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Review

Intraindividual variability in cortisol: Approaches, illustrations, and recommendations

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ABSTRACT

Most of the variance in diurnal cortisol is attributable to intraindividual variability (IIV), defined as relatively short-term, reversible changes. Multiple methods for measuring IIV have been proposed, and some have already been applied to cortisol IIV. In the present review, measurement methods are described and applied to simulated cortisol data with known underlying differences in IIV and to real cortisol data from first-year law students. More slope variance and more residual or net variance were well captured by their individual standard deviations. Explorations of reliability suggested that 10 slopes and 50 residuals result in reliable and stable estimates of the individual standard deviations. A data-analytic plan for cortisol IIV is provided.

Contents

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1. Introduction

Intraindividual variability (IIV) is "relatively short-term changes that are construed as more or less reversible and that occur more rapidly [than developmental change]" (Nesselroade, 1991). Many psychological processes have substantial IIV, including cognitive function, affect, appraisals, and even personality (e.g., Eid and Diener, 1999; Fleeson, 2001; Sliwinski et al., 2009; Vasquez et al., 2016; Whitehead and Bergeman, 2014). Furthermore, IIV is associated with psychological and physical health. Higher reaction time IIV predicted greater likelihood of progression from mild cognitive impairment to dementia, and short-term IIV in cognitive tasks may be associated with loss of gray and white matter integrity, particularly in the frontal lobes (MacDonald et al., 2006; Tales et al., 2012). Higher affective IIV characterizes people high in neuroticism (Eid and Diener, 1999; Kuppens et al., 2007; Timmermans et al., 2010) and predicted worsening psychological and physical health (Hardy and Segerstrom, 2016). Higher IIV in life satisfaction and in perceived control predicted earlier mortality (Boehm et al., 2015; Eizenman et al., 1997). These findings reflect "the new person-specific paradigm in psychology" that emphasizes people as dynamic systems (Molenaar & Campbell, 2009; p. 112).

IIV also characterizes physiological processes. Stressful life events were associated with higher IIV in sleep duration and fragmentation but not with averages (Mezick et al., 2009). Whereas IIV in psychological domains has been associated with worse psychological and physical health, respiratory sinus arrhythmia contributes to IIV in the cardiac interbeat interval and is associated with better health (Appelhans and Luecken, 2006; Stein and Kleiger, 1999; Thayer and Sternberg, 2006).

With regard to cortisol, pulsatile secretion follows both circadian and ultradian patterns. A predictable diurnal pattern is characterized by peak levels just after awakening and decreasing levels during the daytime hours that reach a nadir in the late evening and early morning hours (Dickmeis et al., 2013). Superimposed on the diurnal rhythm, cortisol reacts to stressors that are novel, unpredictable, uncontrollable, or involve a social-evaluative threat (Dickerson and Kemeny, 2004). Cortisol IIV (cIIV), however, overwhelms stable individual differences. Variance in cortisol levels at specific times of day (morning and evening) over short periods of time (3 consecutive days) was attributable about equally to stable individual differences and to cIIV (Kertes and van Dulmen, 2012). Over longer periods of time (weeks to years), stable individual differences in diurnal cortisol parameters such as the diurnal slope and area under the curve account for a minority of the variance (10–25%; Hruschka et al., 2005; Ross et al., 2014; Segerstrom et al., 2014; Shirtcliff et al., 2012). The largest amount of variance in diurnal cortisol parameters over days or months is not systematically related to the passage of time but rather is attributable to idiosyncratic fluctuations, that is, cIIV (Ross et al., 2014; Ram and Gerstorf, 2009; Segerstrom et al., 2014).

Although high cIIV is the rule, not the exception, there has been little examination of individual differences in cIIV and their relationship to psychological and physical health. In the existing research, cIIV seems to follow the same pattern as psychological IIV: Higher IIV is associated with poorer health. Outpatients with major depressive disorder had a lower autocorrelation between cortisol observations (indicating higher cIIV) than did healthy controls (Peeters et al., 2004). After fitting models predicting cortisol from time of day, the standard deviation of the residuals was higher (indicating higher cIIV) among caregivers who had poorer psychological health and among adopted children whose adoptive mothers engaged in more overreactive parenting (Marceau et al., 2013; Sannes et al., 2016). Similarly, depressed patients had higher residual error around the circadian rhythm, compared with controls and PTSD patients (Yehuda et al., 1996). cIIV may reflect person influences (e.g., reactivity or neuroticism), situation influences (e.g., unstable or intermittently stressful environments), or dysregulation of the HPA axis (e.g., insensitivity to negative feedback inhibition; Yehuda et al., 1996).

Further research is needed to establish the causes and correlates of cIIV. The present review is intended to facilitate such research by providing methodological demonstrations and recommendations. It compares statistical approaches for quantifying IIV, considers their implications for measuring cIIV, and applies them to both simulated and real diurnal cortisol data. The measurement of IIV is not always straightforward, and multiple methods have been proposed that capture different properties of variability. Furthermore, cIIV differs from many other IIV domains in that people have IIV at multiple levels. The diurnal cortisol slope can and does vary from day to day, and individual values can deviate more or less from this slope. Therefore, cIIV has at least two levels: IIV in the slope from day to day (slope cIIV), and IIV net of this slope (net cIIV), that is, the degree to which individual cortisol values deviate from the line of the slope (see Table 1).

Fig. 1 shows 4 hypothetical individuals with 12 cortisol observations each. Points represent cortisol observations (4 per day over 3 days), and lines represent the slopes on each day. Individual A has low cIIV at both levels; slopes across days are similar and the individual cortisol values lie close to the slopes. B has high slope cIIV, but low net cIIV; slopes differ across days, but the cortisol values on each day lie close to that slope. C is just the reverse; slopes are similar across days, but the cortisol values vary markedly from those slopes. D has high cIIV at both levels because slopes across days are different, and the cortisol values also vary markedly from those slopes.

These two sources of variance may have different underlying correlates. As an example of how two different levels of cIIV might arise, it is possible that B is reactive to the environment but well-regulated with regard to the daily slope: the diurnal slope reacts to environmental variation across days, but individual cortisol values conform to that day's slope. By contrast, C is not reactive but also not well-regulated: the diurnal slope is the same across days, but the cortisol values vary markedly around that slope. One possibility is that one of these types of cIIV predicts health outcomes to a greater degree than the other. Therefore, appropriate selection of a measurement strategy for cIIV and understanding what level of IIV is captured by that strategy is important for the development of research on cIIV.

2. Measurement of IIV

The following section reviews a number of measurement strategies that can be used to quantify IIV, focusing on their practical implications for cIIV. For the mathematical bases of these strategies, see Wang et al. (2012). The strategies are considered in order of their computational complexity, from least complex to most complex. See Table 1 for a summary.

2.1. Intraindividual standard deviation (iSD)

The iSD is the simplest method for quantifying IIV, and perhaps for that reason is the most commonly used measure. Its simplicity is also its strength: It is easy to calculate and to understand. The iSD is merely each individual's standard deviation over all of his or her observations. A higher iSD reflects more IIV.

However, some properties of the iSD require consideration. First, the iSD is agnostic with regard to the order of observations. As a simple example, the data sequence 4-3-2-1 and the sequence 1-4-2-3 have the same iSD, but reflect entirely structured IIV in the first case (variability is perfectly correlated with order) and entirely