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Real-time subjective assessment of psychological stress: Associations with objectively-measured physical activity levels

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ABSTRACT

Psychosocial stress may be a factor in the link between physical activity and obesity. This study examines how the daily experience of psychosocial stress influences physical activity levels and weight status in adults. Temporally ordered relationships between sedentary, light, and moderate-to-vigorous physical activity levels and real-time reports of subjective psychosocial stress levels are reported. Adults ($n = 105$) wore an accelerometer and participated in an ecological momentary assessment (EMA) of stress by answering prompts on a mobile phone several times per day over 4 days. Subjective stress was negatively related to sedentary activity in the minutes immediately preceding and immediately following an EMA prompt. Light activity was positively associated with a subsequent EMA report of higher stress, but there were no observed associations between stress and moderate-to-vigorous activity. Real-time stress reports and accelerometer readings for the same 4-day period showed no association. Nor were there associations between real-time stress reports and weight status.

1. Introduction

Obesity affects nearly one in three adult Americans, with even higher prevalence among those who are socially and economically disadvantaged (Centers for Disease Control and Prevention & Behavioral Risk Factor Surveillance System (BRFSS), 2015; Flegal, Carroll, Kit, & Ogden, 2012). Obesity is associated with serious chronic health conditions including heart disease, diabetes, cancer, and osteoarthritis (Centers for Disease Control and Prevention, 2012), making it one of the largest contributors of excess mortality and morbidity in the United States today. Weight gain, at the individual level, is fundamentally caused by consuming more calories than one burns over a given time period (Hall et al., 2012).

However, current research suggests that this "energy balance equation" might have other important inputs. For example, chronic exposure to psychosocial stress has been implicated as a factor in excess weight, abdominal fat deposition, and weight gain over time (Bjorntorp, 2001; Block, He, Zaslavsky, Ding, & Ayanian, 2009; Harding et al., 2014; Iversen, Strandberg-Larsen, Prescott, Schnohr, & Rod, 2012; Rod, Gronbaek, Schnohr, Prescott, & Kristensen, 2009; Torres & Nowson, 2007). Chronic psychosocial stress is defined as exposure to social conditions sufficiently demanding that they threaten homeostasis on a consistent basis over a long duration (Lazarus, 1966; Schneiderman, Ironson, & Siegel, 2005). Examples of such conditions include adverse life events, work stress, low socioeconomic status leading to daily worry and hassles, and exposure to racial discrimination (Schneiderman et al., 2005; Tarani, Eric, & Michael, 2006; Williams, Neighbors, & Jackson, 2003). Such events lead to repeated activation of a biological stress response, often known as the "fight or flight" reaction, which involves the release of stress hormones and other physical responses intended to maintain homeostasis during a period of duress.

Paradoxically, although the fight or flight response prepares the body for bursts of physical activity (such as fighting or fleeing), both acute and chronic stress have been linked to *suppressed* physical activity in the long run (Barrington, Ceballos, Bishop, McGregor, & Beresford, 2012; Bartolomucci et al., 2003; Chandola et al., 2008;

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Laugero, Falcon, & Tucker, 2011). Reduced activity level is thought to disrupt the energy balance equation, over time leading to weight gain. A review by Stults-Kolehmainen and Sinha found support for the general conclusion that both chronic and acute psychosocial stress inhibit physical activity, leading to more time spent in sedentary behavior (2014).

However, there is some countervailing evidence suggesting that under certain circumstances, stress can promote physical activity—as when people engage in physical activity as a stress coping behavior (Stults-Kolehmainen & Sinha, 2014). Substantial evidence points to physical activity as being effective at ameliorating perceived stress and anxiety (Norris, Carroll, & Cochrane, 1992; Salmon, 2001; Schnohr, Kristensen, Prescott, & Scharling, 2005; Skirka, 2000; Stults-Kolehmainen & Sinha, 2014; Wipfli, Rethorst, & Landers, 2008) and reducing the longer-term negative health consequences of chronic stress (Gerber & Puhse, 2009; Rethorst, Wipfli, & Landers, 2009; Stults-Kolehmainen & Sinha, 2014). People who are already physically active are more likely to exercise to cope with stress, hinting that the stress-activity-obesity relationship is moderated by habitual behaviors, predisposition for physical activity, and other individual factors (Stults-Kolehmainen & Sinha, 2014).

Exposure to psychosocial stress is frequently assessed using a retrospective survey approach, in which respondents are asked to recall their experience of stress over some defined recent time period. Ecological Momentary Assessment (EMA) is a data collection method that uses repeated, *in-situ* measurement to address some limitations of retrospective assessment techniques (Stone & Shiffman, 1994). For example, the lookback window, survey setting and the time of day that a survey is given may affect the information recalled and reported on traditional paper-and-pencil retrospective recall survey instruments, limiting the generalizability of such data (Shiffman, Stone, & Hufford, 2008). People tend to recall more recent events more accurately and strongly than more temporally distal events, leading them to provide reports that are driven by recent events (Cohen, Kessler, & Gordon, 1995). Recall biases may also be introduced by individual-level coping mechanisms, education, and even fluctuations in mood (Carels, Douglass, Cacciapaglia, & O'Brien, 2004). In contrast, EMA data are captured *in situ*—that is, in the place and time that the events occur—minimizing recall and setting biases (Shiffman et al., 2008). EMA is able to capture moment-to-moment differences in experience and responses, a characteristic that is lost in recalled reports (Stone et al., 1998). EMA contributes critical information about psychosocial states and moment-to-moment changes in behavior, and may have a stronger correlation with predicting maladaptive behaviors than does recalled data (Anestis et al., 2010). Steptoe et al. found that EMA detected significant relationships between positive affect and post-stress recovery, as well as fluctuations in cortisol levels over the course of a day—a biomarker of stress—where retrospective survey techniques failed to find relationships (2007). An EMA approach to stress and physical activity may be able to broaden our understanding of daily variation in stress and behavioral changes in response to stress, and ultimately contribute to our understanding of the stress-activity-obesity link. In this work, we also exploit real-time physical activity data captured from a wearable device. Accelerometer data, similar to EMA data, are less subject to the biases introduced by self-reporting, and are thus preferable for valid measurement of moderate-to-vigorous physical activity and sedentary activity (Pedisic & Bauman, 2015).

Although stress levels normally fluctuate throughout the day and over the course of a typical week (Dunton, Atienza, Castro, & King, 2009), to date there has been little work exploring real-time variation in perceived stress and its relationships with health behaviors, including activity level. Because physical activity self-efficacy can vary over short time periods (Dunton, Huh, Castro, Hedeker, & King, 2013; Pickering et al., 2016), within-person variation—or variation in response to specific stimuli throughout the day—may be critical to understanding how people make decisions related to activity behavior. In a pilot study, Dunton et al. showed that negative affect—a global measure which included subjective stress—was associated with reduced physical activity later in the same day (2009). The present study extends the literature linking within-person psychosocial stress to physical activity by focusing on subjective reports of stress, as measured by EMA, and the relationship between stress and time spent in subsequent sedentary activity, light activity, or moderate-to-vigorous physical activity. We address two questions using an adult population: is an EMA measure of stress associated with sedentary, light, and moderate-to-vigorous physical activity level in real-time? And second, is stress as reported by EMA related to overall sedentary, light, and moderate-to-vigorous physical activity levels and weight status?

2. Subjects and methods

2.1. Data and participants

The primary sample consisted of 120 community-dwelling adults living in and around Chino, California (a suburb of Los Angeles). This study used baseline (Wave 1) data from the Project on Measuring our Behaviors and Living Environments (Project MOBILE) (Dunton, Liao, Kawabata, & Intille, 2012). Participants were recruited to the study through posters, letters sent to home addresses, and referrals from a parent study known as Healthy PLACES. Participants were at least 28 years of age and able to answer EMA surveys on a study-provided mobile phone during the day, including at work where applicable. Individuals were excluded if they did not speak and read English fluently or had a high annual household income (>US $210,000). Because the goals of the larger study were related to increasing physical activity behavior, participants were also excluded if they were already meeting the physical activity guideline of 150 min per week, or had physical limitations that made them unable to exercise. Participants were compensated up to $50 for participating in the study. This research was reviewed and approved by the Institutional Review Board at the University of Southern California.

2.2. Procedure

During a baseline data collection session, participants self-reported age, sex, ethnicity, and annual household income. At that time, they also completed a traditional paper-and-pencil retrospective report of stress, mood, and cognition. Anthropometric measures were collected by trained data collectors at the time of the baseline survey. Weight was recorded to the nearest 0.1 kg using a digital scale (Tanita WB-110A), and height was recorded to the nearest 0.1 cm using a professional stadiometer (PE-AIM-101). Waist circumference was measured in triplicate and recorded to the nearest 0.1 cm.

Project MOBILE used EMA to capture participants' current stress state several times per day over a 4-day period. Participants were provided with an HTC Shadow mobile phone (T-Mobile USA, Inc.) equipped with a customized software program (app) based on the MyExperience platform (myexperience.net, 2007). The app was programmed to display a short electronic survey to which participants responded using the device's touch screen. Data were stored on the device and later downloaded by the research team. Participants were trained in how to use the device and complete the survey, and completed a guided practice assessment prior to the start of the study period. Participants were asked to carry the phone at all times and stop their current activity when they received a survey prompt on the phone, except if they were engaged in an incompatible activity such as driving or sleeping.

Participants were prompted 8 times per day across four days (Saturday- Tuesday) during normal waking hours. To ensure that EMA responses were adequately spaced across the day, the timing for each of the 8 daily EMA surveys was random within 8 preset time windows. If there was no response to the initial prompt, the respondent was reminded at 5-min intervals up to three times. After the 3rd reminder, the EMA survey became inaccessible. Each EMA survey took 2–3 minutes to complete.

Study participants also wore an activity monitor (Actigraph, Inc. GT2M, firmware v06.02.00) for a 7-day period, inclusive of the 4-day EMA study period. The activity monitor was worn on the right hip on an adjustable belt. Participants were instructed to wear the activity monitor at all times except when sleeping, bathing, or swimming. Further information about the study protocol is reported elsewhere (Dunton et al., 2012).

3. Measures

3.1. Real-time stress

Each EMA prompt included a sequence of questions about current activities and mood states. Respondent burden in EMA studies is a serious concern due to the frequent repeated assessments (Collins & Muraven, 2007). Therefore, it was not feasible to field a multiple-item stress questionnaire by EMA in this study. We relied on the single-item measure of current stress, “How STRESSED were you right before the beep went off?” The available responses were a 5-point scale with response options for “not at all,” “a little,” “moderately,” “quite a bit,” and “extremely.” Other work has found that single-item stress measures are both reliable and valid, and perform comparably to longer stress scales (Littman, White, Satia, Bowen, & Kristal, 2006). Our data include up to 24 unique measures of real-time stress for each participant across the four days of assessment. In addition to these reports of stress, for each respondent, we created two summary variables: an average stress score (i.e., within-person mean of all real-time stress scores), and the within-person standard deviation of real-time stress. Standard deviation was selected as a measure of the within-person variability of stress because it maximized the available variation in our data.

3.2. BMI, waist circumference, and physical activity

Body Mass Index (BMI) was calculated as measured weight (in kilograms) divided by the square of measured height (in meters). Waist circumference was measured in centimeters. We used data from accelerometers to measure physical activity levels. The cut-points for activity levels were consistent with studies of national surveillance data (Belcher et al., 2010; Troiano et al., 2008). Sedentary activity was defined as less than 100 counts per minute (Healy et al., 2008), light activity was defined as 100–2019 counts per minute, and moderate-to-vigorous physical activity was defined as at least 2020 counts per minute (equivalent to 3 METs) (Healy et al., 2008). We also report associations of stress reports with activity counts from the accelerometer data to provide a continuous metric of activity. All accelerometer recordings were time-stamped and linked with EMA data captured on the mobile phone. The two devices were synced to the same computer clock at the outset of the study. Fifteen-minute time windows were created for the period preceding and following each EMA prompt. We were interested in the real-time, ordered relationship of stress and decisionmaking around physical activity, so we selected this time windows as representative of a reasonable, short window in which an effect was likely to present.[1] Total minutes of sedentary activity, light activity, and moderate-to-vigorous physical activity during each window were computed. We also computed the steps and activity counts within each time window. Finally, we calculated the average minutes per day of sedentary activity, light activity, and moderate-to-vigorous physical activity for up to 7 valid days of activity monitor data.

3.3. Retrospective stress

Finally, for validation purposes, we compared EMA stress reports to results of a traditional retrospective survey measure of stress. The 4-item Cohen Perceived Stress Subscale (CPSS4) measures recalled levels of usual stress over the preceding month (Cohen & Williamson, 1988). CPSS4 is a brief retrospective questionnaire that asks respondents to recall and summarize their recent experience of psychosocial stress. CPSS4 was captured via paper-and-pencil survey at the time of the Wave 1 data collection.

3.4. Data analysis

To study the relationship between real-time stress and physical activity, we used a repeated-measures multilevel modeling approach with a fixed effect to account for the clustering of observations within study participants. These models also controlled for each person's own mean level of real-time stress, which allowed us to separate the variation in activity that is attributable to within-person variation in stress and that which is attributable to the average differences in stress reports between people (Curran & Bauer, 2011).

To study the relationship between average real-time stress and weight status, we used bivariate correlations and multilevel OLS regression models. For all multivariate models, we controlled for key covariates which could be causally related to both stress measures and physical activity behavior: age, gender, and ethnicity.

4. Results

4.1. Sample

At the EMA prompt level, 628 of the 2282 (27.5%) EMA surveys of real-time stress were missing because the subject did not respond to the prompt. This compliance rate is similar to that found in other EMA studies of mood and affect (e.g.,Silvia, Kwapil, Eddington, & Brown, 2013). Nonresponse to individual prompts was significantly more likely for women, non-Hispanic Blacks, and for people with higher physical activity levels. However, the overall number of missing prompts per person was not associated with any demographic variables, average stress level on nonmissing prompts, or activity levels. EMA prompts occurring during periods of accelerometer nonwear (identified as >60 consecutive minutes of 0 activity counts, 30 min on each side of the prompt) were dropped from the analysis (n = 230 EMA prompts). We used listwise deletion to handle cases missing data on individual-level covariates (n = 9 individuals). Our final analytic sample included 105 adults, with a total of 1318 completed EMA surveys rating real-time stress (mean = 12.6, range = 2–24 reports per respondent). Each prompt has temporally matched accelerometer data.

[1] In analyses not presented, we also tested relationships between activity level and stress in 30-, 60- and 120-min windows before and after each prompt. Results showed similar patterns as those presented here, and are available from the authors upon request.

Table 1 shows the characteristics of our data and sample, which was three-quarters female, and aged 40 years on average. Our sample had a diverse ethnic mix and was moderate in income for this region of Southern California (US Census Bureau, 2013). On average, respondents were moderately overweight, comparable to the national adult average BMI (Flegal et al., 2012). The mean CPSS4 summary score was 5.8 out of 16, about 1.3 points higher than the last available nationally representative comparison sample, performed in 1983 (Cohen & Williamson, 1988). On average, our respondents engaged in 24 min per day of moderate-to-vigorous physical activity.

On average, real-time stress was low, 1.6 (possible range of 1–5) (Table 1). The within-person standard deviation of real-time stress provides a metric of variability in stress for each person. The mean of within-person standard deviation of real-time stress was 0.7, indicating that there was some variation in real-time stress reports within each respondent.

4.2. Relationship between retrospective and real-time stress reports

To examine construct validity, we first report results comparing real-time stress with the more traditional approach to reporting psychosocial stress, the CPSS4. Although the recall period for the CPSS4 assessment did not cover the same time period as the real-time stress report, CPSS4 has long been used as a relatively time-invariant measure of the overall stress experience. If it is truly a durable measure of stress experience, we would expect to find good concordance between the CPSS4 stress report and the EMA stress report, in spite of their having different lookback periods. Retrospective stress based on the CPSS4 measure was positively, but not strongly, correlated with the within-person average of real-time stress ($r = 0.38$, $p < 0.001$). Table 2 shows the relationship between psychosocial stress as measured by the two methods under consideration in this study. We performed multilevel OLS regression of within-person average stress as measured by EMA, using stress as measured by the CPSS4 as the key independent variable.

Table 2
Coefficients from OLS regression of average real-time psychosocial stress as measured by EMA, with CPSS4-measured stress as the independent variable (n = 105).

	Model a	Model b	Model c
	β	β	β
Intercept	0.20	0.36	0.94
CPSS4-measured stress	0.07 ***	0.08 ***	
Age		−0.00	−0.00
Female		0.06	0.01
Race/Ethnicity			
White		–	–
Latino		−0.26*	−0.22
Non-Hispanic Black		−0.34	−0.34
Non-Hispanic Asian		0.06	0.07
Non-Hispanic Other Race		−0.24	0.12
Sigma_u	0.434	0.421	0.474
Sigma_e	0.751	0.751	0.751
Rho	0.25	0.24	0.28
Prob > Chi2	<0.001	<0.001	0.32

Notes: EMA = Ecological Real-time Assessment. CPSS4 = 4-item Cohen Perceived Stress Scale.
* = significant at $\alpha = 0.05$ ** = significant at $\alpha = 0.01$ *** = significant at $\alpha = 0.001$.

Table 1
Sample characteristics (n = 105).

	% or Mean (SD)
Female	72%
Marital Status	
Married	67%
Single	19%
Divorced, separated, or widowed	14%
Age	40.3 (9.8)
Educational attainment	
Less than high school	3%
High school diploma	12%
Some college	30%
College degree	55%
Race/Ethnicity	
Latino	30%
Non-Hispanic Black	6%
Non-Hispanic Asian	26%
Non-Hispanic White	34%
Other	5%
BMI	28.0 (6.6)
Waist Circumference (cm)	95.8 (15.7)
Physical activity level (min/day)	
Sedentary	552 (91)
Light	245 (62)
Moderate-to-vigorous	24 (19)
Accelerometer nonwear time (mins/day)	619 (95)
CPSS4 stress (range 0–16)	5.8 (2.7)
Number of EMA reports of real time stress	14.6 (3.9)
Mean of within person mean real time stress (range 1–5)	1.6 (0.5)
Mean of within-person standard deviation of real-time stress (range 0–4)	0.7 (0.4)

Notes: BMI = Body Mass Index. EMA = Ecological Real-time Assessment. CPSS4 = 4-item Cohen Perceived Stress Scale.

Table 3a
Coefficients from multilevel regression models of activity levels in 15 min prior as predictors of real-time stress outcomes (n = 1318 EMA prompts).

Outcome	Model a	Model b	Model c	Model d
	Real-time stress level	Real-time stress level	Real-time stress level	Real-time stress level
Intercept	0.92	1.13	0.79	0.94
Activity count (per 10,000 count)	0.0635			
Sedentary activity (mins)		−0.019***		
Light activity (mins)			0.024***	
Moderate-to-vigorous physical activity (mins)				0.007
Sigma_u	0.476	0.478	0.477	0.476
Sigma_e	0.750	0.748	0.750	0.750
Rho	0.29	0.29	0.29	0.29
Prob > chi2	0.223	0.012	0.005	0.401

Notes: All models control for gender, age, and race/ethnicity.
* = significant at $\alpha = 0.05$ ** = significant at $\alpha = 0.01$ *** = significant at $\alpha = 0.001$.

We also show models controlling for demographic variables. CPSS4 scores had a small but significant relationship to real-time stress. In both bivariate and a multivariate models (models 1 and 2, respectively), a one-point increase in CPSS4-measured stress was significantly associated with a fractional increase in real-time stress reports by EMA. Model 3 shows the relationships between age, sex, and race/ethnicity and real-time stress alone. None of these demographic characteristics were associated with average real-time stress.

4.3. Relationship between activity level and subsequent real-time stress reports

Sedentary activity in the 15 min before the prompt was negatively related to the level of real-time stress reported (Table 3a, model b). That is, each additional minute of sedentary activity in the 15 min leading up to the EMA prompt was associated with slightly *lower* stress reported at that prompt. In contrast, light activity predicted a subsequent report of higher stress (Table 3a, model 3). There were no observed associations between moderate-to-vigorous physical activity or total activity count and subsequent real-time stress. Furthermore, the observed effects were primarily located at the within-person level. For example, the relationship between sedentary/light activity and psychosocial stress was driven by the variation in stress reports within individuals from EMA prompt to EMA prompt, rather than by variation between individuals in overall real-time stress experience.

4.4. Relationship between real-time stress reports and subsequent activity level

At the prompt level, increased real-time stress predicted lower sedentary activity in the 15 min just after the prompt (Table 3b, model b). In contrast, stress predicted increased light activity. Again, there were no associations between levels of stress and activity counts or moderate-to-vigorous physical activity. These effects were also driven by within-person variation in real-time stress, not variation between individuals.

4.5. Real-time stress as predictor of overall physical activity and weight status

Table 4a shows the results of multivariate OLS regression of stress as a predictor of sedentary activity, light activity, and moderate-to-vigorous physical activity (in average mins/day), as well as BMI and waist circumference (in cm).[2] We observed no associations between real-time stress reports averaged over the 4-day study period and the accelerometer readings for the same period. Nor did we find associations between real-time stress reports and weight status. In contrast, a one-point increase in the retrospective, CPSS4 report of stress (Table 4b) was associated with an increase of about 0.5 BMI points ($\beta = 0.48$, $p = 0.04$). We did not observe associations between CPSS4 reports of stress and waist circumference or any of the activity types measured by accelerometer.

5. Discussion

Our first research question examined whether physical activity levels were associated with real-time reports of stress via EMA. Our results show that in this sample of adults, lower stress and sedentary activity are positively related to each other, and are temporally ordered. We found that sedentary activity in the prior 15 min predicted lower real-time stress, and lower stress reports were followed by sedentary activity minutes. On the other hand, light activity predicted *higher* real-time stress, and higher stress reports were followed by more minutes of light activity. There was no relationship between real-time stress and moderate-to-vigorous physical activity or total activity counts at the prompt level. Our findings can be interpreted to mean that on average, our respondents reported lower stress when engaged in sedentary activities, and they reported higher stress when engaged in light active tasks. To find out what these specific tasks were, we explored qualitative responses to the EMA prompt, "what were you doing right before the beep went off?". Sedentary activities included "reading," "watching TV," or performing sedentary work. When we recorded light activity via accelerometer, participants were for example, "getting ready for work," "shopping," and "cooking." These responses confirm that at 40% of all prompts, participants were engaged in some type of sedentary activity. Very predictably, for EMA prompts during which participants reported engaging in a sedentary activity such as "sitting in class," "reading," or "on the computer", their accelerometers showed substantially more sedentary minutes in the preceding 15 min window.

To further explore the relationship between specific activities, stress, and physical activity level, we categorized the qualitative responses to the question of what the respondent was doing into active/not-active types. The active category included physical

[2] Note that we were unable to fully exploit the repeated measurements of stress via EMA in a multilevel modeling approach because available statistical methods restrict us to an outcome variable at the prompt level. In this case, our outcomes—BMI, waist circumference, and overall activity levels during the study period—were at the person level, not at the prompt level. Therefore, we were constrained to using the within-person average of real-time stress as the predictor of average daily sedentary minutes, MVPA, and weight status in standard OLS models.

Table 3b
Coefficients from multilevel regression models of real-time stress as a predictor of activity levels in the subsequent 15 min (n = 1318 EMA prompts).

	Model a	Model b	Model c	Model d
	Activity count	Sedentary activity (mins)	Light activity (mins)	MVPA (mins)
Intercept	3992.71	11.15	3.64	0.52
Real-time stress level	139.8	−0.37 ***	0.41 ***	−0.01
Sigma_u	1597.9	1.20	0.99	0.25
Sigma_e	4524.9	3.31	3.06	1.10
Rho	0.11	0.12	0.09	0.06
Prob > chi2	0.765	0.046	0.007	0.354

Notes: All models control for gender, age, and race/ethnicity.* = significant at α = 0.05 ** = significant at α = 0.01 *** = significant at α = 0.001. MVPA = moderate-to-vigorous physical activity.

Table 4a
Associations of real-time psychosocial stress with global outcomes (n = 105).

	Outcome: Body Mass Index (BMI)	Outcome: Waist Circumference (cm)	Outcome: Sedentary Activity (min/day)	Outcome: Light activity (mins/day)	Outcome: MVPA (min/day)
	β	β	β	β	β
Intercept	29.47	99.81	438.43	221.04	39.58
Real-time stress	0.09	2.83	26.65	2.26	1.74
Age	<0.01	0.16	1.76	0.31	−0.20
Female	−1.75	−6.08	5.61	16.90	−9.75*
White (ref)	–	–			
Latino	1.91	4.51	12.04	−11.37	−2.11
Non-Hispanic black	0.98	−0.77	18.13	−18.73	2.04
Non-Hispanic Asian	−4.37 **	−10.58 **	65.38 **	13.35	−5.31
Non-Hispanic other	1.27	5.04	13.45	−33.52	2.73
Adj R-Sq	0.08	0.11	0.08	0.00	0.00
Prob > F	0.029	0.008	0.036	0.531	0.461

* = significant at α = 0.05 ** = significant at α = 0.01 *** = significant at α = 0.001. MVPA = moderate-to-vigorous physical activity.

Table 4b
Associations of CPSS4 psychosocial stress with global outcomes (n = 105).

	Outcome: Body Mass Index (BMI)	Outcome: Waist Circumference (cm)	Outcome: Sedentary Activity (min/day)	Outcome: Light Activity (mins/day)	Outcome: MVPA (min/day)
	β	β	β	β	β
Intercept	26.11	91.44	419.65	229.84	40.65
CPSS4 stress	0.48 *	0.96	6.19	−0.92	0.08
Age	0.01	0.10	1.74	0.27	−0.21
Female	−1.31	−5.19	11.21	16.04	−9.67 *
White (ref)					
Latino	1.65	4.38	2.74	−11.43	−2.55
Non-Hispanic black	0.89	−0.35	7.88	−19.43	1.41
Non-Hispanic Asian	−4.40 **	−10.71 **	66.29 **	13.51	−5.23
Non-Hispanic other	0.07	2.74	−3.15	−31.36	2.44
Adj R-Sq	0.12	0.14	0.09	0.00	0.00
Prob > F	0.006	0.003	0.025	0.517	0.485

Notes: CPSS4 = 4-item Cohen Perceived Stress Scale. * = significant at α = 0.05 ** = significant at α = 0.01 *** = significant at α = 0.001. MVPA = moderate-to-vigorous physical activity.

activity and exercise as well as shopping, cooking, childcare, housework, errands, and attending sporting events with children. The not active category included typically sedentary activities such as reading, working, attending class, attending church, riding in a car, sleeping, and sitting. A two-sample *t*-test finds that real-time stress was significantly higher when engaged in "active" tasks (mean = 0.77) as compared to "not active" tasks (mean = 0.58) ($p = 0.0004$).

Although the literature shows that physical activity is an effective stress-reliever, our findings did not support the notion that our respondents engaged in moderate exercise to reduce stress. Effective obesity interventions for working-aged adults with children in the home might target both sides of the calorie balance equation and the mediating factor of psychosocial stress by encouraging people to choose moderate activity when they want to relax, and to take short breaks from sedentary activities even if they are low in psychosocial stress.

When we examined the relationship between physical activity level and real-time stress at the person-level, we did not find significant associations. Without considering the within-person variation in stress, we might have assumed that there was no relationship between stress and physical activity level. However, this assumption would be a form of the ecological fallacy, applying a higher-order or more general result to a lower-order relationship. Temporal ordering of activity level and stress would have been lost. Differences in the relationship between stress and sedentary activity at the person level versus the real-time level highlight the unique contribution of time-intensive data such as that available through real-time data collection approaches.

Our second research question also addressed whether average real-time stress, measured using EMA, was associated with waist circumference and BMI. Counter to our expectations, average real-time stress was unrelated to weight status and to average physical activity levels during our study period. However, stress as reported on the CPSS4 was positively related to BMI. In addition, we found a surprisingly small (but significant) positive correlation between CPSS4-reported stress over the past month and average real-time stress ($r = 0.38$). Taken together, these results suggest that, at least in our sample, real-time measures of stress did *not* capture the same information as the paper-and-pencil recall approach that has been typical in stress measurement to date. Stone et al. similarly found that retrospective reports of stress-related coping behaviors did not correspond well to reports measured using EMA (1998); we extend the evidence to stress reports themselves. Further studies using EMA measures of stress should endeavor to collect a more traditional stress recall such as the CPSS4 that is temporally matched to EMA studies to fully explore this finding.

The theoretical foundations of EMA indicate that people evaluate and report experiences differently in the moment, in their natural setting, compared to when they are asked to recall and summarize their experience over a longer time frame (Shiffman et al., 2008). Shiffman et al. argue that EMA methods can "minimize recall bias, maximize ecological validity, and allow study of microprocesses that influence behavior" (2008). Given our results, we conclude that real-time stress measured at multiple times across a study period likely does *not* represent the same thing as one single recollection of stress that characterizes an entire month. A number of complex cognitive and recall tasks are necessary to produce a single assessment of one's stress over this relatively long time frame. Little evidence to date has addressed how multiple real-time experiences accumulate and aggregate over time to produce poor health outcomes and behavior, and how this may vary by individual characteristics. A key question for EMA researchers moving forward is: how do individual characteristics moderate the ways that real-time experiences are translated into recalled experiences and, ultimately, into health behaviors and outcomes?

Our finding that retrospective stress and real-time stress reported were differentially related to sedentary activity implies that obesity prevention strategies should investigate the ways that people cope with stress. Providing individuals with improved stress coping skills and the ability to "let go" of the inevitable hassles of daily life, work, adverse life events, and so on has proved effective for reducing self-reported stress (Fjorback, Arendt, Ornbol, Fink, & Walach, 2011), and may also prove to be an effective obesity prevention strategy. Smyth et al. found that patients with bulimia nervosa had significant within-day and within-week variation in both stress and symptoms of their disorder; they recommend a strategy for targeting the highest-risk times for binge-eating based on these patterns (2009). Context-sensitive, "just-in-time" interventions of this kind hold promise in obesity prevention (Intille, Kukla, Farzanfar, & Bakr, 2003; Riley et al., 2011). The positive relationships between stress reports and light physical activity reported here also hint at health-relevant processes that could be important for obesity prevention. For example, our qualitative data suggest that subjects found running errands, childcare, housework, and other active times to be relatively stressful—which may lead to a lagged effect later in the same day, when busy adults attempt to cope with the stresses of a busy day with behaviors such as watching TV, reading, or even exercising. However, further research is needed to understand the complex relationships between transitory experiences of stress, long-term experiences of stress, and how these are related to the specific behaviors and metabolic changes that lead to obesity. For example, while we interrogate the relationships between activity and stress immediately before and after a self-report of stress levels, we do not look for lagged effects that may occur later in the same day or even accumulate over the course of several days.

Our study has several important limitations. First, a limitation of our data is that the period of EMA reporting and accelerometer wear covers a shorter time frame than the CPSS4 stress measure. Due to EMA's high respondent demand, it has been difficult to obtain EMA data over longer time periods. Future work in measuring stress using EMA should take this data need into consideration. Also, it was beyond the scope of this study to investigate explanatory mechanisms for the relationship between stress and activity level, such as stage of change, habitual exercise patterns, self-efficacy for exercise, social and physical context, or outcome expectations for exercise (Lutz, Stults-Kolehmainen, & Bartholomew, 2010; Stults-Kolehmainen & Sinha, 2014). These possible moderators of the relationships reported here deserve investigation, as they are likely key to understanding how stress and physical activity interact with one another. Another limitation is the possibility that high stress was causally associated with missed prompts. Other researchers have written about the challenge of EMA data being missing not at random. Sokolovsky, Mermelstein, and Hedeker (2014) discuss the possibility that a causal relationship between EMA prompt response and the subject under study can lead to error and possibly even spurious results. Reassuringly, Silvia et al. (2013) find that within-day variation in mood and experiences do not have a strong effect on prompt-level compliance in a similarly structured EMA study. Person-level and situational variables (such as time of day) are much stronger predictors of EMA non-response. That said, if our subjects were in fact less likely to respond to a prompt when they were under high stress, we would expect variability in stress to be reduced, and associations between stress and sedentary activity, light activity, and moderate-to-vigorous physical activity to be attenuated. In our case, it is unlikely that missing high stress reports would lead to inflated effect sizes; if anything, we have underestimated the relationships between real-time stress and activity levels. This limitation is, however, an ongoing methodological challenge for EMA studies of stress. Finally, our sample is limited: our results are difficult to generalize beyond this group. However, our results are suggestive of future directions for the study of links between stress and sedentary activity. We are particularly interested in examining the relationships between self-reports of stress and concurrent activity in a general population sample, and in understanding how light and moderate physical activity is related to within-daily stress variation.

In sum, we have shown that real-time psychosocial stress, as reported by EMA, predicts sedentary activity in a way that is temporally ordered. However, stress had no moment-to-moment relationship with light activity or moderate-to-vigorous physical activity in our sample. Furthermore, we conclude that EMA may not capture the same information about stress as does the typical retrospective data collection method to date, a brief paper-and-pencil retrospective instrument. While retrospective stress was positively related to BMI, real-time stress based on the EMA measure was not related to weight status. EMA data collection approaches are becoming increasingly popular, as is interest in stress as a fundamental predictor of health outcomes. Given the rising importance of these issues, we have highlighted several key theoretical, data and methodological questions which are outstanding in this field.

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