## Title
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BRIEF REPORT

# Intra-individual Associations of Perceived Stress, Affective Valence, and Affective Arousal with Momentary Cortisol in a Sample of Working Adults

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## Abstract

***Background*** Research pairing ecological momentary assessment (EMA) methodology and ambulatory cortisol during daily life is still rare, as is careful testing of the within-person associations between stress, affect, and cortisol. Using a circumplex approach, we considered both valence and arousal components of affect.

***Purpose*** To examine the within-person covariation of momentary cortisol with momentary perceived stress, affective valence, and affective arousal in everyday life.

***Methods*** 115 working adults ($M_{age}$ = 41.2; 76% women; 76% white) completed six EMA surveys per day over 3 days. Each assessment included reports of perceived stress and affect (used to construct indicators of affective valence and arousal), followed by a saliva sample (from which cortisol was assessed). Multi-level models were used to examine the momentary associations between perceived stress, affective valence, affective arousal, and cortisol.

***Results*** Moments characterized by higher perceived stress were associated with higher cortisol ($p$ = .036). Affective valence covaried with cortisol ($p$ = .003) such that more positive valence was associated with lower cortisol and more negative valence with higher cortisol. Momentary affective arousal was not related to cortisol ($p$ = .131). When all predictors were tested in the same model, only valence remained a significant predictor of cortisol ($p$ = .047).

***Conclusion*** Momentary perceived stress and affective valence, but not affective arousal, were associated with naturalistic cortisol. Cortisol was more robustly associated with affective valence than perceived stress or affective arousal. These findings extend our understanding of how moments of stress and particular characteristics of affective states (i.e., valence but not arousal) may "get under the skin" in daily life.

**Keywords** Stress · Affect · Cortisol · Ecological momentary assessment

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## Introduction

Negative affective experiences, intense affective responses, and perceived stress have all been linked to poor health [1–4]. One proposed pathway linking these constructs with negative health outcomes is through repeated release of cortisol as a result of activation of the hypothalamic–pituitary–adrenal axis (HPA-axis; [5]). Repeated activations of this system may lead to physiological wear and tear over time, increasing the susceptibility to disease [1]. Prior work has identified a few key contributors to cortisol activation including perceived stress and affect [6–14], but there are some important limitations to this research. First, it is not yet clear the degree to which stress and affect are independent from one another or whether they are uniquely predictive of cortisol. Second, much of the research conducted to date compares individuals to one another (i.e., between-person comparisons); this approach is useful for examining if those individuals experiencing more stress or worse affective states are also those with worse cortisol profiles (e.g., higher cortisol, or greater area under the curve). Using an approach that allows us to compare how stress and affect are related to cortisol within an individual over time and across contexts (i.e., within-person approach) provides unique information about moments of risk within an individual (which may be particularly informative for implementing person-specific treatments to reduce the impact of stress on health). Finally, these associations are often examined in controlled lab settings. Although this is desirable for many reasons (e.g., experimental control, internal validity), laboratory experiences of stress and affect may not generalize to everyday life [15]. Taken together, concurrently examining perceived stress (the subjective evaluation of feeling stressed, typically conceived as the degree to which demands are exceeding available resources; [16]) and affect in the context of everyday life to evaluate their unique associations with cortisol may help indicate potential targets for intervention.

Although cortisol is released as a part of the acute stress response, evidence linking cortisol with perceived stress in everyday life has been mixed, with some studies finding that greater stress perceptions are associated with higher levels of cortisol [8, 11–13], whereas others report mixed [10, 14] or null associations [7]. One potential contributor to these mixed results is that not all studies have carefully separated perceptions of stress and affect (particularly high arousal negative affect). Affect is often measured (independently) as positive and negative affect, such as is often done with the Positive and Negative Affect Schedule; as such, these approaches primarily consider only the valence dimension of affect. Other work has suggested that arousal is a distinct dimension of affect [17, 18]. In this view, affect should be conceptualized as having a valence dimension capturing the hedonic quality of the affective experience and an arousal dimension assessing the perception of activation, often referred to as the Circumplex Model of Affect [18]. By not measuring and testing each dimension separately, we may be limited in our understanding of how different aspects of affective experience may relate to HPA-axis functioning in daily life.

Most research investigating the covariation of affect and cortisol has not examined components of valence and arousal separately. For example, higher momentary negative affect has been associated with increased momentary cortisol [7–9, 11, 12], and increased positive affect has been associated with lower cortisol [11, 19]. To date, the contribution of affective arousal to these associations is less clear. A limited number of studies have taken a circumplex approach to assessing momentary affect while also examining associations with momentary or day-level cortisol [20, 21], with one study in particular indicating that affective valence may be particularly important in the prediction of momentary cortisol [21]. However, affective arousal, perhaps independently of valence, has been shown to covary with cardiovascular and respiratory processes in a manner similar to what would be expected in a physiological stress response (e.g., [22–24]), but it is unclear whether affective arousal would similarly be related to cortisol levels.

In sum, although existing studies provide some indication as to how perceived stress and affect are separately related to cortisol levels, there has been limited research examining how the subjective appraisals of stress, affective valence, and affective arousal may uniquely predict cortisol levels in everyday life. The purpose of this research is to take a within-person approach to examine the unique contributions of perceived stress, as well as both the valence and arousal components of affect, to momentary cortisol; such analyses may provide insights into the micro-processes underlying the long-term associations of stress and affect to health outcomes.

## METHODS

### Participants

A community sample of 115 working adults were recruited from the greater metropolitan area of a mid-sized city in the Northeastern USA via random calls from a local telephone directory, public listings on an email listserv, and from local event websites. Eligible participants were: (a) over the age of 18, (b) employed Monday through Friday with regular work hours between 6:00 AM and 7:00 PM, (c) not employed on weekends, (d) available to visit the lab on Wednesday evening and the following Monday, (e) fluent in English, (f) required to have had no changes to psychiatric therapy or medications in the past 3 months, and (g) were not pregnant.

### Materials and Procedure

All materials and procedures were approved by the appropriate institutional review boards. Eligible participants attended an initial laboratory visit (Wednesday evening), where they provided written informed consent and sociodemographic information. Participants were provided with test devices and trained on how to complete ecological momentary assessment (EMA) surveys. Participants were also provided with salivettes (Sarstedt AG & Co, Germany) and trained how to collect and store saliva samples. Each participant was provided with three small bags that contained six salivettes per bag and asked to use one bag per day.

For the next 3 days (i.e., Thursday to Saturday), EMA surveys were gathered using handheld devices (Z22, Palm Inc. Sunnyvale, CA) that participants carried during waking hours (with wake and sleep times pre-specified by participants). Auditory alarms on the devices signaled participants to complete six surveys each day at semi-random intervals (intervals were ~2.5 hr apart) with at least 30 min between each survey. EMA surveys were programmed and collected using a free, open-source software package Experience Sampling Program (http://www.experiencesampler.com) and each survey was automatically dated and time-stamped. Immediately following each EMA survey, participants were reminded to provide a saliva sample and to record the date and time on the salivette. Upon completion of the EMA and salivary collection protocol, participants returned all study materials and were compensated $100 with an additional $20 for completing at least 17 of 18 EMA surveys. Saliva samples were sent to a technical lab (Dresden, Germany) to assay cortisol using standardized methods.

The EMA self-report surveys assessed perceived stress and affect at the time of the assessment. Momentary perceived stress was assessed using the four-item Perceived Stress Scale [16], modified to assess in-the-moment perceptions. For example, participants were asked "at the time of the prompt, did you feel like you could not control important things?", and responded using a 0 (*not at all*) to 4 (*very much*) scale. The perceived stress EMA items were averaged to create a single score with higher values indicating greater perceived stress. The momentary affect items were assessed by having participants indicate how they felt at the time of each prompt on a 0 (*not at all*) to 6 (*very much*) scale. Following past work [24] and dimensional models of affect [25], we operationalized valence using the two self-report items of happy and sad (within-person $r = -.43$, $p < .0001$), and arousal using the two self-report items of interested and tired (within-person $r = -.34$, $p < .0001$). The items sad and tired were reverse scored, and then the pairs of EMA items were averaged to create valence and arousal scores, where higher valence scores indicate more positive affect, and higher arousal scores indicate greater arousal.

Additionally, other time-varying (momentary) indicators that can influence cortisol assessments were collected at each beep. Notably, participants reported on recent consumption of medication, caffeine, alcohol, cigarettes, food or drink and recent physical activity.

### Analytic Procedure

Given the non-normal distribution (skew = 6.67; kurtosis = 71.57) observed in cortisol, the values were log-transformed prior to analysis (log10; [26, 27]), which was effective for achieving normality (skew = −0.18; kurtosis = 1.01). Momentary perceived stress, affective valence, and affective arousal were used to predict log cortisol in each analysis. The predictors in the models were within-person centered on the person-means for each individual to capture within-person fluctuations around their typical levels, as well as the person-mean to capture general tendencies of stress and affect. Covariates included time of day (wherein time of day was recoded into six 3-hr blocks, ranging from 1 to 6, consistent with the window of time each EMA prompt took place), type of day (i.e., weekend or weekday), recent consumption of food or drink, and recent physical activity. As an initial process to determine covariates, other potential covariates were tested (i.e., oral contraceptive use at the person level, recent medication, caffeine, alcohol, and cigarette consumption at the momentary level) but were not significant in any of the models, and were therefore removed.

To account for the nested three-level data structure (i.e., assessments nested within days, days nested within people), all models were estimated in the mixed modeling framework using PROC MIXED in SAS (v9.4). First, three separate models tested the contemporaneous association between the predictors—(a) momentary perceived stress, (b) momentary affective valence, and (c) momentary affective arousal—and log-transformed momentary cortisol. These models examined the influence of each predictor on the outcome of momentary cortisol. A final model in which all predictors were included in the same model were constructed to examine the potential unique influence of each predictor on log-transformed cortisol. Models were fit with random intercepts (as individuals are likely to differ in their average cortisol levels) and a spatial power (i.e., SP(POW)) covariance structure (to control for observations temporally closer to each other being more strongly related than observations further apart). Models were tested allowing for random slopes of momentary variables (e.g., momentary arousal, time of day) on cortisol; random slopes were retained in models where significant at $p \leq .05$ (see Table 1). This secondary analysis was not pre-registered.

## RESULTS

### Sample Characteristics

A total of 115 participants enrolled in this study. Participants ranged in age from 19 to 63 years old ($M = 41.23$, $SD = 11.87$) and were mostly women (76%) and married (53%). A total of 76% of participants identified as White, 13% as Black or African American, 6% as Asian, 3% as multiethnic, and 2% as American Indian or Alaska Native. Annual household incomes ranged from: 21% low income (< $30k), 52% middle income ($30k to

**Table 1** The association of momentary perceived stress, affective valence, and affective arousal with momentary cortisol

| | Perceived Stress (Model 1) | Valence (Model 2) | Arousal (Model 3) | Combined (Model 4) |
|---|---|---|---|---|
| | *b* (*SE*) | *b* (*SE*) | *b* (*SE*) | *b* (*SE*) |
| *Fixed effects* | | | | |
| Intercept | 0.98 (.083)* | 1.03 (.133)* | 1.02 (.097)* | 0.85 (.241)** |
| Time of day | **−0.14 (.007)*** | **−0.14 (.007)*** | **−0.14 (.007)*** | **−0.14 (.007)*** |
| Type of day (weekend) | −0.05 (.018)** | −0.05 (.018)** | −0.05 (.018)** | −0.05 (.018)** |
| Recent eat/drink | −0.05 (.021)*** | −0.05 (.021)*** | −0.05 (.021)*** | −0.05 (.021)*** |
| Recent activity | 0.08 (.038)*** | 0.08 (.038)*** | 0.08 (.038)*** | 0.08 (.038)*** |
| Mean perceived stress | 0.02 (.034) | / | / | 0.04 (.048) |
| Mean valence | / | −0.001 (.025) | / | 0.01 (.039) |
| Mean arousal | / | / | 0.001 (.020) | 0.01 (.028) |
| Momentary perceived stress | 0.03 (.014)*** | / | / | 0.02 (.014) |
| Momentary valence | / | −0.03 (.008)** | / | −0.02 (.009)*** |
| Momentary arousal | / | / | −0.01 (.007) | −0.004 (.007) |
| *Random effects* | | | | |
| Var (intercept) | 0.04 (.013)* | 0.05 (.01)* | 0.05 (.01)* | 0.05 (.01)* |
| Var (time of day) | <0.01 (.001)** | <0.01 (.001)** | <0.01 (.001)** | <0.01 (.001)** |
| Cov (intercept, time of day) | −0.01 (.003)*** | −0.01 (.003)*** | −0.01 (.003)*** | −0.01 (.003)*** |
| SP(POW) | 0.99 (.002)* | 0.99 (.002)* | 0.99 (.002)* | 0.99 (.002)* |
| Residual | 0.02 (.006)* | 0.02 (.005)* | 0.02 (.005)* | 0.02 (.006)* |

Bolded effects indicate a random slope. Results are unchanged when covariates are removed.

*SP*(*POW*) spatial power covariance structure.

*$p < .001$, **$p < .01$, ***$p < .05$.

$75k), 27% high income (> $75k). Most participants reported having a college education (31% with college degree, 17% with graduate degree), while others reported some college education (26%), an associate degree (15%), high school or GED (9%), vocational certificate (1%), or some high school (1%).

Across the 115 participants, 1,733 momentary assessments were collected, with a compliance rate of 84%. Participants reported a mean perceived stress score of 1.81 ($SD = 0.71$), a mean valence score of 4.80 ($SD = 1.07$), and a mean arousal score of 3.86 ($SD = 1.38$). Across all observations, person-mean centered perceived stress was significantly correlated with both person-mean centered affective valence ($r = -.31$, $p < .001$) and person-mean centered affective arousal ($r = -.16$, $p < .001$), which also correlated with each other ($r = .31$, $p < .001$). These small correlations suggest that these are not colinear measures and thus can be interpreted if entered in the same model. A total of 1,593 cortisol samples were collected, with a compliance rate of 77%. Across all samples and all participants, mean log-cortisol values were 0.52 nmol/l ($SD = 0.38$). Of the 1,733 momentary assessments, 1,580 (91.2%) had a paired cortisol measure.

### Models Testing Each Predictor Separately

#### *Perceived stress*

Momentary perceived stress was a significant predictor of momentary salivary cortisol, $p = .023$ (Table 1; Model 1). Moments characterized by greater perceived stress than typical for a person were associated with higher cortisol in that moment compared to moments with less perceived stress than typical for that individual.

#### *Affective valence*

Similarly, momentary affective valence covaried with cortisol, wherein moments of higher positive affective valence than typical for the individual were associated with lower cortisol, $p = .002$ (Table 1; Model 2), compared to moments with less positive valence.

#### *Affective arousal*

Momentary affective arousal was not significantly associated with cortisol, $p = .121$ (Table 1; Model 3).

### Model Testing All Predictors Together

To examine if momentary perceived stress, affective valence, and affective arousal show unique associations with momentary cortisol (above and beyond variance shared with the other variables), the primary predictors were tested in the same model (Table 1; Model 4). This model revealed that only momentary affective valence remained a significant predictor of momentary cortisol, $b = -0.021$, $SE = .009$, $p = .022$.

It is possible that the affective dimensions of valence and arousal interact; for example, arousal may matter more when the valence is negative. Thus, in an exploratory manner, we tested affective valence, affective arousal, and the valence-by-arousal interaction in the same model predicting cortisol; the two-way interaction was not significant, $b = 0.01$, $SE = .007$, $p = .085$.

## Discussion

The examination of associations between stress, affect, and salivary cortisol using ambulatory methodology is of longstanding interest (for review see [28]). Examination of the momentary (within-person) associations between perceived stress, affect, and cortisol, however, are still rare [28], and little is known about the specific role of affective arousal in these associations. This paper extends our understanding of the momentary covariation of perceived stress, affective valence, affective arousal, and cortisol in daily life. In our analysis, initial models in which perceived stress, affective valence, and affective arousal were tested individually identified significant associations between both perceived stress and affective valence with momentary cortisol. These results are largely consistent with assertions that naturally occurring variation in stress and affect in everyday life is associated with HPA-axis activation [8]. When these predictors were included in the same model, however, only momentary affective valence remained a significant predictor of momentary cortisol. This provides some evidence that affective valence may be more important for cortisol secretion than either perceived stress or affective arousal.

The concept that momentary affect mediates the effects of momentary stress on cortisol secretion has been reported previously (e.g., 11), and only a few studies have further clarified these relationships. One recent study has provided some insight into the role of affective valence and arousal on momentary cortisol by applying a circumplex approach to the measurement of affect in a sample of women [21]. The authors report that higher momentary levels of high arousal negative affect and lower levels of positive affect (regardless of arousal level) were associated with higher cortisol secretion, whereas stress and low arousal negative affect were not associated with cortisol. Combined with the results of this analysis, it is suggested that future research on this topic should consider assessing and characterizing affect using a circumplex approach to better characterize which components of affect may be driving these associations.

In terms of limitations, the items used to measure affective valence and arousal did not fully characterize a robust circumplex measure (although our approach was based on other work; [29]). Future studies are needed to replicate these findings using a more comprehensive measure of affective dimensions of arousal and valence. Second, stress may affect cortisol indirectly through affective valence, yet this temporal model would be difficult to capture in ambulatory settings. Ideally it would require measures at the onset of a stressor, followed by short assessments of stress appraisals, and then measures of affective valence. With most EMA designs using signal-contingent sampling at semi-random times (as was done in this study), it is unlikely to capture many moments precisely when stress is beginning and the spacing between assessments (e.g., ~2–3 hr) is insufficiently granular to model dynamics that occur more rapidly. Laboratory studies in which tight control of temporal patterns and repeated short-term assessments are possible may be better equipped to study fast-acting temporal processes. Finally, participants collected cortisol immediately after completing the EMA survey. Given that cortisol is typically slow to peak (i.e., ~20 to 30 min; [30]), it is possible that we may not have been capturing the peak of the cortisol responses and thus have underestimated the effects.

## Conclusions

Our results indicated that momentary perceived stress and affective valence, but not affective arousal, predicted momentary levels of cortisol in the natural environment. We also observed that within-person variability in cortisol was more strongly predicted by affective valence than by perceived stress and affective arousal. When repeated over time, these micro-processes may represent one mechanism underlying the long-term associations of stress and affect to health outcomes.

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### Compliance with Ethical Standards

**Authors' Statement of Conflict of Interest and Adherence to Ethical Standards** The authors have no conflicts of interest to report.

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