current study demonstrates the value of a day-centered growth mixture modeling approach to the study of diurnal cortisol, showing that deviations from the classic robust rhythm of diurnal cortisol are associated with older age, male sex, use of medications previously shown to affect cortisol levels, poorer health behaviors, and poorer self-reported health.

* Corresponding author at: Box 3003, Center for the Study of Aging and Human Development, Duke University Medical Center, Durham, NC 27710, USA. Tel.: +1 919 660 7536; fax: +1 919 668 0453.
E-mail address: natalia.dmitrieva@duke.edu (N.O. Dmitrieva).

0306-4530/$ — see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.psyneuen.2013.05.003

1. Introduction

Cortisol is an integral component of the hypothalamic–pituitary–adrenal (HPA) axis, as it is one of the primary hormones to activate the body's response to stress and mobilize energy stores (Chrousos and Gold, 1992). The classic diurnal pattern previously described in the literature is characterized by a marked cortisol awakening response (CAR) approximately 30–45 min after awakening in the morning, followed by a gradual drop (i.e., diurnal slope) throughout the rest of the waking hours. Although this diurnal waveform is moderately predetermined by heredity (Bartels et al., 2003), and is partially preprogrammed by the body's central biological clock (Van Cauter et al., 1996), it is also dynamic in its response to many chronic and episodic behaviors and environments (Dickerson and Kemeny, 2004). Unlike the stress-responsive increases in cortisol, the CAR appears to be a distinct component of diurnal cortisol, primarily regulated by a preprogrammed endogenous circadian pacemaker (for reviews, see Van Cauter and Buxton, 2001; Fries et al., 2009; Clow et al., 2010a,b). The CAR may mobilize the body's energy reserves in light of awakening in the morning (Pruessner et al., 1997b), switch the immune system to daytime activity (Hucklebridge et al., 1999), and orient the self in time and space, and promote anticipation of the upcoming day's events (Fries et al., 2009). The degree of subsequent decline of cortisol throughout the day, or the cortisol diurnal slope, may indicate an intact HPA-axis negative feedback loop, and has been hypothesized to represent an ability to recover and disengage from stressful events at the end of the day (Heim et al., 2000; Miller et al., 2007).

Although the precise physiological functions of diurnal cortisol are still unclear (e.g., Fries et al., 2009), a dysregulation in the diurnal rhythm has been associated with a number of health conditions, and may be an important marker of physiological activation that may be linked with individual differences in health among adults (Miller et al., 2007; Epel, 2009). For example, both relatively high and relatively low cortisol levels have been linked to a number of outcomes, and have been posited as dysregulated total output, as was elegantly stated in the classic work by Sapolsky and colleagues (1986, p. 285):

> [...] both an absence of and an overabundance of glucocorticoids during stress have profound, if contrasting, pathophysiological consequences, and an inability to appropriately terminate glucocorticoid secretion at the end of a stressor can ultimately be as damaging as the inability to appropriately initiate secretion at the onset of a stressor.

Other studies have shown that in addition to total cortisol output, a disruption in the dynamic quality of cortisol across the day is also crucial to understanding the relation between health and diurnal cortisol. Much of the diurnal cortisol research shows that poorer outcomes are linked with a flattened or blunted profile; however, the great variability in operationalization of the flattened rhythm across different studies gives rise to a complex set of results. Flatter diurnal patterns that are characterized by either low or high overall cortisol output have both been linked to poorer outcomes (for review, see Heim et al., 2000). The hyperactive, but flat diurnal profile – typically distinguished by a high awakening level that remains relatively high throughout the rest of the day – has been associated with cigarette smoking (Steptoe and Ussher, 2006), older age (Van Cauter et al., 1996; Deuschle et al., 1997), and current stressor exposure (Miller et al., 2007). A hypoactive blunted diurnal profile – characterized by a relatively low waking level that is followed by a less negative diurnal slope throughout the day, and results in a relatively high bedtime level – has been linked with being male (Pruessner et al., 1997a; Wust et al., 2000), PTSD diagnosis among Holocaust survivors (Yehuda et al., 2005), chronic fatigue symptoms (Bower et al., 2005), and an increased time following cessation of an acute stressor (Miller et al., 2007).

Whereas a large body of previously published studies have examined individual aspects of diurnal cortisol, there has been relatively little enquiry into simultaneous modeling of the entire cortisol rhythm within a day (*cf*. Adam et al., 2006). Moreover, relatively few studies have conducted a formal investigation into heterogeneity of the diurnal rhythm by identifying commonly observed cortisol profiles (*cf*. Lasikiewicz et al., 2008; Van Ryzin et al., 2009; Kumari et al., 2010). The primary aim of the current study was to identify typical day-centered profiles of diurnal cortisol among a large heterogeneous sample of participants living in the United States. We used growth mixture modeling (GMM) in order to identify latent groups of days based on distinct patterns of cortisol change over the day among a national sample of 1101 adults, who provided a total of 2894 days of salivary cortisol data. Finally, we examined the role of several demographic-, health- and stress-related predictors of cortisol profile membership.

2. Methods

2.1. Participants and procedure

The participants were from the second wave of The National Study of Daily Experiences (NSDE II), which is the daily diary satellite study of the larger National Survey of Midlife Development in the United States (MIDUS II) – a survey of non-institutionalized, English-speaking adults. A comprehensive description of NSDE methodology has been previously reported (Almeida et al., 2002). Briefly, NSDE II respondents (N = 2022) completed eight consecutive evening telephone interviews regarding their experiences during the previous 24 h, including questions on daily stressors, positive events, sleep duration, daily health symptoms, psychological distress, and time use. The interviews were conducted by trained interviewers from the Pennsylvania State University's Survey Research Center using a computer-aided telephone interview system (CATI). All respondents provided informed consent, and were compensated with $25 for taking part in the NSDE II protocol.

2.1.1. Demographic characteristics of participants

Following implementation of exclusion criteria (for details, see Section 2.2.1.1), the analytic dataset consisted of 2894 complete cortisol days, provided by 1101 participants. As shown in Table 1, over one-half of participants were women (56.2%), with age ranging from 34 to 87 years