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Finding the Middle Ground: Curvilinear Associations Between Positive Affect Variability and Daily Cortisol Profiles

Lauren J. Human
University of California, San Francisco

Ashley V. Whillans and Christiane A. Hoppmann
University of British Columbia

Petra Klumb
University of Fribourg

Sally S. Dickerson
University of California, Irvine

Elizabeth W. Dunn
University of British Columbia

There is growing evidence that there are stable and meaningful individual differences in how much people vary in their experience of positive affect (PA), which in turn may have implications for health and well-being. Does such *PA variability* play a role in physiological processes potentially related to stress and health, such as daily cortisol profiles? We explored this question by examining whether PA variability across and within days in middle-aged adults (Study 1) and across weeks in older adults (Study 2) was associated with daily salivary cortisol profiles. In both studies, individuals who exhibited moderate PA variability demonstrated more favorable cortisol profiles, such as lower levels of cortisol and steeper slopes. Interestingly, for middle-aged adults (Study 1), high levels of within-day PA variability were associated with the least favorable cortisol profiles, whereas for older adults (Study 2), low levels of across-week PA variability were associated with the least favorable cortisol profiles. Collectively, these findings provide some of the first evidence that PA variability is related to daily cortisol profiles, suggesting that it may be better to experience a moderate degree of positive affect variability. Too much or too little variability, however, may be problematic, potentially carrying negative implications for stress-related physiological responding.

Keywords: Positive affect, intraindividual variability, daily cortisol profiles

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Positive affect (PA) fluctuates dynamically across time and situations. Interestingly, there are stable individual differences in the extent to which people vary in their affective states, or in their *PA variability* (Chow, Ram, Boker, Fujita, & Clore, 2005; Eaton & Funder, 2001; Trull et al., 2008). That is, some people are far more likely to experience such fluctuations in PA than others. In turn, PA variability and related constructs play a role in psychological functioning, above and beyond PA levels (Eid & Diener, 1999; Gruber, Kogan, Quoidbach, & Mauss, 2013; Kashdan & Rottenberg, 2010; Kuppens, Allen, & Sheeber, 2010). Although PA levels have been linked to both psychological and physical health (Cohen & Pressman, 2006; Fredrickson, 2001; Lyubomirsky, King, & Diener, 2005; Pressman & Cohen, 2005; Steptoe, Dockray, & Wardle, 2009), it is not yet clear whether PA variability also plays a role in physiological stress-relevant processes that may have implications for physical health. The current studies examined this question by exploring whether variability in PA was associated with an indicator of hypothalamic-pituitary-adrenal (HPA) axis functioning: daily salivary cortisol profiles. Specifically, we assessed PA variability across and within days using 36 repeated daily life assessments from a sample of 106 middle aged adults (M_{age} = 36.77) across a 6-day period in Study 1 and using six repeated daily life assessments from a sample of 88 older adults (M_{age} = 70.83) across 6 weeks in Study 2.

Research is accumulating to suggest that variability in intrapersonal states and traits, such as affect and personality, is important to psychological and physical health above and beyond mean

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Lauren J. Human, Department of Psychiatry, University of California, San Francisco; Ashley V. Whillans and Christiane A. Hoppmann, Department of Psychology, University of British Columbia; Petra Klumb, Department of Psychology, University of Fribourg; Sally S. Dickerson, Department of Psychology and Social Behavior, University of California, Irvine; Elizabeth W. Dunn, Department of Psychology, University of British Columbia.

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Correspondence concerning this article should be addressed to Lauren J. Human, Department of Psychiatry, University of California, San Francisco, 3333 California Street, Suite 465, San Francisco, California, 94143. E-mail: Lauren.Human@ucsf.edu

levels (e.g., Eizenman, Nesselroade, Featherman, & Rowe, 1997; Gruber et al., 2013; Human et al., 2013). For example, greater variability in personality traits has been linked to the development of the metabolic syndrome (Human et al., 2013) and greater mortality risk (Eizenman et al., 1997). Broadly, this may be because greater variability may be both psychologically and physiologically stressful (Human et al., 2013), and reflective of less effective coping (Brandtstädter & Greve, 1994; Eizenman et al., 1997), in turn contributing to worse health and longevity. Thus, intraindividual variability appears to be an important construct to examine in the context of physical functioning but additional research is needed. The present studies attempt to contribute to this area of research by examining how positive affect variability relates to a more proximal stress-relevant physiological process, daily cortisol profiles, that could be a mechanistic link in the broader associations between intraindividual variability and physical functioning.

Defining Intraindividual Variability

Intraindividual variability, relative to more enduring change, can be conceptualized as "relatively short-term changes that are construed as more or less reversible" (Nesselroade, 1991, p. 215). Thus, PA variability refers to fluctuations around one's mean level of PA across situations and time. We are focused here on variability that is presumed to be unstructured with respect to time, as opposed to examining variability that is time-lagged or cycled (e.g., affect as a function of time of day or day of week), or longer-term changes that reflect developmental processes. Such time-insensitive intraindividual variability has been operationalized in a multitude of ways including intraindividual standard deviations (iSDs), within-person residuals, mean square of successive differences (MSSDs), and autocorrelations (see Ram & Gerstorf, 2009 for review). We chose to examine iSDs primarily because they are a very common and easily interpretable indicator of intraindividual variability, and have been shown to have similar associations with psychological adjustment as residual scores (when mean levels are controlled for; Baird, Le, & Lucas, 2006) and MSSDs (Gruber et al., 2013). Further, autocorrelations would seem to be ideal when PA is assessed at very close time intervals, which was done in Study 1 but not Study 2, where PA was assessed at 1-week intervals. Additionally, the analytic models for assessing variability as autocorrelations, which requires multilevel modeling (see Kuppens et al., 2010), are difficult to integrate with our multilevel approach for assessing cortisol daily profiles.

Nevertheless, the iSD does not take into account the time ordered nature of measurements so we also calculated intraindividual variability as the commonly used MSSD, which resulted in a very similar pattern of findings as reported below (see Supplemental Online Materials). Note also that the iSD is often correlated with mean levels (i.e., those who are high or low in PA are likely to have lower standard deviations, in part because they are close to the ceiling or floor of the variable; see Baird et al., 2006), making it unclear whether variability or mean levels drive associations when these constructs are examined separately. As such it is critical to examine both mean levels and variability simultaneously (e.g., Baird et al., 2006; Eid & Diener, 1999). Thus, in the current studies we examine the independent associations of mean levels and variability in PA with respect to daily cortisol profiles.

The HPA Axis and Daily Cortisol Profiles

One of the key physiological systems argued to play a role in how psychosocial experiences influence physical health is the hypothalamic-pituitary-adrenal (HPA) axis (McEwen, 1998). The HPA axis can be activated by a broad spectrum of stressors, triggering a cascade of different processes ultimately leading to the secretion of the hormone cortisol, which can be reliably measured in saliva (Piazza et al., 2010). The release of cortisol in turn influences a variety of systems in the body that are critical for effective responding to acute stressors, including the metabolic and immune systems (Sapolsky, Romero, & Munck, 2000). However, repeated or extended activation of the HPA axis can result in altered cortisol profiles, which could have downstream negative implications for physical health (McEwen, 1998; Seeman & Gruenewald, 2006). In the current studies, we sampled multiple days out of the lives of middle-aged and older adults in an effort to get a snapshot of daily cortisol profiles.

Cortisol has a characteristic diurnal profile, in which cortisol levels rise and reach a peak shortly after awakening and then fall throughout the day, with the rate of decline slowing later in the day (Kirschbaum & Hellhammer, 1989). Although generally relatively stable across days within persons, this characteristic rhythm can be altered by psychological and environmental influences (e.g., Lasikiewicz et al., 2008). Again, short-term alterations are typically adaptive responses to environmental cues. However, more stable alterations to one's daily cortisol profile could have downstream implications for physical health (McEwen, 1998; Seeman & Gruenewald, 2006). There are several aspects of this daily cortisol rhythm that may be relevant to physical health, including cortisol levels, the strength of the morning rise (the cortisol awakening response), and the rate of decline in cortisol throughout the day (the steepness and degree of curvilinearity in the cortisol slope; e.g., Adam, 2006; Kirschbaum & Hellhammer, 1989). The specific cortisol profile that we examined in the current studies was (a) the level of the cortisol slope at midday, (b) the steepness of the linear cortisol slope, and (c) the degree of curvilinearity in the slope. We also examined total cortisol output, indexed by area under the curve (AUC), but did not find consistent patterns of association with this variable and therefore do not present those results (results available upon request).

Although there is not necessarily one uniform pattern of unfavorable cortisol profiles as a result of psychological stress (Miller, Chen, & Zhou, 2007), a flattening of the cortisol slope across the day is perhaps the most agreed upon indicator of an unfavorable cortisol profile. Indeed, flatter cortisol slopes have been linked to greater depression (Knight, Avery, Janssen, & Powell, 2010), greater tension and anger (Adam, Hawkley, Kudielka, & Cacioppo, 2006), cardiovascular disease risk factors, such as greater coronary calcification (Matthews, Schwartz, Cohen, & Seeman, 2006) and mean arterial pressure (Rosmond et al., 2003), and an increased risk of mortality, due to cardiovascular disease (Kumari, Shipley, Stafford, & Kivimaki, 2011) and due to cancer among breast cancer patients (Sephton, Sapolsky, Kraemer, & Spiegel, 2000). Although levels of cortisol are less consistently linked to health and well-being (both high and low levels can be problematic), levels of cortisol tend to be higher in people with depression (Stetler & Miller, 2011). Finally, the degree of curvilinearity in cortisol profiles has only recently been examined with the devel-

opment of more sophisticated modeling approaches, but preliminary evidence suggests that less curvilinearity in cortisol slopes is linked to negative psychosocial processes, such as greater loneliness (Doane & Adam, 2010). As such, for the current studies, we take less steep and less curvilinear slopes, as well as elevated slopes (higher levels), to be indicative of less favorable cortisol profiles.

Daily Cortisol Profiles and Positive Affect Levels

Although the majority of studies on affect and cortisol have focused on negative affect, there is growing evidence that positive affect has independent associations with cortisol profiles (for reviews see Pressman & Cohen, 2005; Steptoe et al., 2009). In particular, higher trait and state PA are generally associated with lower cortisol levels in community samples (Cohen et al., 2003; Davydov et al., 2005; Kugler & Kalveram, 1989; Hoppmann & Klumb, 2006; Nater, Hoppmann, & Klumb, 2010; Polk, Cohen, Doyle, Skoner, & Kirschbaum, 2005; Simpson et al., 2008; Smyth et al., 1998; Steptoe, Gibson, Hamer, & Wardle, 2007; Steptoe, Wardle, & Marmot, 2005). There is also preliminary evidence that higher trait PA is associated with steeper cortisol slopes (Polk et al., 2005). Taken together, these findings suggest that high positive affect is associated with more favorable daily cortisol profiles, in the form of steeper slopes and lower levels.

Although perhaps less directly related to daily cortisol profiles, experimentally induced PA has been shown to both decrease cortisol levels (e.g., Buchanan, al'Absi, & Lovallo, 1999; McCraty, Barrios-Choplin, Rozman, Atkinson, & Watkins, 1998) and increase cortisol levels (Brown, Sirota, Niaura, & Engebretson, 1993; Hubert, Möller, & De Jong-Meyer, 1993). These findings suggest that momentary experiences of PA have the ability to activate the HPA axis, triggering either an increase or decline in cortisol, perhaps depending on the intensity of the experience or contextual factors.

Positive Affect Variability as Maladaptive Lability Versus Adaptive Flexibility

How would we expect positive affect *variability* to be associated with cortisol profiles? Although prior work examining PA levels and aspects of cortisol profiles demonstrates that PA and cortisol are associated, it is less able to inform us of how PA variability would be associated with cortisol profiles. Most previous research that has examined PA variability and individual functioning has focused on psychological functioning. As such, although we are examining physiological processes in the current studies, we review this previous literature to develop hypotheses regarding how PA variability might relate to daily cortisol profiles.

On the one hand, coherence and stability have long been argued to be a sign of healthy psychological adjustment (Block, 1961; Rogers, 1961). One way that coherence and stability could manifest in daily life is as less variability in the experience of PA. Conversely, individuals who are less stable may react more strongly and variably to different situations, experiencing large fluctuations in their PA. This interpretation of PA variability can be defined as *maladaptive lability*, potentially both reflecting and creating greater stress responses to daily life events. Specifically, large fluctuations in PA, for instance feeling very high happiness one moment and very low happiness the next, could trigger a physiological stress response, which could in turn alter cortisol profiles and eventually have negative downstream consequences for physical health (e.g., Seeman & Gruenewald, 2006). Indeed, greater PA variability within and across days has been associated with lower psychological well-being (Gruber et al., 2013) and greater neuroticism (Eid & Diener, 1999). Furthermore, greater PA variability in the afternoon was associated with elevated evening levels of cortisol in a sample of 41 older adults (Simpson et al., 2008). However, only two cortisol samples were taken per day and therefore cortisol slopes were not examined. Nevertheless, these preliminary findings support the argument that individuals who experience high PA variability may experience greater HPA axis activity, potentially resulting in less favorable cortisol profiles.

On the other hand, greater PA variability could also be interpreted as *adaptive flexibility*, indicating that an individual is reacting and responding appropriately to daily experiences. Considered in this light, greater PA variability may promote effective coping (Frijda, 1998). For example, we might expect to be very happy after receiving a promotion and less happy after getting into an argument with a colleague—feeling similarly across these different situations may indicate a rigidity that could be maladaptive. Indeed, more broadly, psychological flexibility has been argued to be indicative of greater mental health (Kashdan & Rottenberg, 2010). Psychological flexibility, indexed as lower autocorrelations in affect over a 2-week period or within interactions, has been linked to higher self-esteem and lower depression (Kuppens et al., 2010). Similarly, more flexible affective responses to varying stimuli have been associated with greater resilience (Waugh, Thompson, & Gotlib, 2011). Thus, if greater PA variability captures greater affective flexibility, it is possible that it could be associated with more adaptive physiological responses to daily events, and therefore be linked to more favorable cortisol profiles.

Overall then, research on intraindividual variability in PA suggests that greater variability can be maladaptive. On the other hand, work on affective flexibility suggests instead that lower PA variability, to the extent that it reflects low flexibility, is maladaptive. These differential findings may in part be due to methodological differences in the assessment of variability versus flexibility, but it is also possible that both high and low PA variability, even when measured in the same manner, could be maladaptive. That is, some degree of positive affect variability may reflect an adaptive flexibility to the ups and downs of daily life. However, too much variability may reflect maladaptive lability, or a tendency to be overly responsive to daily experiences, and too little variability could reflect maladaptive rigidity, whereby individuals are not responsive enough. For example, experiencing too great of change in happiness after receiving a promotion versus getting into an argument may be detrimental physiologically. Thus, there may be an optimal level of PA variability somewhere along the continuum from rigidity to lability. Previous research appears to have focused on the linear relationships between affect variability and psychological outcomes, leaving it unclear whether more nuanced, nonlinear relationships underlie these associations.

The Current Studies

Overall, there is reason to believe that both too much and too little positive affect variability could result in less favorable cor-

tisol profiles. In the current studies, we explored whether both perspectives may be valid by examining the potential curvilinear associations between PA variability and cortisol profiles. That is, perhaps both very low and high levels of PA variability are associated with less favorable cortisol profiles, whereas a moderate degree of PA variability is most favorable. We explored these possibilities using two preexisting datasets that were well suited to address these questions. Specifically, we examined positive affect variability across and within days in middle-aged adults (Study 1) and across weeks in older adults (Study 2). In both studies, cortisol was assessed multiple times per day, for 6 days, enabling a multilevel modeling approach to assessing daily cortisol profiles. We focus on the role of PA variability because previous research has found stronger associations with PA variability, relative to negative affect variability, with individual functioning (Gruber et al., 2013). We did, however, explore the associations between negative affect variability and cortisol profiles and present those results in the Supplemental Online Materials.[1]

Study 1

Method

Overview. The data from this study came from a larger time sampling study examining the balance between work and family in dual-earner couples with small children (Hoppmann & Klumb, 2006). As part of this study, participants' positive affect was measured six times per day for 6 consecutive days through the use of a handheld computer (Psion 3a). Participants also provided six saliva samples for cortisol assays corresponding with each affect assessment.

Participants. Employed couples were recruited from Berlin, Germany through advertisements in the community. Eligibility was confirmed over the phone and required that participants (a) had received higher education (defined as more than 13 years of school); (b) worked at least 20 hr per week; (c) had at least one joint child under 6 years of age; (d) that neither parent had a history of chronic medical or psychiatric disorders that could impact salivary cortisol levels; and (e) that female participants were not breastfeeding or pregnant. Of the 53 eligible couples (106 participants) who participated in the study, two participants were eliminated from the sample due to missing cortisol data (providing $< 50\%$ of the requested samples), resulting in a total of 104 participants for statistical analyses (see Table 1 for sample demographics). Note that the final sample consisted of dual-earner parents with at least one preschool child (Hoppmann & Klumb, 2006 for additional methodological details).

Procedure. Participants first completed an online questionnaire assessing demographic information, followed by an in-home training session with a research assistant. During this session, couples were provided with an overview of the study procedures and were introduced to the use of the time-sampling materials: a Psion series 3a pocket computer and saliva sampling devices (salivette; Sarstedt, Germany). The time sampling phase, which included six questionnaires and saliva samples per day, started the next morning and proceeded for 6 consecutive days, which always included 4 weekdays and both weekend days. For completing the study, couples were offered feedback about their time use, and were entered into a lottery for a wellness weekend. All procedures were in accordance with the ethical guidelines of the University of Technology, Berlin, Germany.

Measures.

Affect. Positive affect was assessed in this study with three items from the Multidimensional Affect Scale, including *good*, *alert*, and *relaxed* (Steyer, Schwenkmezger, Notz, & Eid, 1997). At each time point, participants reported the extent to which they currently felt each affect indicator on a scale ranging from 1 (*not at all*) to 5 (*very much*). Out of the 3,744 daily questionnaires that were administered (104 participants $\times$ 6 days $\times$ 6 measurement occasions), 2.6% were missing. Two thirds of the questionnaires were completed within 15 min of prompting, suggesting a high level of compliance with the sampling protocol. To assess mean positive affect scores we computed a unit-weighted average of the three positive affect items ($M = 3.47$, $SD = .40$, $\alpha = .84$).

Two types of within-participant affect variability were calculated, with intraindividual standard deviations (iSD; Ram & Gerstorf, 2009). *Across-day affect variability* was calculated by first calculating each participant's within-day mean score on each positive affect indicator, then calculating their iSD across days on each affect indicator, and finally, taking the average of these across day, within-indicator iSDs ($M = .42$, $SD = .13$, $\alpha = .64$).

We also calculated each participant's average *within-day affect variability*. To assess average within-day variability, each participant's iSD on each positive affect indicator was calculated for each day, and then averaged across days and indicators ($M = .79$, $SD = .18$, $\alpha = .71$). In order to examine whether there were curvilinear associations between affect variability and cortisol diurnal rhythms, we computed quadratic terms for both across-day and within-day positive affect variability.[2] We also calculated variability scores for each individual affect indicator in order to examine each item separately (see Appendix A for each item's individual mean and variability information).

Salivary cortisol. At each measurement point, participants were asked to provide saliva samples for cortisol analyses. To collect saliva, participants were asked to roll a cotton swab without added flavor ("salivette") in their mouth for 1 min (SARSTEDT, Inc.). Participants were instructed not to brush their teeth, eat, or drink beverages containing alcohol or caffeine 30 min before taking each sample. Otherwise, subjects were free to follow their normal daily routines during each sampling day. The first saliva sample was taken upon waking. The following five saliva samples were taken approximately every 3 hr with suggested sampling times at 9 a.m., 12 p.m., 3 p.m., 6 p.m., and 9 p.m.. Participants were able to individually adjust these times to their schedules to reduce the disruptiveness of the study. Average wake-up time was 7:04 a.m. ($SD = 77$ min) and average following sampling times

[1] Note also that all effects reported below are consistent when negative affect levels and variability were included within the model.

[2] We also examined whether each within-day affect variability score (prior to averaging across days) was associated with same- and next-day cortisol profiles. There was a marginal association between greater within-day PA variability and greater same-day cortisol levels at midday ($b = .11$, $z = 1.91$, $p = .06$) but generally the associations were nonsignificant, all $ps > .13$. This may be because assessments based on a single day are less reliable than averaged cortisol and PA variability indicators, or because the relationship between PA variability and HPA axis functioning are cumulative in nature and therefore would not necessarily emerge on a day-to-day basis.

Table 1
Descriptive Statistics for PA Levels and Variability, and Demographic and Health Characteristics in Study 1 and Study 2

PA or Control Variable	Mean or % (*SD*)	PA Levels	Correlations (*r*s)						
			Across-day/week PA iSD	Within-day PA iSD	Age	Female	BMI	Smoker	Exercise
Study 1									
PA levels	3.47 (0.40)	—							
Across-day PA iSD	0.42 (0.13)	−.24*	—						
Within-day PA iSD	0.79 (0.18)	.00	.22*	—					
Age	36.77 (4.93)	.13	−.22*	−.10	—				
Female %	50	−.08	.07	.21*	−.15	—			
BMI	23.61 (3.14)	−.08	−.15	−.25*	.22*	−.36*	—		
Smoker %	4.72	−.02	.07	−.07	.12	.07	−.03	—	
Exercise	.99 (1.57)	.01	−.05	.06	.03	.10	.07	.04	—
Contraceptive use %	13.21	.01	−.03	.09	−.24*	.39*	−.11	.01	.14
Study 2									
PA levels	3.50 (0.48)	—							
Across week PA iSD	0.62 (0.21)	−.49**	—						
Age	70.83 (4.94)	−.02	.07		—				
Female %	70.50	−.09	−.07		.01	—			
BMI	25.70 (4.40)	.11	.03		.12	.26	—		
Smoker %	4.50	.03	.07		.06	.28	.04	—	
Exercise %	77.46	.07	−.08		.19+	.01	−.00	−.25*	—

Note. $N = 104$ for Study 1, $N = 88$ for Study 2; *SD* = standard deviation (provided for applicable variables); iSD = intraindividual standard deviation; *r* = bivariate correlation coefficients; BMI = body mass index (calculated as weight in pounds divided by height in inches squared). Smoker reflects the percentage of participants who are current regular smokers. Exercise reflects hours of physical exercise throughout the study period in Study 1 and percentage of days participants exercised across the 6 days of cortisol sampling in Study 2.
+ $p < .10$. * $p < .05$. ** $p < .01$.

were 9:26 a.m. (*SD* = 51 min), 12:22 p.m. (*SD* = 22 min), 3:17 p.m. (*SD* = 60 min), 6:13 p.m. (*SD* = 59 min) and 8:51 p.m. (*SD* = 99 min). The standard deviations refer to standard deviations of the time that participants reported taking each sample.

Saliva samples were kept in participants' home freezers during the study and then stored at the Technical University of Berlin at −20 C° until they were analyzed in Clemens Kirschbaum's laboratory at the Technical University of Dresden. Salivary cortisol concentrations were measured using a commercially available chemiluminescent technique (IBL-Hamburg; Hamburg, Germany). This assay has a sensitivity of .16 ng/ml and intra- and interassay coefficients of variation of less than 6% and 8%, respectively (Dressendörfer et al., 1992).

Out of the saliva samples taken by participants during each day of the study only 5.5% were missing indicating a high level of compliance with the cortisol sampling procedure. We did not impute scores for these missing cortisol values given that the multilevel modeling approach used in this study has a high tolerance for missing data (Adam, 2006). The cortisol data were not normally distributed so cortisol values were log-transformed prior to analysis.

Demographic and health covariates. We also obtained a variety of demographic variables, including age and gender, and health and health behavior variables, including BMI, current smoking status, time spent in physical activity throughout the study period, and hormonal contraceptive use (see Table 1). All participants in this study were Caucasian so ethnicity was not examined.

Analytic approach. Multilevel modeling was utilized to examine whether individual differences in affect variability were associated with daily cortisol profiles (e.g., Adam, 2006), using *R*'s *lme4* package (Bates & Sarkar, 2007; R Development Core Team, 2009); see Appendix B for sample R code for these analyses). This approach capitalizes on the opportunity to simultaneously model multiple cortisol parameters and also enhances statistical power (see Adam & Gunnar, 2001; Hruschka, Kohrt, & Worthman, 2005). Specifically, a multilevel growth curve model was used with the effects of time of day on cortisol levels modeled at Level 1, and the effects of individual differences in affect levels and variability, on average across the six days, modeled at Level 2. The cortisol data from each of 6 days were combined together to more accurately estimate the shape of each person's basal cortisol slope and level, and to increase the amount of available degrees of freedom in the Level 1 model.

Dyadic random effects to represent married couples were also modeled at Level 3 to account for this potential source of nonindependence. We also modeled day level random effects to account for correlated within-day error structure, but including these random effects did not substantially alter the results reported below. Therefore, to keep our models more parsimonious and consistent with the models in Study 2, we instead included effect codes for day of assessment at Level 1 to account for possible systematic differences in cortisol levels across days, in line with previous approaches (Adam, 2006). Note that none of the effect codes for day were significant predictors of cortisol levels, all *p*s > .10.

To model diurnal cortisol profiles, each person's cortisol values (log-transformed) were predicted by the time of day of each sample, expressed as the number of hours since awakening for each person each day. Typically, change in cortisol levels through-

out the day is not linear, so a curvilinear model was examined by modeling both linear (time since wakening) and quadratic (time since waking squared) terms for time of day predicting cortisol levels (see Adam, 2006). We centered the time of day variables at the middle of the day (8 hr postawakening); as such, the intercept can be interpreted as cortisol levels at midday or as the level of the participant's cortisol slope at midday (Adam, 2006).[3] Because of the timing of the cortisol samples, we were not able to model the cortisol awakening response in either study. A simplified version of the Level 1 model (where i represents the individual and j represents the assessment occasion), is as follows in Equation 1.1:

$$LogCort_{ij} = \beta_{0ij} + \beta_{1ij}Time_{ij} + \beta_{2ij}Time_{ij}^2 + \varepsilon_{ij}$$

To examine the relationship between individual differences in affect variability and mean levels and diurnal cortisol rhythms, we included affect means and variability (both the linear and quadratic terms) as predictors of the Level 1 coefficients, as outlined in Equation 1.2:

$$\beta_{0ij} = \beta_{00} + \beta_{01}\,Affect_iSD_i + \beta_{02}Affect_iSD_i^2 + \beta_{03}\,Affect_iMean_i + \upsilon_{0i}$$

$$\beta_{1ij} = \beta_{10} + \beta_{11}\,Affect_iSD_i + \beta_{12}Affect_iSD_i^2 + \beta_{13}\,Affect_iMean_i + \upsilon_{1i}$$

$$\beta_{2ij} = \beta_{20} + \beta_{21}\,Affect_iSD_i + \beta_{22}Affect_iSD_i^2 + \beta_{23}\,Affect_iMean_i + \upsilon_{2i}$$

Health-relevant and demographic control variables, specifically BMI, hours of physical activity, current smoking status, age, gender, and oral contraceptive use, were also included as predictors of the Level 1 coefficients. Each potential control variable was first included individually in the model to explore whether it was associated with cortisol profiles in this sample; control variables that were not significantly associated with cortisol profiles were not retained in the final model in order to preserve degrees of freedom (see Adam, 2006).

Results

Descriptive statistics and intercorrelations among the PA variables and covariates are presented in Table 1. Across-day positive affect variability was significantly negatively correlated with positive affect levels, $r = -.27$, $p < .001$, in line with previous research (e.g., Gruber et al., 2013). However, within-day PA variability was not significantly associated with mean levels. The positive affect variability indicators were significantly positively correlated with one another, $r = .25$, $p < .001$; the magnitude of this correlation suggests that within and across day PA variability are related yet distinct constructs.

Average cortisol profiles and associations with covariates. This sample of middle-aged adults showed the expected cortisol diurnal profile: There was a strong, significant decline in cortisol levels across the day, with a significant positive quadratic effect, indicating that cortisol levels declined more slowly later in the day (see Table 2, Figure 1a). Furthermore, there were significant individual differences in the levels and shape of participants' diurnal cortisol slopes (see Table 2 random effects). We first examined whether the demographic and health control variables could account for some of these individual differences by including each control variable as a predictor of the Level 1 coefficients separately. The only control variable that was significantly associated with cortisol profiles was gender, in line with previous research (Adam et al., 2006; Polk et al., 2005; Van Cauter, Leproult, & Kupfer, 1996). Specifically, men's cortisol slopes were significantly flatter than women's, $b = .01$, $z = 1.99$, $p < .05$, and they also had significantly less quadratic curvature, $b = -.0004$, $z = -2.36$, $p < .01$. There were significant differences in the relationships between the affect indicators and cortisol profiles as a function of gender and therefore three-way interactions were included within the analyses presented below.

Affect mean levels and variability. Were positive affect levels and variability associated with cortisol diurnal rhythms? On average across genders, mean levels of positive affect were not significantly associated with cortisol profiles, all ps $> .41$ (see Table 3). Furthermore, there were no significant associations between *across-day* positive affect variability and cortisol profiles, all ps $> .26$.

Linear *within-day* positive affect variability was not significantly associated with cortisol profiles, all ps $> .26$ (see Table 3). Importantly, however, there were significant associations between the quadratic positive affect variability term and cortisol slope levels and curves, all ps $< .05$, such that participants who varied a great deal within days had significantly more elevated and flatter cortisol slopes, and less curvilinearity in their cortisol slopes (see Table 3, Figure 2a). For example, participants at mean and low levels (1.5 standard deviations below the mean) of positive affect variability demonstrated a steeper decline in cortisol throughout the day (mean: $b = -.07$, $z = -20.38$, $p < .0001$; low: $b = -.07$, $z = -18.37$, $p < .0001$), compared with participants at high (1.5 standard deviations above the mean) levels of PA variability, $b = -.06$, $z = -10.22$, $p < .001$. Note that 1.5 standard deviations above and below the mean were used for simple slope calculations and figures to help illustrate this subtle effect. Thus, low and moderate levels of PA variability were associated with more favorable cortisol profiles than high levels of PA variability (see Figure 2a for illustration).

As noted above, there were significant three-way interactions between gender and positive affect variability predicting cortisol profiles, such that the associations were generally stronger for males than females. Indeed, simple slopes analyses revealed that each of the significant effects with the quadratic PA variability term were significant for men (all ps $< .05$) but not women (all ps $> .43$).

Item-level effects. In order to further shed light on what aspects of positive affect may be most related to cortisol daily profiles, we also examined how variability and mean levels of each positive affect indicator were associated with cortisol profiles. A similar pattern emerged for variability in the item *alert* within days, such that there was a trend toward steeper cortisol slopes as variability increased, $b = -.15$, $z = -1.56$, $p = .12$, but there was

[3] We also centered time such that the intercept would reflect cortisol levels at waking (although cortisol was not measured at waking in Study 2). The PA variables were not significantly associated with cortisol at waking in either study, all ps $> .10$.

Table 2
Level 1 Multilevel Model: Cortisol Values Predicted by Time of Day and Time of Day Squared

	Study 1		Study 2	
Fixed effect	Coefficient (*SE*)	*z*-value	Coefficient (*SE*)	*z*-value
Average cortisol intercept (midday)	.73*** (.024)	30.51	.58*** (.040)	14.70
Average cortisol linear slope	−.07*** (.003)	−23.17	−.10*** (.006)	−16.59
Average cortisol quadratic slope	.001*** (.0002)	4.60	.004*** (.0005)	8.43
Random effect	Standard deviation	Chi-square	Standard deviation	Chi-square
Cortisol intercept	.11***	17.26	.20***	53.59
Cortisol linear slope	.02**	10.49	.04***	14.21
Cortisol quadratic effect	.001*	6.06	.003***	10.94

Note. The time variables were centered at midday (8 hr after awakening). The models also included effect codes representing day of assessment.
* $p < .05$. ** $p < .01$. *** $p < .001$.

a marginal quadratic effect, $b = .08$, $z = 1.65$, $p = .10$, such that high levels of variability in alert were associated with flatter slopes. Variability in good and relaxed, however, did not show strong associations with cortisol daily profiles, all $|z|$s < 1.32. Taken together, these results suggest that variability in alert is a stronger predictor of cortisol daily values than good or relaxed. Nevertheless, the composite PA variability indicator demonstrated stronger associations.

Summary

In sum, middle-aged adults, particularly men, who exhibited low to moderate levels of positive affect variability demonstrated favorable cortisol profiles. However, as PA variability levels increased, associations with cortisol profiles became less favorable, such that participants who exhibited the highest levels of PA variability demonstrated flatter cortisol slopes and higher levels at midday. Overall, these findings are consistent with the argument that moderate PA variability may reflect adaptive flexibility, but that too much variability may come to reflect maladaptive lability. Although we did not find clear evidence that low PA variability was indicative of maladaptive rigidity, it is interesting that low levels were no more favorable than moderate levels of PA variability. Study 2 sought to explore the associations between PA variability and cortisol in a sample of retired older adults, whose daily lives differ quite meaningfully from adults who are still participating in the workforce. Study 2 also examined a different time scale, whereby affect ratings were obtained one day per week over a period of 6 consecutive weeks.

Study 2

Method

Overview. This study involved community-dwelling adults aged 65 and older who participated over the course of 6 consecutive weeks. General demographic information and positive affect ratings were collected as part of an initial lab visit. Both positive affect and cortisol were then measured one day per week across 6 weeks; saliva samples were collected the day after affect ratings were completed. This study involved an experimental manipulation in which participants were randomly assigned to spend a small windfall of money ($40) on others or to spend a small windfall on themselves for three weeks over the course of the 6-week study. This experimental manipulation had no effects on the variables

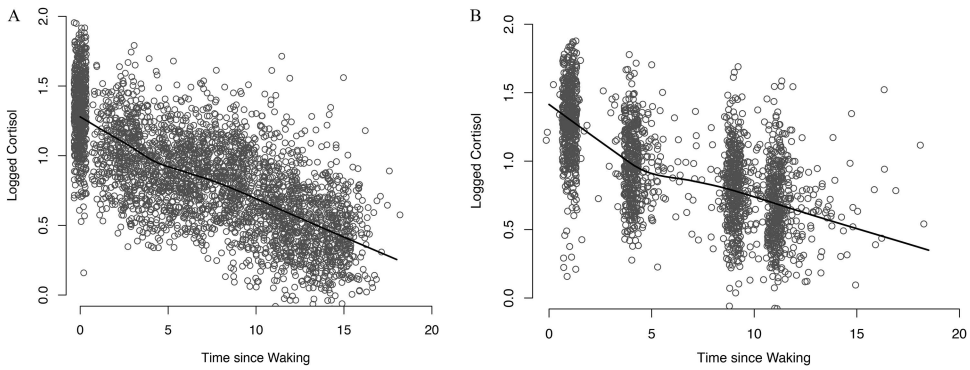

Figure 1. Time since waking predicting logged cortisol values in Study 1 (A) and Study 2 (B). Data are slightly jittered (randomly perturbed) to minimize overplotting and the nonparametric loess curves are plotted.

Table 3
Level 2 Multilevel Model: Predicting Cortisol Values and Slopes From Selected Control Variables and Positive Affect Indicators

Fixed effect	Study 1			Study 2		
	Coefficient (*SE*)	*z*-value	Interpretation	Coefficient (*SE*)	*z*-value	Interpretation
Predicting cortisol intercept (midday)						
Intercept	.70*** (.025)	27.41	$\hat{y}_{midday}$ = 5.01 nmol/L	.56*** (.049)	11.40	$\hat{y}_{midday}$ = 3.60 nmol/L[a]
Gender	.01 (.017)	.26	n.s	.08* (.037)	2.20	20% increase if male[b]
BMI	—	—	—	.01 (.007)	1.49	n.s.
PA mean	.003 (.017)	.22	n.s	−.07† (.036)	−1.87	14% decrease per *SD*
PA iSD	.02 (.017)	1.11	n.s	−.08* (.036)	−2.09	16% decrease per *SD*
PA iSD^2	.03* (.013)	2.01	6% increase per *SD*	.06* (.163)	2.28	15% increase per *SD*
Predicting linear cortisol slope						
Intercept	−.07*** (.004)	−20.38	15% decrease per hour	−.11*** (.008)	−13.48	22% decrease per hour
Gender	.003 (.004)	.93	n.s	.01* (.001)	2.07	3% flatter if male
BMI	—	—	—	.003* (.001)	2.00	.6% flatter per scale pt
PA mean	.003 (.003)	.93	n.s.	−.01† (.007)	−1.93	3% steeper per *SD*
PA iSD	.002 (.003)	.59	n.s	−.01* (.007)	−1.87	3% steeper per *SD*
PA iSD^2	.005* (.002)	2.05	1% flatter per *SD*	.01* (.005)	2.12	2% flatter per *SD*
Predicting quadratic cortisol slope						
Intercept	.001* (.0002)	5.52	.3% increase per hour	.004*** (.001)	7.16	1% increase per hour
Gender	.02 (.001)	.51	n.s.	−.001 (.001)	−1.43	n.s.
BMI	—	—	—	−.0002† (.001)	−1.94	.04% less per scale pt
PA mean	−.0002 (.0002)	−.90	n.s.	.001* (.001)	2.14	.2% more per *SD*
PA iSD	−.0002 (.0002)	−.87	n.s.	.001* (.003)	2.15	.2% more per *SD*
PA iSD^2	−.003* (.0001)	−1.98	.06% less per *SD*	−.001* (.002)	−2.09	.2% less per *SD*

Note. *SE* = standard error; BMI = body mass index; PA = positive affect; PA iSD = within-person positive affect standard deviation (within-day in Study 1; across-week in Study 2); PA iSD^2 = within-person positive affect standard deviation squared. Gender was effect coded (women = −1, men = 1), BMI was grand mean centered, and the positive affect mean and iSD variables were standardized prior to analyses. Effect codes representing day of assessment were also included. Note that the analysis in Study 1 also included three-way interaction terms between gender, affect indicators, and time predicting cortisol values that are not presented here for simplicity.
[a] Because the outcome variable (cortisol value) was logarithmically transformed, the inverse function of that transformation was applied to return the intercept to its original scale of measurement. [b] Special properties of the logarithmic outcome variable allow coefficients predicting the outcome to be interpreted as % change in the outcome per unit of change in the independent variable, after the following transformation to the coefficient B: $B_{\%change} = [10^{(B)}] - 1$ (Neter, Wasserman, & Kutner, 1990; Woolridge, 2000).
† $p < .10$. * $p < .05$. ** $p < .01$.

examined here and all results reported in this article are robust upon controlling for condition assignment.

Participants. Ninety-six older adults between the ages of 65 and 85 (M = 70.77, SD = 4.86) were recruited from the Vancouver, British Columbia area through public advertisements. After completing the initial laboratory visit, two participants withdrew from the study due to personal reasons. An additional two participants were eliminated because they provided insufficient cortisol data (< 50% of the requested samples), and four participants were excluded due to extremely elevated cortisol levels across the 6 weeks (see Cortisol Collection section below), resulting in a total of 88 participants for statistical analyses (see Table 1 for final sample demographics). One participant did not report their gender and six participants did not report their ethnicity; analyses including these control variables therefore include 87 and 82 participants, respectively.

Procedure. Individuals who were interested in participating were screened for eligibility over the phone and in the lab. Individuals were considered eligible to participate if they (a) were 65 years of age or older, (b) were not taking corticosteroid medication, (c) were without a history of medical or psychiatric disorders relevant to our key health measures of interest in the larger study (blood pressure, cortisol, and sleep quality), (d) scored higher than 26 on the Montreal Cognitive Assessment (Nasreddine et al., 2005), and (e) were not leaving town for more than 4 consecutive days during the 6-week study period.

Participants first completed initial laboratory assessment, during which they were given an overview of the study procedures and provided written consent. Participants also completed their first positive affect assessment at this time, and, as part of the larger study, completed additional questionnaires and health measures such as blood pressure and body mass index (BMI). Participants were given materials and instructions for providing saliva samples 1 day per week for 6 consecutive weeks, starting the day following the initial lab visit. Participants also received phone calls 1 day a week for the remaining 5 weeks of the study to assess positive affect, the day prior to the saliva sampling days. Participants returned to the lab during Week 6 when overall study compliance were assessed and all study materials were returned. In total, participants received $150 as compensation for their participation in all parts of the study. The Behavioral Research Ethics Board at the University of British Columbia approved all procedures.

Measures.

Affect. Participants reported their current affect each week on positive affect scale of the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988), which asks participants to report their current affect in relation to 10 positive affect prompts (e.g., interested, alert, determined). Specifically, participants reported the extent to which they felt each emotion "today" on a scale ranging from 1 (*very slightly or not at all*) to 5 (*extremely*). To assess mean positive affect scores, we averaged

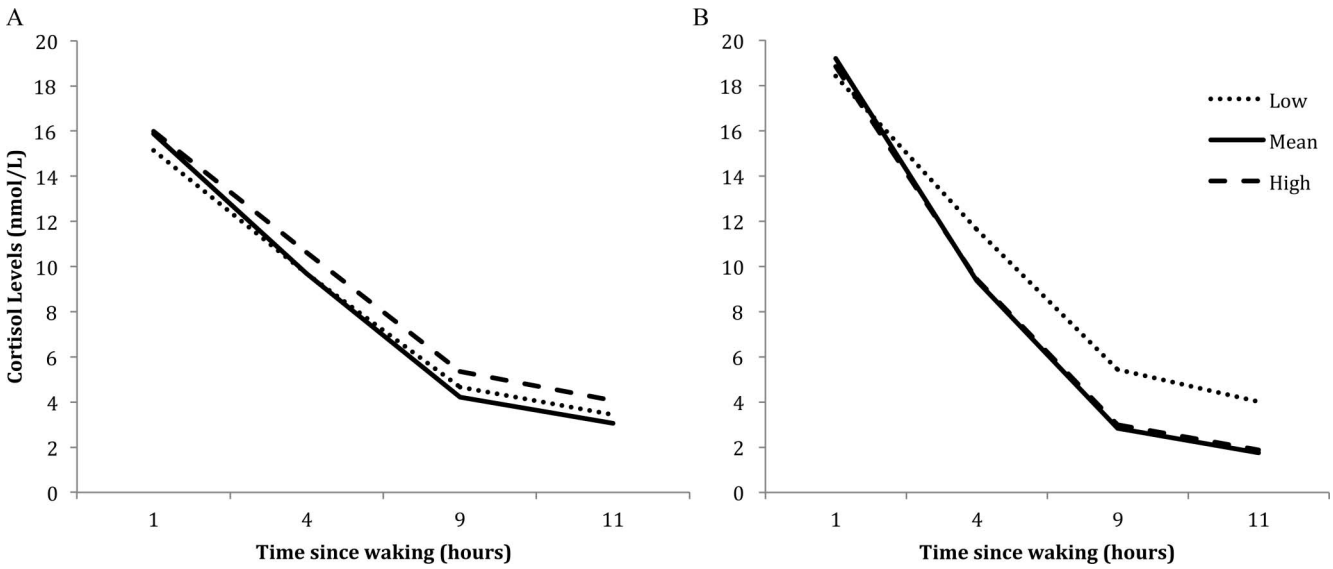

Figure 2. Time in hours since waking predicting cortisol levels as a function of mean, high (1.5 *SD* above the mean), and low (1.5 *SD* below the mean) positive affect variability (PA iSD) in Study 1 (A) and Study 2 (B).

across the 10 positive affect items from each day ($M = 3.50$, $SD = .48$, $\alpha = .91$).

To assess *across-week affect variability*, each participant's iSD on each positive affect indicator across the 6 weeks was calculated, and then the individual iSDs were averaged together to form a single PA variability indicator ($M = .62$, $SD = .21$, $\alpha = .80$). In order to examine whether there were curvilinear associations between affect variability and cortisol profiles, we also computed a quadratic term (positive affect iSD squared). Each participant's PA mean and iSD scores were examined simultaneously to control for the tendency for means and variability to be correlated (Baird, Le, & Lucas, 2006). As in Study 1, mean and variability scores for each individual affect indicator were examined as well (see Appendix A for descriptive information).

Cortisol collection. To assess diurnal cortisol levels, participants were provided with instructions to take their saliva samples at 1, 4, 9, and 11 hr after waking. This schedule was consensually recommended by the MacArthur Research Network on Socioeconomic Status and Health (www.maces.ucsf.edu) for obtaining a reliable measure of cortisol, while simultaneously minimizing participant burden. As in Study 1, the cortisol awakening response (CAR) was not measured, although it is possible that the first measurement at 1 hr after awakening would capture part of the CAR, a potential limitation of this sampling procedure. As in Study 1, to collect saliva, participants were asked to roll a salivette in their mouth for 1 min (SARSTEDT, Inc.). Participants then hand-recorded the time each sample was taken on an accompanying form. Saliva samples were kept in participants' home freezers during the study until their next scheduled appointment; they were then stored at the University of British Columbia at −30 C°. As in Study 1 the samples were analyzed in a laboratory at the Technical University of Dresden (Dressendörfer, Kirschbaum, Rohde, Stahl, & Strasburger, 1992). Salivary cortisol concentrations were measured using an identical chemiluminescent technique as in Study 1.

Overall, only 2.6% of cortisol samples were missing, indicating a high level of compliance. Further, 75.13% of all samples were collected within 1 hr of the instructed time, indicating satisfactory compliance with the sampling instructions. On average, the time that participants reported taking their samples deviated approximately 16 min from the time that they were scheduled to take their samples. Note that the shape of cortisol diurnal rhythms and the results below did not significantly differ as a function of whether cortisol samples were taken within 1 hour of the instructed time or outside of this criteria (maximum deviation from instructed time = 7.5 hr).

If salivary cortisol concentrations exceeded 50 nmol/L, the cortisol value was set to missing (Hellhammer, Wüst, & Kudielka, 2009). This value represented a cortisol value of more than 2.5 standard deviations above the average waking mean of participants in this sample (no samples in Study 1 greatly exceeded 2.5 standard deviations). Four participants had cortisol levels above this cutpoint for the majority of their samples (> 50%) and were excluded from our analyses; an additional 16 samples from other participants were set to missing based on this criterion. Altogether, including outliers set to missing, 3.4% of cortisol samples were missing ($n = 66$ of 1,944 samples). We did not impute scores for these missing cortisol values given that the multilevel modeling approach used in this study has a high tolerance for missing data (Adam, 2006).

Data were imputed for participants who failed to report the time they had woken up and/or failed to report the time they had taken their samples (less than 10% of sample or wake-times were missing: 180 of 1,944). Wake times were imputed by estimating that participants had taken their first sample 1 hour after waking, thus subtracting 1 hour from the time that the first sample was taken accordingly. Sample times were imputed by estimating that participants had taken each sample as scheduled (at 4, 9, and 11 hr after waking). The results reported below did not differ as a function of whether the participants had imputed sample times. The cortisol data were not normally distributed; thus, cortisol values were log-transformed prior to analysis.

Demographic and health covariates. We also obtained measures of a variety of demographic and health and health behavior variables. Demographic variables included age, gender, and ethnicity. Participants were predominantly European American (81.80%), with 6.82% reporting being of Asian descent and 4.55% selecting another category. Health-relevant variables included current smoking status, whether or not participants exercised on the day they provided saliva samples, and body mass index (BMI; see Table 1 for descriptive statistics).

Analytic approach. The data were analyzed in models parallel to those described for Study 1, although only participant level random effects were modeled at Level 2, because we did not have dyadic effects and the models did not converge with the inclusion of day level random effects. Thus, as in Study 1, day of assessment was modeled as dummy coded variables at Level 1 of the model.

Results

Table 1 includes descriptive statistics and intercorrelations for the PA variables and covariates. Positive affect mean levels were significantly negatively correlated with positive affect variability, $r = -.46$, $p < .001$, indicating that individuals who tended to vary more in positive affect experienced lower mean levels of positive affect, in line with previous research (e.g., Gruber et al., 2013) and Study 1. Most of the covariates were not significantly associated with the PA indicators (see Table 1), although Caucasian participants reported marginally higher positive affect mean levels, $r = .19$, $p < .10$.

Average cortisol profiles and covariates. On average, this sample of older adults also showed the expected cortisol diurnal profile: there was a strong, significant decline in cortisol levels across the day, with a significant positive quadratic effect, indicating that cortisol levels declined more slowly later in the day (see Table 2, Figure 1b). Furthermore, the random effects estimates for cortisol intercepts, linear slopes, and quadratic slopes were all significant (see Table 2), indicating that there were significant individual differences in the level and shape of participants' diurnal cortisol profiles.

We first examined whether the demographic and health control variables could account for some of these individual differences by including each control variable as a predictor of the Level 1 coefficients separately. The only control variables that were significantly associated with cortisol profiles were gender (effect coded: women = −1, men = 1) and BMI. Specifically, similar to Study 1, men's diurnal cortisol levels were significantly more elevated at midday and their slopes were significantly flatter than women's, and men had marginally less curvilinearity in their cortisol slopes all ps $< .10$ (see Table 3). Participants with a higher BMI also had significantly flatter cortisol slopes as well as marginally less curvilinearity in their cortisol slopes, all ps $< .10$. Participant gender and BMI were therefore included as covariates when examining the relationships between affect means and variability and cortisol profiles. Note that there were no significant differences in the associations between affect and cortisol profiles as a function of gender or BMI, all ps $> .29$, and therefore three way interactions terms (e.g., between time, affect, and gender predicting cortisol values) were not included within the analyses presented below.

Affect levels and variability. Were positive affect levels and variability across the 6 weeks associated with daily cortisol profiles? Participants with higher average levels of positive affect had marginally lower levels of cortisol at midday, marginally steeper cortisol slopes, and significantly more curvilinearity in their cortisol slopes, all ps $< .10$ (see Table 3). Participants who varied more in positive affect across the 6 weeks also had significantly lower levels of cortisol at midday, significantly steeper cortisol slopes, and significantly more curvilinearity in their cortisol slopes, all ps $< .05$ (see Figure 2b). Thus, greater mean levels and variability in positive affect appear to be associated with more favorable daily cortisol profiles. Importantly, however, there were again significant associations between the quadratic positive affect variability term and cortisol slope levels and curves, such that the association between greater positive affect variability and less elevated, steeper, and greater curvilinearity in cortisol slopes leveled off for individuals with higher levels of positive affect variability. Specifically, participants at mean and high (1.5 standard deviations above the mean) levels of positive affect variability demonstrated the steepest declines in cortisol throughout the day, (mean: $b = -.11$, $z = -13.48$, $p < .001$; high: $b = -.10$, $z = -8.14$, $p < .001$), compared with participants at low (1.5 standard deviations below the mean) levels of PA variability ($b = -.07$, $z = -4.86$, $p < .01$). Thus, in this study, the lowest levels of PA variability were associated with the least favorable cortisol profiles (e.g., flatter slopes; see Figure 2b). Nevertheless, although high levels of variability were not associated with worsening cortisol profiles, they were not associated with increasingly favorable profiles either.

Item-level effects. As in Study 1, we again examined how variability and mean levels of each positive affect indicator related to cortisol profiles. Participants who demonstrated greater variability in enthusiastic had steeper and more curvilinear slopes, all $|z|$s > 1.62. Once again, however, there were also significant and marginal associations with the quadratic terms for enthusiastic, such that high levels of variability were associated with flatter and less curvilinear slopes, all $|z|$s > 1.84. Similar quadratic effects were seen for variability in the items proud and determined, all $|z|$s > 1.72, although the linear effects were not significant. Variability in the remaining items did not, however, show strong associations with cortisol daily profiles, all $|z|$s < 1.57.

General Discussion

Across two studies we found evidence that moderate PA variability was associated with more favorable daily cortisol profiles, such as lower levels of cortisol and steeper and more curvilinear cortisol slopes. This pattern was found for both middle-aged and older adults, and both within days and across weeks. These studies provide some of the first evidence that PA variability is linked to daily cortisol profiles, suggesting that moderate PA variability may reflect adaptive flexibility in this context. That is, moderate PA variability may reflect a tendency to effectively respond to daily experiences without excessive reactivity that could ultimately alter HPA axis functioning.

Of interest, the least favorable levels of PA variability differed across studies. Specifically, high levels of PA variability within days were associated with the least favorable cortisol profiles in middle-aged adults, whereas low levels of PA variability across

weeks were associated with the least favorable cortisol profiles in older adults. Nevertheless, the nonlinear nature of the associations in both studies demonstrated that it was not increasingly beneficial to continue to go above or below moderate levels of PA variability. Instead, taken together, these findings suggest that moderate PA variability may be optimal, whereas both very high and very low levels of variability may be maladaptive at times.

More broadly, the results of these studies contribute to a growing recognition of the importance of intraindividual variability (e.g., Nesselroade, 1991; Ram & Gerstorf, 2009), acknowledging the dynamic nature of affect. In line with evidence that PA variability relates to psychological processes above and beyond mean levels (e.g., Gruber et al., 2013; Kuppens et al., 2010), the current studies extend previous research by suggesting that PA variability is associated with HPA axis functioning. Indeed, higher PA levels were associated with somewhat more favorable cortisol profiles in Study 2, but the associations were weaker and less consistent across studies compared with PA variability. Furthermore, these studies demonstrate the importance of examining *curvilinear* associations between PA variability and daily cortisol profiles. Such curvilinear associations may also extend to other biological processes as well as psychological functioning. Finally, these findings are in line with previous work suggesting that variability in PA may be more relevant to individual functioning than variability in NA (Gruber et al., 2013; see Supplemental Online Materials), further emphasizing the importance of investigating PA variability in future work.

To the extent that less favorable cortisol profiles reflect more general HPA axis functioning, such profiles could in turn have downstream implications for physical health outcomes (McEwen, 1998; Seeman & Gruenewald, 2006), such as cardiovascular disease (Kumari et al., 2011; Rosmond et al., 2003). Indeed, other indicators of intraindividual variability have been linked to longer-term physical health outcomes and processes. For example, greater variability in perceived control in older adults is associated with greater mortality risk (Eizenman, Nesselroade, Featherman, & Rowe, 1997), and greater personality change over time is associated the development of the metabolic syndrome (Human et al., 2013). The current studies, then, may shed light on one potential physiological mechanism, altered HPA axis functioning, which may link intraindividual variability to longer-term health outcomes. Longitudinal work that examines both proximal and distal health-relevant processes and outcomes, such as cardiovascular disease risk, is needed.

Is it Worse to be Very High or Very Low in PA Variability?

Although the general pattern of results across studies was consistent, it is interesting that high levels of PA variability associated with the least favorable profiles in Study 1, whereas low levels of PA variability were associated with the least favorable profiles in Study 2. Why might this be the case? There were a number of differences between these two studies that may account for this differential pattern.

Age-related processes. One possible reason the pattern of results differed slightly across studies could be due to differences in the affective experiences of middle-aged and older adults (Carstensen et al., 1999, 2011; Charles, 2010). Community-dwelling older adults generally report higher levels of PA (Carstensen et al., 2011) and their lives are likely less variable from having already retired and gained more control over their time use. As such, these older adults may be less likely to consistently experience the very high levels of variability that may negatively impact HPA axis functioning in their typical daily lives, compared with midlife adults. Thus, very high levels of PA variability would likely be maladaptive in this sample, perhaps even more so than for middle-aged adults (e.g., Charles, 2010), but perhaps they are less common and therefore do not have the opportunity to take a cumulative toll on HPA axis functioning.

In contrast, middle-aged adults likely experience much more variability in their daily lives, given that these participants were all employed adults caring for a child under the age of six. As such, high levels of rigidity may be less frequent and therefore less likely to have a sustained impact on cortisol profiles, but may nevertheless still be maladaptive if exhibited more consistently. Indeed, middle-aged and younger adults tend to value high arousal PA experiences more than older adults (Scheibe et al., 2013). As such, to the extent that low PA variability limits high arousal PA experiences, less variability may actually be more detrimental for younger compared with older adults. Note that levels of PA variability seem quite similar across studies, but that it is difficult to compare across studies given differences in methodology. Furthermore, age within each sample did not significantly moderate any of the effects reported above. However, these samples are not well suited to examining age differences, as despite the age ranges within each sample, participants within each sample were in a very similar life stage (working parents in Study 1 and retired healthy adults in Study 2). Ideally, future studies that include different age ranges and life stages within the same sample will be able to replicate these findings and examine the sources of these differing patterns in order to establish when and for whom high versus low PA variability is most problematic.

Timescale of PA variability. Another difference between studies was that it was PA variability within days that was linked to cortisol profiles in Study 1, yet it was PA variability across weeks that was linked to cortisol profiles in Study 2. These different time scales may partially account for the slightly different patterns across studies—indeed, just as high PA variability may be harder to detect in older adult samples, it may also be harder to detect across larger time scales, such as across weeks versus within days. Yet, the fact that PA variability across different time scales showed similar associations with daily cortisol profiles, at a broad level, suggests that although they are distinct, they may indeed both reflect the same larger underlying construct. Indeed, PA variability within days and across days were significantly correlated in Study 1, consistent with other studies examining different timescales (Gruber et al., 2013; Kuppens et al., 2010). The current findings suggest that PA variability across weeks may also be related to PA variability within and across days, given similar patterns of associations with cortisol profiles. A more systematic investigation of the relationships between these different timescales of variability is warranted in order to better understand the nature of this individual difference.

Cultural differences. Another difference between these two samples is their cultural background, as the sample in Study 1 was German and the sample in Study 2 was Canadian. There are many differences between these nations, which may have contributed to

some of the differences we see in the pattern of results. However, at a broad level these nations are very similar, both being Westernized, individualistic, and wealthy nations, with strong economies and supportive government infrastructure. Nevertheless, potential cultural differences in the links between PA variability and cortisol profiles would be interesting to examine in future research, especially among even more culturally distinct samples where differences in affective processes are well-established (e.g., Tsai, Knutson, & Fung, 2006).

The role of gender. We also found gender differences in Study 1 such that the associations between PA variability and cortisol profiles were stronger, and indeed only significant, for men. However, this gender difference was not predicted and we did not find a similar gender difference in Study 2, so we hesitate to interpret this finding. Nevertheless, this preliminary finding suggests that future work on PA variability should also explore potential gender differences.

Limitations and Future Directions

Causality. Although the presented studies have many strengths, including the repeated daily life assessments of both affect and cortisol, our findings have to be interpreted in light of several limitations. First, for our primary analyses, the repeated measures nature of these data was utilized to obtain more reliable indicators of both PA variability and daily cortisol profiles, rather than to examine time-lagged associations among these variables. In Study 1, we did examine whether within-day PA variability was associated with same and next day cortisol profiles, but did not find strong associations (see Footnote 2), and this type of analysis was not possible in Study 2, as it was only possible to calculate PA variability across weeks (not within weeks). As such, our results are generally cross-sectional, limiting causal inferences. Ideally, these initial findings will encourage future research that includes additional PA and cortisol assessments over longer time periods, in order to examine the temporal relationships between these variables.

Sources of variability and mechanisms. Another important future research direction will be to examine the processes underlying PA variability and its links to cortisol profiles. For example, to what extent is PA variability systematic, in response to daily events, or more random, and is one type more or less relevant to stress-relevant physiological processes? Unfortunately, the current studies did not measure daily events or stressors in a manner that would allow for such examinations. However, previous work suggests that at least part of the variability in PA across time and situations is systematic in nature, predicted by factors such as the goal-relevance of activities (Hoppmann, Gerstorf, Smith, & Klumb, 2007; Hoppmann & Klumb, 2006) and the presence or absence of various social partners (Chui, Hoppmann, Gerstorf, & Luszcz, 2014). Yet, even if PA variability is generally systematic, it remains unclear whether high levels of PA variability reflect overly strong reactions to daily events versus actually being exposed to more variable or intense events (and vice versa for low PA variability). In order to tease apart sources of systematic variance, such as changes in appraisals and exposure to events, from more random variability, daily events will need to be examined with both subjective and objective measures. Several useful approaches to assessing objective stressors have been developed, such as research examining occupational stress in air traffic controllers (Repetti, 1993) or in work utilizing the Electronically Activated Recorder (EAR; Mehl, Pennebaker, Crow, Dabbs, & Price, 2001), which unobtrusively records ambient sounds in people's daily lives.

Examining the sources of PA variability will also help to shed light on the mechanisms underlying this effect. In addition to examining the role of events, it will also be important to examine whether PA variability is the primary driving force behind these associations, or if it is an indicator of other psychological processes that may underlie these links, such as deficits in emotion regulation. Further, the intermediate links between PA variability and physiological stress responses need to be explored, such as whether PA variability creates difficulties in social or working relationships and increases in psychological stress, in turn contributing to HPA axis activation.

The role of high versus low arousal PA. Finally, it is unclear the extent to which these effects generalize across different aspects of positive affect. Although the PA scales differed across studies, in both studies the majority of PA items assessed high arousal or activated PA (see Russell, 1980), with the exception of the item "relaxed" in Study 1. Nevertheless, the individual items that showed the strongest individual associations, such as alert and enthusiastic, were very high arousal, suggesting that it may indeed be variability in high arousal PA that is most relevant to cortisol daily profiles. Relatedly, variability in high arousal PA seems to be more strongly related to psychological adjustment: In another study that examined item-level effects, variability in higher arousal items (happy and excited) were significantly associated with self-esteem, whereas lower arousal items were not (relaxed and satisfied; Kuppens et al., 2010, Study 1). With respect to cortisol profiles, it seems quite likely that high arousal PA would be more relevant, as it may be more likely to contribute to activation of the HPA axis. Indeed, experimental studies that have found that PA causes both decreases (Buchanan et al., 1999; McCraty et al., 1998) and increases in cortisol (Brown et al., 1993; Hubert et al., 1993) have generally demonstrated these effects with high arousal PA. Although it is unclear why high arousal PA would lead to both increases and decreases, these findings nevertheless lend support to the idea that high arousal PA may be particularly relevant to HPA axis activation.

More generally, high and low arousal PA seem to have different patterns of association with physiological activation, with high arousal PA being more likely to activate stress-related physiological systems (such as increases in blood pressure, heart rate, and circulating immune cells), whereas low arousal PA states are more likely to have weaker or calming effects (see Pressman & Cohen, 2012, for review). Taken together, these pieces of evidence suggest that variability in high arousal PA may be more relevant to physiological stress-relevant processes, although additional research is needed.

There are also age differences in preferences for high versus low arousal PA, with older adults preferring low arousal PA compared with younger adults (Scheibe et al., 2013), suggesting there may also be age-related differences in the consequences of high versus low arousal PA variability. Furthermore, older adults may have more difficulty recovering from high arousal affective experiences, which could in turn result in greater negative psychological and physiological consequences (see Charles, 2010). Thus, variability

in high arousal PA may be particularly problematic for older adults. Hopefully future research will examine the role of different types of PA variability by assessing both high and low arousal PA within the same study and examining the consequences of both across different age groups.

Conclusion

Overall, in both middle-aged and older adults, moderate PA variability was associated with more favorable cortisol profiles. These findings help to bridge two somewhat contradictory lines of research, which suggest that intraindividual variability is either adaptive or maladaptive, by demonstrating the validity of both perspectives. Hopefully these findings will prompt future research on this topic that will shed light on the longitudinal and mechanistic relationships between PA variability and cortisol profiles. In conclusion, in the context of cortisol profiles, the current studies provide novel evidence that moderate PA variability may reflect an optimal degree of adaptive flexibility, indicating a balance between the extremes of less adaptive rigidity and lability.

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Appendix A

Mean Levels and ISDs for Each PA Indicator

PA Item	Level Mean (*SD*)	iSD Mean (*SD*)
Study 1		
Alert	3.44 (.50)	.89 (.23)
Good	3.69 (.43)	.68 (.18)
Relaxed	3.28 (.47)	.75 (.20)
Study 2		
Alert	3.84 (.49)	.53 (.32)
Active	3.69 (.60)	.69 (.38)
Excited	2.74 (.85)	.80 (.40)
Determined	3.53 (.63)	.64 (.33)
Enthusiastic	3.58 (.66)	.60 (.36)
Interested	3.93 (.47)	.59 (.35)
Inspired	3.34 (.74)	.55 (.39)
Strong	3.53 (.53)	.56 (.31)
Proud	3.22 (.86)	.60 (.41)
Attentive	3.74 (.56)	.55 (.33)

Note. PA = positive affect; *SD* = standard deviation; iSD = intraindividual standard deviation.

(*Appendices continue*)

Appendix B

Sample R Code for Multilevel Models in Study 1

Package(lme4)
lmer(Cort ~ Time + Time2 + Day2+ Day3 + Day4 +Day5 +Day6 + (Time + Time2 | ID)+ (Time + Time2 + Day | DyadID), data = data)
Primary Model Examining Whether PA Means and Variability Predict Cortisol profiles:
lmer(Cort ~ Timec* PAisd + Time2* PAisd + Timec* PAisd2 + Time2* PAisd2 + Time* PAmean + Time2* PAmean + Day2+ Day3 + Day4 +Day5 +Day6 +(Timec + Time2 | ID) + (Timec + Time2 | DyadID), data = data)
Where:
Cort = Logged Cortisol Value
Time = Time Since Waking, Centered at Midday
Time2 = Time Since Waking Squared, Centered at Midday
Day = Day Dummy Coded With Day 1 as the Reference Group
ID = Participant ID
DyadID = Couple ID
PAisd = Intraindividual Standard Deviation for PA Composite, Mean Centered
PAisd2 = Intraindividual Standard Deviation for PA Composite Squared, Mean Centered
PAmean = PA Level, Mean Centered
Data = Dataset Label

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