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Do fluctuations in positive affective and physical feeling states predict physical activity and sedentary time?

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ABSTRACT

Objectives: Higher levels of positive affect and feelings of energy are associated with greater physical activity (PA) and lower sedentary time (ST). However, whether fluctuations in these feelings contribute to the regulation of these behaviors is unclear. This study examined the extent to which subject-level variability (i.e., degree of intraindividual variability) in positive affect and feeling energetic predicted participants' overall levels of PA and ST.
Design: This analysis combined data from four ecological momentary assessment (EMA) studies (age_{range}: 8–73 years) with ambulatory monitoring via waist-worn accelerometry (N = 661).
Methods: Positive affect and energy were assessed through EMA several times per day across 4–7 days. Accelerometer data was used to create the following behavioral outcomes: (1) meeting MVPA guidelines (children: 60 minutes/day, adults: 30 minutes/day) and (2) minutes of ST per hour of accelerometer wear. A two-stage analytic approach was used to test the study aim. In the first stage, mixed-effects location scale modeling decomposed mean levels and variability in positive affect and energy. In the second stage, a linear or logistic regression (depending on whether the outcome was continuous or dichotomous, respectively) was tested to investigate associations between subject-level mean and variability in EMA ratings and the behavioral outcome.
Results: Greater subject-level variability but not subject-level mean of feeling energetic was associated with lower odds of meeting MVPA guidelines ($\beta = -0.43$, $p < 0.05$).
Conclusions: Fluctuations in physical feeling states may deplete self-regulatory resources involved in planning and implementing PA behavior. Alternatively, being more physically active may stabilize one's perceived energy levels.

1. Introduction

Physical activity and sedentary behavior are health behaviors that have implications for health and well-being across the lifespan (e.g., risk of premature death, prevalence of non-communicable diseases and chronic conditions; Physical Activity Guidelines Advisory Committee, 2008). As a result, extensive resources have been devoted to understanding the role that subject-level characteristics, such as affect and arousal, play in regulating these behaviors. Both usual (i.e., chronic) and momentary (i.e., acute) levels of affect (e.g., positive affect) and arousal (e.g., feeling energetic) have been linked with physical activity and sedentary behavior (Liao, Shonkoff, & Dunton, 2015; O'Connor & Puetz, 2005; Puetz, 2006). While assessing these constructs in this way provides valuable information, this approach is unable to account for intraindividual, or within-person, variability in affect or arousal as a subject-level construct. Understanding the extent to which a person experiences intraindividual variability in a given construct is significant because individuals may exhibit similar mean or usual levels of a construct, but the way they experience that construct naturally over time in the context of everyday life, can differ greatly (Nesselroade & Ram, 2004; Ram & Gerstorf, 2009). For example, two individuals may exhibit similar mean levels of positive affect but these individuals can

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differ in the extent to which their positive affect varies across assessments thus achieving the aggregate mean in very different ways. It is unclear what role subject-level variability (i.e., the degree to which a person experiences intraindividual variability or within-subject variability) in affect or arousal play in the regulation of physical activity and sedentary behavior.

Greater variability in affect or arousal may adversely impact an individual's ability to self-regulate (Daly, Baumeister, Delaney, & MacLachlan, 2014). Self-regulation represents one's ability or capacity to change or inhibit thoughts, emotions, impulses, or overt behaviors. Self-regulation systems are designed to adapt to changing environments via coping procedures that make efficient use of resources based upon valid representations of the environment (Leventhal, Leventhal, & Contrada, 1998). The ability to self-regulate is thought to be crucial to goal pursuits and goal strivings (Mann, de Ridder, & Fujita, 2013). However, self-regulatory resources are limited and deplete over shortened time scales as a result of coping with daily events, hassles, and stressors (Muraven & Baumeister, 2000). Individuals who experience depleted self-regulatory resources are likely to struggle to carry out goal-directed health behaviors such as engaging in physical activity or limiting sedentary behavior (Buckley, Cohen, Kramer, McAuley, & Mullen, 2014). Therefore, experiencing greater subject-level variability in affect or arousal may be associated with lower levels of physical activity as well as greater time spent sitting.

Ecological Momentary Assessment (EMA) is a real time data capture strategy where participants are repeatedly assessed via a mobile device on constructs, such as affect or arousal, in the context of everyday life (Stone & Shiffman, 1994) and therefore is a useful methodological approach for capturing variability in affect and arousal. The repeated assessment nature of EMA provides momentary information about affect and arousal in naturalistic settings (Shiffman, Stone, & Hufford, 2008). Additionally, EMA is thought to reduce recall errors and biases and enhance ecological validity because it collects self-reports more proximal to the time and place that the phenomenon of interest (in this case affective and physical feeling states) is occurring (Schwarz, 2007). EMA methods are more conducive to capturing phenomena that vary through time or space than traditional cross-sectional, retrospective, and summary methods (Dunton, 2017). Therefore, EMA may yield new insights into the prediction and modeling of activity-related behaviors such as physical activity and sedentary behavior (Dunton, 2017).

EMA has been employed to study associations between affective states and aspects of health and well-being. Variability in positive affect is associated with increased likelihood of impaired health and diagnosis of affect-related illnesses such as angina and depression (Chan, Zhang, Fung, & Hagger, 2016). Additionally, in a daily diary study of US adults, Hardy and Segerstrom (2017) concluded that greater variability in both positive and negative affect was associated, concurrently and longitudinally, with higher levels of psychological distress as well as poorer physical health. Regarding associations between affective variability and specific health behaviors, high levels of variability in affect are associated with increased frequency of alcohol consumption as well as higher likelihood of drinking to cope among young adults (Gottfredson & Hussong, 2013) and increased odds of engaging in dysregulated eating behaviors such as binge eating (Anestis et al., 2009). Regarding physical activity, a study by Dunton et al. (2014) found that greater variability in positive affect was associated with lower levels of physical activity in children aged 9–13 years old but that variability in feelings of energy was unrelated to children's overall physical activity levels. It is unclear if this association remains in samples from other segments of the lifespan such as adolescents or adults or if affective variability is associated with sedentary time. Additionally, it is unclear if high levels of variability in an indicator of arousal, such as feelings of energy, adversely impact levels of physical activity and sedentary time across various segments of the lifespan.

1.1. The present study

To investigate the extent to which subject-level variability in positive affect and feeling energetic predicted overall levels of physical activity and sedentary time, this study pooled data from four EMA studies with ambulatory physical activity and sedentary monitoring via accelerometer. A two-stage approach employing mixed-effects location scale modeling (Hedeker & Nordgren, 2013) was used to simultaneously model subject-level mean and variability in positive affect and feeling energetic and their associations with subject-level physical activity and sedentary time. It was hypothesized that greater subject-level variability in positive affect and feeling energetic is associated with less physical activity and more sedentary time.

2. Methods

2.1. Participants

This study pooled data from four EMA studies with ambulatory monitoring via accelerometer: Mobile Healthy PLACES (Dunton, Liao, Intille, Spruijt-Metz, & Pentz, 2011), Project MOBILE (Dunton, Liao, Kawabata, & Intille, 2012), AsthEMA (Dzubur et al., 2015), and MATCH (Dunton et al., 2015). Participants were recruited through a variety of channels including posters placed at community locations, letters sent to places of residence, classroom and after school program announcements, flyers sent home through the schools, informational tables at community events and referrals by physicians at health clinics. Collectively, these studies sampled from populations across the lifespan with Mobile Healthy PLACES and AsthEMA including children and adolescents, Project MOBILE including adults, and MATCH including mother-child dyads. A general description of study and participant characteristics is displayed in Table 1.

2.2. Procedures

In all studies, participants attended an introductory session at the University of Southern California or a local community center where they were familiarized with the study procedures and the equipment to be used in the study. Participants were provided with a mobile phone (in MATCH mothers were allowed to use their own phone if compatible) and waist-worn accelerometer to complete the study procedures. EMA data were collected through custom software applications for mobile phones with either (a) a Windows Mobile operating system (Microsoft, Inc.; used in Mobile Healthy PLACES and Project MOBILE) or (b) an Android operating system (Google USA, Inc.; used in EMA Asthma MATCH). EMA data were collected across 4–7 continuous days with multiple EMA surveys prompted per day. Each EMA survey was prompted at a random time within pre-programmed intervals to ensure adequate spacing across the monitoring period (See Supplementary Table 1 for more details on specific sampling protocols). No EMA surveys were prompted during school hours (before 3pm on weekdays) for children. EMA surveys were prompted using an auditory signal. Adult participants in Project MOBILE were asked to answer EMA surveys when prompted while at work. Upon receiving a survey signal, participants were instructed to stop their current activity and complete a short EMA survey. Each survey required approximately 2–3 minutes to complete. If a prompt occurred during an incompatible activity (e.g., sleeping or bathing), participants are instructed to ignore it. If no entry was made upon initial prompting, the phone emitted up to three reminder signals at 3–5 minute intervals. After this point if no entry was made, the EMA survey becomes inaccessible until the random survey prompt during the next interval. In one study, AsthEMA, participants were also given a Bluetooth asthma inhaler. Participants’ use of the asthma inhaler resulted in an automatic event-contingent EMA prompt.

Table 1
General description of study and participant characteristics.

Study	N	Participants	Research Design	Inclusion Criteria	Exclusion Criteria
Mobile Healthy PLACES	122	Sample: Healthy children Age: M = 11 years, Range: 9–13 years Sex: 48% Female Ethnicity: 32% Hispanic Weight Status: 59% Normal/ Underweight, 28% Overweight, 13% Obese	Longitudinal (baseline, 6 mo)	(i) child currently enrolled in the 4–8th grade (ii) living in Chino, CA or a surrounding community (iii) ability to complete questionnaires in English	(i) annual household income greater than $165,000
AsthEMA	21	Sample: Children with asthma Age: M = 14 years, Range: 10–18 years Sex: 43% Female Ethnicity: 100% Hispanic Weight Status: Data not available	Cross-sectional	(i) ages 10–18 years old (ii) ever diagnosed with asthma (iii) prescribed the use of a rescue inhaler for asthma.	
MATCH	402	Sample: Healthy mother-child dyads Age_{Mother}: M = 41 years, Range = 24-57 Age_{Child}: M = 10 years, Range = 8–12 years Sex_{Child}: 51% Female $Ethnicity_{Mother}$: 49% Hispanic $Ethnicity_{Child}$: 54% Hispanic $Weight\ Status_{Mother}$: 34% Normal/ Underweight, 33% Overweight, 33% Obese $Weight\ Status_{Child}$: 61% Normal/ Underweight, 25% Overweight, 14% Obese	Longitudinal (baseline, 6 mo, 12 mo, 18 mo, 24 mo, 30 mo)[a]	(i) child in the third to sixth grade (ii) ≥50% of child's custody is with the mother (iii) mother and child were able to read English or Spanish	(i) currently taking medications for thyroid function or psychological conditions (ii) health issues that limited physical activity (iii) enrolled in special education programs (iv) currently using oral or inhalant corticosteroids for asthma (v) pregnant (vi) child classified as underweight (vii) mothers who worked ≥2 weekday evenings/week or >8 h on weekend day
Project MOBILE	116	Sample: Healthy adults Age: M = 40.2 years, Range: 27-73 Sex: 72% Female Ethnicity: 31% Hispanic Weight Status: 34% Normal/ Underweight, 33% Overweight, 33% Obese	Longitudinal (baseline, 6 mo, 12 mo)	(i) age 25 years or older (ii) able to speak and read English fluently (iii) ability to access a smartphone while at work to complete EMA questionnaires	(i) annual household income greater than US $210,000 (ii) regularly performed more than 150 minutes per week of physical activity (iii) had a physical limitation that prevented them from exercising
Pooled Dataset	661	Age: M = 25 years, Range: 8-73 Sex: 69% Female Ethnicity: 45% Hispanic Weight Status: 48% Normal/ Underweight, 29% Overweight, 23% Obese			

[a] MATCH is an ongoing study. Therefore this analysis only included EMA and accelerometer from the first two waves of MATCH.

These event-contingent EMA prompts were in addition to the random-interval EMA prompting schedule described in Table 2. During the EMA monitoring period, participants received one phone call and up to two text messages from researchers to inquire about any technical problems and remind them to recharge the phone each night. Across all studies participants were instructed to wear the Actigraph accelerometer on the right hip, attached to an adjustable belt, at all times except sleeping, bathing, or swimming. All EMA and accelerometer data were date- and time-stamped. Prior to completing the introductory session, participants provided demographic information via a paper and pencil questionnaire. Mobile Healthy PLACES, MATCH, and Project MOBILE had multiple waves of data collection. Mobile Healthy PLACES and MATCH included two waves of data collection whereas Project MOBILE included three waves of data collection. All study procedures were approved by local the Institutional Review Board. Adults provided written informed consent. Parental consent plus child assent was obtained for minor participants.

2.3. Measures

Positive affect. Participants' positive affect was measured in all EMA studies by assessing distinct affective states; however, the distinct affective states assessed differed across studies. Across all studies, participants were asked to report about the extent to which they felt various emotions right before the beep went off. Positive affect was assessed in children and adolescents using two items (i.e., HAPPY/JOYFUL). Among adults, positive affect was assessed in MATCH using two items (i.e., HAPPY/CALM) and in Project MOBILE using three items (i.e., HAPPY/CHEERFUL/CALM). These items are derived from the Positive and Negative Affect Schedule (PANAS) (Laurent et al., 1999; Watson, Clark, & Tellegen, 1988). Participants in Mobile Healthy PLACES, AsthEMA, and MATCH responded to items on a 1 (*not at all*) to 4 (*extremely*) scale. Participants in Project MOBILE responded to items on a 1 (*not at all*) to 5 (*extremely*) scale. Data from Mobile Healthy Places, AsthEMA, and MATCH were recoded so that 3 (*quite a bit*) and 4 (*extremely*) would correspond to 4 (*quite a bit*) and 5 (*extremely*), respectively, on the response scale used in Project MOBILE. Responses across available positive affect items were internally consistent (Chronbach's alpha ranged from .75 to .92 across studies) so available positive affect items were averaged to create a composite score. The positive affect composite score values were rescaled by multiplying by 10 so that the response scale used in analyses ranged from 10 to 50.

Feelings of energy. Participants' feelings of energy were assessed in three EMA studies (i.e., Mobile Health PLACES, AsthEMA, and Project MOBILE) using the single-item, "How ENERGETIC or FULL OF PEP were you feeling just before the beep went off?" This single-item has been used in previous research to assess feeling of energy (Dunton, Atienza, Castro, & King, 2009). Participants in Mobile Healthy PLACES and AsthEMA responded to this item on a 1 (*not at all*) to 4 (*extremely*) scale. Participants in Project MOBILE responded to this item on a 1 (*not*

Table 2
Availability and descriptive statistics for ecological momentary assessment (EMA) and accelerometer data.

Study	Average Compliance to EMA Prompts	Percent with ≥4 Valid Days[a] of Accelerometer Data	Positive Affect[b]	Feelings of Energy[b]	Average Daily minutes of MVPA[c]	Sedentary Time per Valid Hour of Wear[d]	Percent Meeting Physical Activity Guidelines[e]
Mobile Healthy PLACES	80% (range 7%–100%)	92%	M = 32.8 (SD = 13.4)	M = 28.0 (SD = 14.9)	M = 41.7 (SD = 24.1)	M = 37.4 (SD = 4.9)	19.8%
AsthEMA	52% (range 20%–100%)	85%	M = 39.4 (SD = 9.4)	M = 38.9 (SD = 10.3)	M = 33.6 (SD = 40.7)	M = 40.7 (SD = 3.1)	12.2%
MATCH	Mothers: 78% (range 10%–100%) Children: 75% (range 11%–100%)	Mothers: 84% Children: 77%	$M_{Mothers}$ = 32.1 (SD = 11.6) $M_{Children}$ = 37.7 (SD = 13.4)		$M_{Mothers}$ = 25.7 (SD = 16.7) $M_{Children}$ = 56.1 (SD = 20.9)	$M_{Mothers}$ = 40.6 (SD = 4.4) $M_{Children}$ = 35.2 (SD = 3.9)	Mothers: 29.1% Children: 41.1%
Project MOBILE	82% (range 25%–100%)	89%	M = 30.6 (SD = 9.9)	M = 26.2 (SD = 11.5)	M = 22.0 (SD = 13.2)	M = 40.2 (SD = 3.8)	20.3%
Pooled Dataset	79.2% (range 7%–100%)	87%	M = 33.5 (SD = 12.3)	M = 27.0 (SD = 12.7)	M = 34.4 (SD = 22.8)	M = 38.7 (SD = 4.7)	29.0%

Note. EMA = Ecological Momentary Assessment. MVPA = Moderate-to- vigorous intensity physical activity.
[a] A valid day of accelerometer data were defined as having at least 10 h of valid per day. Valid hours were determined by screening accelerometer data for 60 minutes of consecutive zero-count data (which constituted non-wear time).
[b] Positive Affect and Feelings of Energy were scored on a 10 to 50 scale with higher values representing more of the construct.
[c] For adults, MVPA was defined as ≥ 2020 activity counts per minute. For children, MVPA ranged from ≥1770 to ≥2393 activity counts per minute based on age-specific cut offs for children.
[d] Sedentary time was operationalized as minutes of sedentary behavior per valid hour of wear to account for differences in sedentary time as a result of wear the activity monitor more.
[e] Meeting physical activity Guidelines were defined as engaging in ≥30 minutes of MVPA per day for adults and ≥60 minutes of MVPA per day for children.

at all) to 5 (*extremely*) scale. Data from Mobile Healthy Places and AsthEMA were recoded so that 3 (*quite a bit*) and 4 (*extremely*) would correspond to 4 (*quite a bit*) and 5 (*extremely*), respectively, on the response scale used in Project MOBILE. After recoding, feelings of energy values were rescaled by multiplying by 10 so that the response scale used in analyses ranged from 10 to 50. Feelings of energy were not assessed in MATCH. Therefore participant data from MATCH were not included in analyses pertaining to feelings of energy.

Physical activity and sedentary time. Physical activity and sedentary time were objectively-measured via an Actigraph Model GT2M or GT3X accelerometer-based activity monitor (Actigraph, Pensacola, FL). Accelerometer data was used to derive the average daily minutes of moderate- or vigorous-intensity physical activity (MVPA). MVPA ranged from ≥1770 to ≥ 2393 activity counts per minute based on age-specific cut offs for children and ≥ 2020 activity counts per minute for adults (Troiano et al., 2008). Average daily minutes of MVPA were then used to determine if participants were meeting guidelines for physical activity (≥60 minutes of MVPA per day for children and adolescents; ≥30 minutes of MVPA per day for adults) (Physical Activity Guidelines Advisory Committee, 2008). Physical activity was operationalized as whether or not participants were meeting physical activity guidelines based on their daily MVPA minutes (0 = not meeting guidelines, 1 = meeting guidelines). Sedentary time was operationalized as the average minutes of sedentary behavior (i.e., <100 counts per minute for children and adults) per hour of wear time. Sedentary time was adjusted for the duration of valid accelerometer device wear time to account for potential differences in sedentary time as a result of some participants having more valid wear time than other participants. Sedentary time was left as a continuous variable because there are currently no established US guidelines for limiting sedentary time. Data were screened to include valid days. A valid day consisted of ≥10 hours of valid wear time. Non-wear was defined as 60 minutes of consecutive zero-count data.

Demographic information. Across all studies, age, sex, and ethnicity data were collected via a paper and pencil questionnaire (in MATCH, mothers reported on child's ethnicity). For sex and ethnicity, female and Hispanic/Latino were coded as the higher values. A series of dummy coded variables were created to control for study with Mobile Healthy PLACES serving as the reference group.

Temporal processes. Time of day, day of week, and wave were ascertained from date- and time-stamped EMA and accelerometer data. Time of day of the EMA prompt was coded as morning (6:30am to 11:59am), afternoon (12:00pm to 5:59pm), or evening (6:00pm to 10:00pm). Day of week of the EMA prompt was coded as weekend day or weekday with weekend day being the higher value. Wave values were assigned for all participants.

2.4. Data analysis

Statistical modeling. This study uses a two-stage modeling approach to test the subject level effect of time-varying variables (i.e., positive affect and feeling of energy) on subject-level physical activity and sedentary time. For each time-varying outcome (i.e., positive affect and feelings of energy), the first stage consists of a mixed-effects location scale model (Hedeker, Mermelstein, & Demirtas, 2008) where $y_i^{(1)}$ is the n_i x 1 vector of outcomes for the time-varying variable of subject i, namely:

$$\boldsymbol{y}_i^{(1)} = \boldsymbol{X}_i^{(1)}\boldsymbol{\beta}^{(1)} + \upsilon_i^{(1)} + \varepsilon_i^{(1)} \quad (1)$$

with submodels for the variances:

$$\sigma_{\upsilon ij}^{2(1)} = exp\,(\boldsymbol{u}_{ij}^{(1)}\boldsymbol{\alpha}^{(1)})\,, \quad (2)$$

$$\sigma_{\varepsilon ij}^{2(1)} = \exp\,(\boldsymbol{w}_{ij}^{(1)}\boldsymbol{\tau}^{(1)} + \omega_i^{(1)}). \quad (3)$$

Here, i denotes subjects, j denotes occasions and each subject is measured at n_i occasions. In addition to the covariates X, the model includes random subject (location) effects $\upsilon_i^{(1)}$ to account for the clustering of repeated observations within subjects, and represent each subject's mean level. The variance of these random location effects represent the between-subject variance, or homogeneity/heterogeneity across subjects, which is modeled in Equation (2) in terms of covariates (which could be the same covariates as in X). The use of the exp function in this model ensures that the resulting variance is always a positive value. Similarly, the within-subject variance, or consistency/

inconsistency within subjects, is modeled in terms of covariates using the exp function in Equation (3), which also includes a random subject (scale) effect $\omega_i^{(1)}$ on their variance. Like the random location effect, the random scale effect accounts for the clustering of observations within subjects, but in terms of the dispersion of each subject's data around their mean level. Both random location and scale effects are assumed to be normally distributed, as are the errors. The ultimate objective of the first stage model is to test fixed effects for covariates while simultaneously generating estimates of random location and random scale effects to be included in the second stage model. Further details on the first-stage model and the MIXREGLS program used to estimate these models are published elsewhere (Hedeker & Nordgren, 2013).

Given that the random effects from the first stage model are at the subject-level, their influence on overall subject-level outcomes is also at the subject-level. The description of the second stage model below provides an example for the modeling of a continuous outcome variable (i.e., sedentary time per valid hour). For a dichotomous outcome variable (i.e., meeting physical activity guidelines or not), a logistic regression was tested. Thus, for a continuous outcome of subject i (i.e., sedentary time per valid hour), denoted as $y_i^{(2)}$, the Stage 2 model is:

$$y_i^{(2)} = \boldsymbol{X}_i^{(2)}\boldsymbol{\beta}^{(2)} + \boldsymbol{\upsilon}_i^{*(1)}\boldsymbol{\gamma}^{(2)} + \varepsilon_i^{(2)}, \quad (4)$$

where the vector $\boldsymbol{\upsilon}_i^{*(1)}$ includes the estimated location ($\upsilon_i^{*(1)}$) and scale ($\omega_i^{*(1)}$) random effects associated with the time-varying outcome (i.e., positive affect or feelings of energy) of the stage one model. In other words, a subject's mean and variance, serve as regressors in the modeling of overall subject-level outcome (i.e., sedentary time per valid hour), and their influence is characterized by the regression coefficients denoted by $\boldsymbol{\gamma}^{(2)}$. The errors $\varepsilon_i^{(2)}$ are assumed to be normally distributed with mean 0 and variance $\sigma_\varepsilon^{2(2)}$.

Two first stage outcomes (i.e., positive affect, feelings of energy) and two second stage outcomes (i.e., odds of meeting physical activity guidelines, sedentary time per valid hour of wear) were investigated in this study. In total, four separate models were run where (1) the first stage outcome was positive affect and the second stage outcome was odds of meeting physical activity guidelines, (2) the first stage outcome was positive affect and the second stage outcome was sedentary time per valid hour of wear, (3) the first stage outcome was feelings of energy and the second stage outcome was odds of meeting physical activity guidelines, and (4) the first stage outcome was feelings of energy and the second stage outcome was sedentary time per valid hour of wear.

Resampling. For the second stage analyses, if either a significant effect of location or scale was observed then resampling was conducted (Carsey & Harden, 2013). Resampling is necessary because the location and scale random effects are estimated quantities, and as estimated quantities there is an amount of uncertainty in these estimates for each subject. Therefore, for each subject 500 resampled random effects were generated, from a multivariate normal distribution using the mean and variance estimates of these random effects for that subject. In a similar manner as in multiple imputation, these resampled random effects were then used to rerun the modeling procedure described 500 times, results from one randomly-selected rerun were reported.

Covariate screening. In the first stage model (Eq. (1)) time-varying covariates, time of day (i.e., morning, afternoon, and evening), day of week (i.e., weekend day vs. weekday), and wave were simultaneously screened. Only day of week was a significant predictor among the mean, between-subject variance, or within-subject variance in positive affect or feelings of energy models ($p < 0.05$). Therefore, day of week was retained as a covariate in the first stage model. In the second-stage model (Eq. (4)) person-level covariates, age, sex, ethnicity, and study (consisting of 3 dummy coded variables) were simultaneously screened. Only age and sex were significant predictors of the behavioral outcomes ($ps < 0.05$). Therefore, age and sex were retained as covariates in the second-stage model.

3. Results

3.1. Data availability

Table 2 shows data availability for the pooled data set as well as for each individual study. Overall compliance with the EMA and accelerometer protocols was high. Averaging across all studies, participants answered an average of 79% of EMA prompts and 87% of participants provided at least 4 valid days of accelerometer data.

For the analysis involving positive affect, complete data were available for 617 participants (20,777 total observations) of the 661 individuals participating in the four studies. Participants were excluded from the analysis (n = 44) for several reasons: (i) participant had no valid accelerometer data (n = 17). (ii) participant had no variability in ratings of positive affect (in most cases this was attributable to participants only have one or two EMA ratings of positive affect, n = 10), (iii) participants did not provide demographic information (n = 10), (iv) participant had no EMA ratings of positive affect (n = 3), (v) participants had no EMA ratings of positive affect nor valid accelerometer data (n = 2) or (vi) participant had no data on any variables included in the model (n = 2).

For the analysis involving feelings of energy, complete data were available for 245 participants (6559 total observations) of the 259 individuals participating in the three studies. Participants were excluded from the analysis (n = 14) for several reasons: (i) participant had no valid accelerometer data (n = 7), (ii) participants did not provide demographic information (n = 3), (iii) participant had no EMA ratings of feelings of energy (n = 2), or (iv) participants had no EMA ratings of feelings of energy nor valid accelerometer data (n = 2).

Across all studies, the likelihood of answering an EMA survey prompt was unrelated to day of week, wave, sex, age, or ethnicity. An EMA survey prompt was more likely to be answered in the evening compared to the morning (OR = 1.20, $p < 0.01$). Additionally, a prompt was less likely to be answered by participants in AsthEMA compared to all other studies (OR = 0.19–0.29, $ps < 0.01$). Participants in MATCH were less likely to comply with the EMA protocol compared to participants in Project MOBILE (OR = 0.67, $p < 0.01$). No other significant differences in EMA compliance were noted by study.

Across all studies, the amount of valid accelerometer wear was unrelated to sex, day of week, wave; however, the amount of a valid accelerometer wear was related to age and ethnicity. As age increased, participants tended to have more valid accelerometer wear time ($b = -0.14$, $p < 0.01$). Hispanic participants had less valid accelerometer wear time on average ($M = 816.0$ minutes per day) compared to non-Hispanic participants ($M = 841.7$ minutes per day, $p < 0.01$). There were no significant differences among the different studies concerning valid accelerometer wear time ($ps = 0.09$–0.59).

3.2. Descriptive statistics

Descriptive statistics regarding variables of interest are displayed in Table 2. Across all studies, participants displayed moderate levels of positive affect ($M = 33.5$, $SD = 12.3$, on a 10 to 50 scale) and feelings of energy ($M = 27.0$, $SD = 12.7$, on a 10 to 50 scale), on average. Accelerometer-derived data indicated that, on average, participants engaged in nearly 35 minutes of MVPA per day ($M = 34.4$, $SD = 22.8$) and approximately 29% of participants met physical activity guidelines. Additionally, participants engaged in nearly 40 minutes of sedentary time per valid hour of wear on average ($M = 38.7$, $SD = 4.7$). Continuous variables, positive affect, feelings of energy, and sedentary time, were examined for skewness and determined to be normally distributed.

Positive affect differed by time of day. Compared to the morning ($M = 33.0$), positive affect was tended to be higher in the afternoon ($M = 33.7$, $p = 0.01$) and evening ($M = 33.8$, $p < 0.01$); however, there was no significant difference between positive affect in the afternoon and evening ($p = 0.70$). Positive affect was higher on weekend days ($M = 34.5$, $p < 0.01$) compared to weekdays ($M = 32.6$). There were no differences in positive affect by wave.

Feelings of energy tended to be significantly higher in the afternoon ($M = 28.5$) compared to the morning or evening ($M = 25.8$ or $M = 26.7$, respectively, $ps < 0.01$); however, there were no significant differences in feelings of energy between the morning and evening ($p = 0.06$). Feelings of energy were unrelated to day of week and wave.

Average daily minutes of MVPA was unrelated to ethnicity. Females engaged in less daily physical activity ($M = 28.5$ minutes, $SD = 18.2$), on average, compared to males ($M = 50.1$ minutes, $SD = 25.5$, $b = -16.31$, $p < 0.01$). Furthermore, as age increased, participants tended to engage in less daily physical activity ($b = -0.59$, $p < 0.01$). Project MOBILE participants differed significantly from all other studies in terms of physical activity levels. Project MOBILE participants engaged in the least amount of daily physical activity ($M = 22.0$ minutes) compared to all other studies. There were no significant differences amongst physical activity levels in Mobile Healthy Places, AsthEMA, and MATCH.

Sedentary time was unrelated to ethnicity. Females engaged in more minutes of sedentary time per hour of wear ($M = 39.2$ minutes, $SD = 4.5$), on average, compared to males ($M = 36.5$ minutes, $SD = 4.9$, $b = 1.23$, $p < 0.01$). Furthermore, as age increased, participants tended to engage in more sedentary time per hour of valid wear ($b = 0.13$, $p < 0.01$). Participants in Mobile Healthy PLACES and MATCH engaged in the lowest levels of sedentary time per hour of wear, on average ($M = 37.4$ minutes and $M = 37.9$ minutes, respectively) and were not significantly different from one another. Participants in Project MOBILE engaged in significantly more sedentary time ($M = 40.4$ minutes) per hour of wear compared to Mobile Healthy PLACES and MATCH ($ps < 0.05$). Participants in AsthEMA engaged in significantly more sedentary time ($M = 40.7$ minutes) per hour of wear than participants in Mobile Healthy PLACES ($p < 0.05$). There were no significant differences in sedentary time between AsthEMA and Project MOBILE.

3.3. *Variability in positive affect predicting physical activity and sedentary time*

Table 3 displays results from the first stage model which included random subject location and scale effects, and examined the effects of covariates (i.e., weekend vs weekday) on mean levels of and variability in (within-subject and between-subject) positive affect. Key findings from the first stage model reveal that ratings of positive affect tended to be higher on weekend days than weekdays ($\beta = 1.63$, $p < 0.01$). Between-person variability in positive affect was significantly greater than zero (on the exp scale) as indicated by the intercept of the between-subject model ($\alpha = 4.07$, $p < 0.01$), suggesting that on average, people differed significantly from one another in their ratings of positive affect. Furthermore, there was less between-person variability (i.e., more homogeneity among people) in ratings of positive affect ($\alpha = -0.12$, $p < 0.01$) on weekend days compared to weekdays. Within-person variability in positive affect was significantly greater than zero (on the exp scale) as indicated by the intercept of the within-subject model ($\tau = 4.44$, $p < 0.01$), suggesting that on average, people varied significantly within themselves in their ratings of positive affect. There were no significant differences in within-person variability (i.e., fluctuation) in positive affect between weekend days and weekdays.

Table 3
Results from first-stage mixed-effects location scale modeling.

	Predicting EMA Ratings of Positive Affect Estimate (Standard Error)	Predicting EMA Rating of Feelings of Energy Estimate (Standard Error)
Mean Model (β)		
Intercept	32.81** (0.32)	27.37** (0.53)
Weekend	1.63** (0.11)	0.88** (0.24)
Between-Subject Variance Model (α)		
Intercept	4.07** (0.06)	4.03** (0.10)
Weekend	−0.12** (0.02)	−0.18** (0.06)
Within-Subject Variance Model (τ)		
Intercept	4.44** (0.03)	4.63** (0.04)
Weekend	0.01 (0.02)	0.15** (0.03)

Note. Model predicting Ecological Momentary Assessment (EMA) ratings of positive affect is based on 20,777 valid observations from 617 participants. Model predicting EMA ratings of feelings of energy is based on 6559 valid observations from 245 participants. **$p < 0.01$.

Table 4
Subject-Level Regression Models predicting Odds of Meeting Physical Activity Guidelines (Logistic) and Sedentary Time (Linear).

	Predicting Odds of Meeting Physical Activity Guidelines Estimate (Standard Error)	Predicting Minutes of Sedentary Time per Valid Hour of Wear Estimate (Standard Error)
Positive Affect		
Intercept	0.58 (0.32)	33.74** (0.68)
Mean level of Positive Affect	0.09 (0.10)	0.33 (0.31)
Variability in Positive Affect	0.07 (0.09)	0.16 (0.23)
Sex (Female)	−0.92** (0.21)	1.04* (0.41)
Age	0.01 (0.01)	0.11** (0.01)
Feelings of Energy		
Intercept	0.51 (0.55)	34.93** (1.03)
Mean level of Feelings of Energy	−0.09 (0.18)	−0.26 (0.30)
Variability in Feelings of Energy	−0.43* (0.21)	0.15 (0.37)
Sex (Female)	−1.13** (0.36)	1.40* (0.58)
Age	−0.01 (0.01)	0.07** (0.02)

Note. Model using positive affect data are based on 617 participants. Model using feelings of energy data are based on 245 participants. For logistic regression models predicting odds of meeting physical activity guidelines, logit (i.e., log odds) estimates are displayed. *$p < 0.05$. **$p < 0.01$.

Table 4 display results from the second stage model testing the associations between subject-level mean (location) and variability (scale) in positive affect and behavioral outcomes. After controlling for sex and age, neither subject-level mean nor variability in positive affect were significantly associated with either the odds of meeting physical activity guidelines ($\beta = 0.09$, $p = 0.36$; $\beta = 0.07$, $p = 0.45$, respectively) or sedentary time per valid hour ($\beta = 0.33$, $p = 0.65$; $\beta = 0.16$, $p = 0.49$, respectively). Across both models, sex was a significant predictor with females being less likely to meet physical activity guidelines ($\beta = -0.92$, $p < 0.01$) and engaging in more total sedentary time ($\beta = 1.04$, $p < 0.05$) compared to males. Age was a significant predictor of sedentary time ($\beta = 0.11$, $p < 0.01$) with older individuals being more sedentary but not a significant predictor of odds of meeting physical activity guidelines ($\beta = 0.01$, $p = 0.74$).

3.4. *Variability in feeling energetic predicting physical activity and sedentary time*

Table 3 also displays results from the first stage model which included random subject location and scale effects, and examined the effects of covariates (i.e., weekend vs weekday) on mean levels of and variability in (within-subject and between-subject) feeling energetic. Key findings from the first stage model reveal that feelings of energy tended to be higher on weekend days as compared to weekdays ($\beta = 0.88$, $p < 0.01$). Between-person variability in feelings of energy was significantly greater than zero (on the exp scale) as indicated by the intercept of the between-subject model ($\alpha = 4.03$, $p < 0.01$), suggesting that on average, people differed significantly from one another in their ratings of positive affect. Furthermore, there was less between-subject variability (i.e., more homogeneity among people) in feelings of energy ($\alpha = -0.18$, $p < 0.01$) on weekend days compared to weekdays. Also, within-person variability in feelings of energy was significantly greater than zero (on the exp scale) as indicated by the intercept of the within-subject model ($\tau = 4.63$, $p < 0.01$), suggesting that on average, people varied significantly within themselves in their ratings of feelings of energy. Participants experienced more within-subject variability (i.e., more heterogeneity within a given person) in feelings of energy ($\tau = 0.15$, $p < 0.01$) on weekend days compared to weekdays.

Table 4 also displays results from the second stage model testing the associations between subject-level mean (location) and variability (scale) in feelings of energy and behavioral outcomes. After controlling for sex and age, variability in feelings of energy was significantly associated with odds of meeting physical activity guidelines ($\beta = -0.43$, $p < 0.05$) such that individuals who experienced more variability in their feelings of energy were less likely to meet physical activity guidelines. Subject-level variability in feelings of energy was not associated with sedentary time ($\beta = 0.15$, $p = 0.67$). Mean level of feelings of energy were not associated with either the odds of meeting physical activity guidelines or sedentary time per valid hour ($\beta = -0.09$, $p = 0.61$; $\beta = -0.26$, $p = 0.38$, respectively). Sex was a significant predictor with females being less likely to meet physical activity guidelines ($\beta = -1.13$, $p < 0.01$) and engaging in more total sedentary time ($\beta = 1.40$, $p < 0.05$) compared to males. Age was a significant predictor of sedentary time ($\beta = 0.07$, $p < 0.01$) with older adults being more sedentary but not a significant predictor of the odds of meeting physical activity guidelines ($\beta = -0.01$, $p = 0.48$). Resampling confirmed the significant association between variability in ratings of feelings of energy and the odds of meeting physical activity guidelines ($\beta = -0.68$, $p < 0.05$).

4. Discussion

Most research investigating the role of affect and arousal in the regulation of physical activity and sedentary behavior has largely focused on the extent to which usual (i.e., chronic) or momentary (i.e., acute) levels of affect and arousal are linked with physical activity and sedentary behavior (Liao et al., 2015; O'Connor & Puetz, 2005; Puetz, 2006). The current study extended beyond previous research by using novel methodology to capture and model subject–level variability in affect and arousal. The results from this study help to untangle relationships between subject-level variability in affect and arousal and overall levels of physical activity and sedentary time. Results indicated that individuals who experienced greater variability in feelings of energy were less likely to meet physical activity guidelines but that variability in positive affect was not associated with either physical activity or sedentary time. Taken together, the results from this study help to provide a more complete understanding of the dynamic nature of affect and arousal, and its relations with physical activity and sedentary time across the lifespan.

This is the first known study to document an association between subject-level variability in an indicator of arousal, feelings of energy, and overall physical activity levels. Greater subject-level variability in feelings of energy may deplete the psychological and self-regulatory resources involved in planning, overcoming barriers, and executing physical activity behaviors (Buckley et al., 2014; Daly et al., 2014). From a motivational perspective, arousal is closely tied to the impulse to act and feelings of energy reflect activation (Niven & Miles, 2013). A series of studies by Ryan and Frederick (1997) revealed that greater feelings of vitality (measured in part by feelings of energy) was associated with enhanced self-actualization, self-determination, and sense of agency. These results suggest that greater variability in feelings of energy as opposed to consistent, high levels may result in lower motivation and have implications for engagement in health behaviors. From a physiological perspective, physical activity requires energy expenditure; thus, inconsistent levels of perceived available energy may lead to less physical activity. Future research is necessary to between understand the mechanisms linking subject-level variability in arousal and physical activity levels.

Because of the nature of this data, this study is unable to make claims about the directionality of the association between variability in arousal and physical activity. Engaging in regular physical activity may stabilize one's perceived arousal levels. Engaging in regular physical activity is associated with improved sleep quality, which can increase feelings of energy and fatigue throughout the day (Atkinson & Davenne, 2007). In an examination of national panel data, US adults meeting physical activity guidelines slept significantly better and reported feeling more alert during the day compared to US adult not meeting physical activity guidelines (Loprinzi & Cardinal, 2011). Longitudinal research is necessary to examine the temporal relationships between subject-level stability or variability in arousal states and physical activity. Furthermore, results from this study do not explore different patterns of variability in arousal. Future research is necessary to parse apart which are the most detrimental aspects of variability (Gruber, Kogan, Quoidbach, & Mauss, 2013).

Perhaps most surprising was the null findings regarding associations between subject-level variability in positive affect and physical activity. Previous research in children found that greater variability in positive affect was associated with lower levels of physical activity (Dunton et al., 2014). Additionally greater variability in positive affect has been linked with other maladaptive health behaviors in various populations including increased frequency of alcohol consumption (Gottfredson & Hussong, 2013) and increased odds of engaging in dysregulated eating behaviors (Anestis et al., 2009). Positive affect levels among the pooled data set were moderate across participants, on average. Approximately 66% of the pooled data set had an average level of positive affect above the mid-point of the scale (30 on a 10 to 50 scale) and approximately one-quarter of the pooled data set had average levels of positive affect at or above 40 (on a 10 to 50 scale). Although the significant intercept of the within-subject variance model indicated that there was significant within-person variability in ratings of positive affect, it is possible that the apparent ceiling effect in ratings of positive affect limited the potential for within-person variability and may have attenuated associations between variability in positive affect and physical activity seen in previous research.

Attenuated associations between subject-level variability in positive affect and physical activity may also stem from the fact that the affect measures employed a distinct-states approach assessing affective states as distinct entities (Izard, 1993) as opposed to a dimensional approach in which affective states are positioned along elemental dimensions (i.e., valence and arousal) (Russell, 1978). The distinct states assessed in the pooled data set (i.e., happy, joyful, cheerful, calm) may not fully capture the entire content domain of positive affect (e.g., optimism, gladness, or excitement) (Ekkekakis, 2013). Thus, it is possible that changes in and variability in positive affect were not fully captured and may have impacted associations between positive affect, physical activity, and sedentary behavior.

Finally, regarding the measure of affective states, the studies included in this analysis all employed items that used unipolar response scales as opposed to a bipolar response scales. The fundamental assumption of the unipolar scale is that positive and negative affect are distinct constructs and not merely opposite ends of the same continuum (Ekkekakis, 2013). Indeed, evidence suggests that ratings of positive and negative affect are not necessarily always strongly negatively correlated in EMA research (e.g., Hyde, Conroy, Pincus, & Ram, 2011; Mermelstein, Hedeker, & Weinstein, 2010). Momentary ratings of negative affect using unipolar response scales were assessed across these EMA studies; however, due to a limited amount of intraindividual variability in negative affect, mixed-effects location scale models were unable to converge. Thus, data from these studies cannot draw conclusions about associations (or lack thereof) between subject-level variability in negative affect and overall levels of physical activity and sedentary behavior.

To the best of our knowledge, this study is the first to model subject-level variability in affective and physical feeling states predicting of sedentary time. Results from this study suggest that neither subject-level variability in affect nor in arousal was associated with sedentary time. In this study, accelerometers captured total sedentary time. While device-based measures are useful in that fact that they reduce memory and other biases that are typically associated with retrospective recall measures (e.g., Adamo, Prince, Tricco, Connor-Gorber, & Tremblay, 2009), they are limited in the fact that these measures are often unable to capture any contextual information regarding the sedentary behavior. Sedentary behavior is a behavior that can occur in a variety of domains (e.g., sitting while watching TV, sitting while using the computer, sitting while socializing, sitting while working). It is possible that subject-level variability in affect or arousal may be unrelated to total sedentary time but may be associated with specific domains of sedentary time, such as television viewing or other sedentary behaviors that represent a choice of how to spend one's leisure time. Sedentary activities such as sitting while at work or in school, or sitting while doing homework represent a large portion of most adults' and adolescent's/children's lives, respectively, and are sedentary activities that are generally obligatory (e.g., Chau, van der Ploeg, Merom, Chey, & Bauman, 2012). Therefore, capturing total as opposed to domain-specific sedentary time may attenuate associations between subject-level variability in affect or arousal and sedentary time. Future research would benefit from combining device-based measures of sedentary time with self-reported contextual information through a real-time data capture strategy such as EMA to gain more insight into the types of sedentary behavior that are occurring (Dunton, 2017).

Taking a more nuanced approach to understanding behavior, as was done in this study by using novel methodology to capture and model individuals' affect, arousal, and behavior as it unfolds in the context of daily life, is likely the most promising way to better understand human behavior. From a theoretical perspective, the results from this study suggest that subject-level variability in relevant time-varying factors, even after controlling for mean levels, may be important in understanding health behaviors. Traditional theories of motivation that focus exclusively on between-person determinants of behavior are missing important information as to how natural variability in time-varying factors contribute to health behaviors. From a promotion perspective, the results from this study suggest that individuals with greater variability in time-varying factors could possibly benefit from behavior change techniques that facilitate self-regulation of behavior (e.g., action and coping planning, self-monitoring of behavior).

This study had some additional limitations. First, although the pooled data set included a relatively diverse sample with respect to age, ethnicity, and weight status, this sample consisted of a majority of women (especially among the adult samples). Furthermore, although included, young (age 18–30 years) and older adults (age 50 + years) were underrepresented in the pooled data set with each group making up less than 5% of the sample. Future research should continue to investigate variability in affect and arousal as predictors of overall health behaviors in samples of men as well as samples across the lifespan. Second, to enhance usability and reduce participant burden, the pooled data set included assessments of positive affect ranging from 2 to 4 items and assessments of feelings of energy using a single-item designed to capture distinct affective and physical feeling states. The narrow assessment of affective or physical feeling states across the studies in the pooled data set may not fully capture these constructs or variability in them. Measurement protocols in EMA studies are often crafted to assess constructs of interest but limit the length of each electronic survey to no more than 3 minutes. Alternative affect measures for future EMA research may include the Feeling Scale (Hardy & Rejeski, 1989) and the Felt Arousal Scale (Svebak & Murgatroyd, 1985) because of the brevity (i.e., two items total) and the completeness (i.e., captures both valence and arousal) of these measures. Third, this study chose to model physical activity as a dichotomous variable (i.e., meeting physical activity guidelines or not) as opposed to a continuous variable (i.e., average daily minutes of MVPA) due to the highly skewed nature of average daily minutes of MVPA (even after log transforming). This analytic decision was made because the highly skewed nature of the physical activity data would violate the assumptions of linear regression regarding the normality of the outcome variable. Future research in more active populations would likely reduce the skewed nature of physical activity data and allow researchers to explore associations between affect and feelings of energy and average daily minutes of physical activity as a continuous variable. With regard to determining whether a participant was meeting physical activity guidelines, minutes of MVPA were considered but bout length was not. For adults, recommendations state that physical activity should be accrued in bouts of at least 10 minutes. Only including bouts of physical activity lasting at least 10 minutes would likely capture intentional exercise as opposed to lifestyle physical activity accumulated in shorter bouts. Associations between variability in affect and feelings of energy may have differential associations with physical activity depending on the conceptualization of physical activity. However, nearly two-thirds (64%) of the pooled data set had no bouts of physical activity lasting at least 10 minutes leaving this data poorly powered to detect associations between variability in affect and feelings of energy and physical activity accrued in bouts of at least 10 minutes. Finally, three of the four studies in the pooled data set did not collect EMA data on weekdays until after 3:00pm to avoid data collection during school hours. Therefore, affect and arousal were under sampled during weekday mornings and early afternoon. Future research should consider sampling across the entirety of both weekdays and weekend days to more fully capture natural variability in affect and arousal as it occurs in everyday life.

In conclusion, this study is one of the first to investigate the role of subject-level variability in affect and arousal in regulating physical activity and sedentary time. Results indicate that variability in arousal is an important predictor of physical activity and adds to our theoretical understanding of the processes regulating health behaviors. These results add to accumulating evidence that researchers should move beyond focusing solely on mean levels and consider the extent to which people experience intraindividual or within-subject variability in relevant time-varying predictors to better understand health behaviors.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.psychsport.2018.01.011.

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