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Bidirectional Associations Between Psychological States and Physical Activity in Adolescents: A mHealth Pilot Study

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Abstract

Objective To understand the predictors and consequences of adolescent moderate-to-vigorous physical activity (MVPA) and sedentary behavior in nearly real-time. **Methods** Participants were 26 adolescents (*M*age = 15.96, *SD* = 1.56) who provided 80 self-reports of subjective states and continuous objective reports of MVPA and sedentary behavior over 20 days. **Results** Random effects were observed for all of the models with affect and feeling variables predicting MVPA. There was a negative fixed effect for within-person positive affect and sedentary behavior and the inverse association for negative affect. Within-person MVPA was a significant positive predictor of positive affect and energy. There was a random effect for within-person MVPA and fatigue. There was a significant random effect for within-person sedentary behavior predicting positive affect. Within-person sedentary behavior was a significant negative predictor of energy. **Conclusions** Findings highlight the importance of the intrapersonal nature of the associations among subjective states and physical activity.

Key words: adolescents; computer applications/ehealth; health behavior; health promotion and prevention.

From a population perspective, individual health behavior is the largest single contributor to the development of chronic illnesses such as obesity, cardiovascular disease, diabetes, and cancer (Ford, Zhao, Tsai, & Li, 2011; Mokdad, Marks, Stroup, & Gerberding, 2004). Physical inactivity is a critical health behavior in need of scientific investigation because it accounts for approximately 1 in 10 preventable deaths (Danaei et al., 2009). Relative to adults, children are sufficiently active until age 13, when they experience a dramatic decline in activity rates through age 15, at which point both boys and girls participate in inadequate moderate-to-vigorous physical activity (MVPA; Nader, Bradley, Houts, McRitchie, & O'Brien, 2008). Current estimates suggest that among high-school students, less than 30% are achieving the recommended 60 min of MVPA per day (Centers for Disease Control and Prevention, 2014; USDHHS, 2008). Similarly, rates of sedentary behavior increase from childhood to adolescence (Ortega et al., 2013), with one study suggesting an increase of approximately 90 min per day from age 12 to 16 (Mitchell et al., 2012). Furthermore, these trends of MVPA and sedentary behavior continue into adulthood when major physical health consequences (e.g., cardiovascular disease, cancers, and diabetes) may emerge from the negative behavioral patterns established in adolescence (Gordon-Larsen, Nelson, & Popkin, 2004; Ortega et al., 2013). Therefore, adolescence appears to be a critical developmental period for promoting MVPA and preventing lifelong inactivity.

Efforts to understand the key predictors of adolescent MVPA and sedentary behavior have largely supported the role of self-efficacy, autonomous motivation, social support, and perceived behavioral control (Babic et al., 2014; Craggs, Corder, van Sluijs, & Griffin, 2011; Lowry, Lee, Fulton, Demissie, & Kann, 2013; Van der Horst, Paw, Twisk, & Van Mechelen, 2007). The aforementioned variables can be thought of as fixed characteristics of the individual or environment that increase the probability of engagement in MVPA or sedentary behavior on a typical day; however, they do little to predict whether an individual will engage in MVPA or sedentary behavior on a specific day. In addition to examining these trait-like, fixed variables, it is important to understand how state-like variables relate to an individual adolescent's MVPA and sedentary behavior.

The variables that affect MVPA or sedentary behavior on a specific day are likely to be dynamic and fluctuate rapidly. Examples of such variables include affect (i.e., positive and negative affect) and physical feeling states (i.e., energy and fatigue; Cushing & Steele, 2011; Dunton et al., 2014). These subjective states are thought to increase or decrease the probability of MVPA and sedentary behavior on a specific day or at a particular moment (Dunton et al., 2014). On the other hand, MVPA and sedentary behavior can also be considered dynamic and fluctuating variables that impact affective and physical feeling states. It has been suggested that physical activity improves emotional well-being (e.g., positive affect and energy), causing a "feel-good" effect (Reed & Ones, 2006) through biological and psychological processes, such as increased beta-endorphins and sense of achievement (Dinas, Koutedakis, & Flouris, 2011). Less research has focused on psychosocial consequences of sedentary behavior; however, one systematic review provided evidence that higher levels of screen time were associated with lower psychological well-being and higher depression in adolescent females, independent of their physical activity levels (Costigan, Barnett, Plotnikoff, & Lubans, 2013). Therefore, variables such as positive affect, negative affect, energy, and fatigue appear to be both important predictors and consequences of MVPA and sedentary behavior in adolescents.

Studies that have attempted to understand the impact of affective and physical feeling states on physical activity have largely been conducted in laboratory settings. A common protocol is to require a participant to engage in moderate exercise and then assess mood in the immediate aftermath of the activity (Liao, Shonkoff, & Dunton, 2015; Schneider, Dunn, & Cooper, 2009; Schneider & Schmalbach, 2015; Subramaniapillai et al., 2016). Such studies reliably demonstrate an effect of exercise on positive affect, with more proximal measurements demonstrating a larger effect size (Reed & Ones, 2006). There are benefits of conducting these studies in laboratory settings, such as the ability to control the intensity and duration of activity and the timing of the assessments of affective and physical feeling states. However, such protocols do not capture adolescents' natural preferences to seek or avoid MVPA and sedentary behavior, and they may not represent the type of activity performed in a free-living environment (Dunton et al., 2014; Liao et al., 2015; Wilhelm & Grossman, 2010). Therefore, there are limitations to studying affective and physical feeling states in relation to activity levels in a laboratory setting.

To address the limitations of studying these variables in laboratory settings, recent studies have begun to examine the associations between state psychosocial variables and MVPA/sedentary behavior in free-living, naturalistic environments. Findings of a recent review of the literature concluded that higher levels of positive affect (e.g., joy, happiness, liveliness) predicted higher levels of MVPA, but did not find support for negative affect (e.g., anger, sadness, fear) predicting MVPA (Liao et al., 2015). In the one study that explored MVPA and subjective states in children (9-13 years), there was also support for higher levels of energy and lower levels of fatigue predicting higher levels of MVPA (Dunton et al., 2014). Furthermore, Liao et al. (2015) indicated that higher levels of MVPA predicted higher levels of positive affect and energy. Dunton and colleagues (2014) also found that higher levels of MVPA predicted lower ratings of negative affect in a preadolescent sample. A notable gap in the literature is that no studies have yet considered affective and physical feeling states in relation to sedentary behavior (Liao et al., 2015).

The current study fills a gap in the available literature by examining the critical developmental period of adolescence, which is simultaneously a critically important and under-studied developmental period for MVPA and sedentary behavior (Liao et al., 2015; Mitchell et al., 2012; Nader et al., 2008; Ortega et al., 2013). Furthermore, this investigation extends the existing literature by examining both MVPA and sedentary behavior using objective physical activity assessment, which is underutilized in the pediatric physical activity literature (Cushing, Brannon, Suorsa, & Wilson, 2014). This study follows the recommended assessment procedures of including electronic devices and accelerometers to measure variables for an extended period (Liao et al., 2015; i.e., 4 times a day for 20 days). Finally, the results of the current investigation may yield new information that can be leveraged in the development of just-in-time adaptive interventions. Future intervention studies will be able to test decision rules based on significant associations observed in the current study.

The goal of the current study was to examine the bidirectional associations among affective and physical feeling states and free-living MVPA and sedentary behavior in adolescents between the ages of 13 and 18 years. The first objective was to examine whether participant reports of affective and physical feeling states were associated with MVPA and sedentary behavior in the following 30-min window, at both the between-person and within-person levels. Consistent with previous literature, it was hypothesized that higher levels of positive affect and energy and lower levels of fatigue would be associated with subsequent higher levels of MVPA and lower levels of sedentary behavior. In addition, higher levels of negative affect were expected to be associated with subsequent lower levels of MVPA and higher levels of sedentary behavior. The second objective was to examine whether objective measures of MVPA and sedentary behavior were associated with participant reports of affective and physical feeling states in the following 30-min window, at both the between-person and within-person levels. In line with previous studies, it was hypothesized that higher levels of MVPA and lower levels of sedentary behavior would be associated with higher levels of positive affect and energy and lower levels of negative affect at both the between- and within-person levels.

Methods

Participants

Participants included 30 adolescents, ages 13 to 18 years ($M = 15.96$, $SD = 1.56$; 42.3% female), from a small, rural Midwestern community in the United States. Adolescents were deemed eligible if: (a) they were between the ages of 13 and 18, (b) they read and spoke English, and (c) their parents or guardians provided written consent for participation. Adolescents were excluded if: (a) they had significant visual impairments or (b) if they had physical maladies that would limit physical activity. Four adolescents dropped out of the study before providing data citing scheduling concerns. Of the 26 remaining participants, the large majority of adolescents identified themselves as Caucasian (69.2%), with a smaller number identifying as American Indian (15.4%), Hispanic (11.5%), and Asian (3.8%). Additionally, the majority (56%) of the participants reported that their annual family income was greater than $60,000; 16% of the sample reported a family income between $50,000 and $60,000, 20% of the sample reported a family income between $30,000 and $50,000, and 8% of the sample reported a family income between $20,000 and $30,000.

Procedures

Research staff recruited adolescents for the 20-day study by distributing brochures and flyers throughout the community, sending direct emails, and announcing the study on various social media platforms (e.g., posting Facebook message on a laboratory page). Interested parents and adolescents called the research laboratory to receive more information about the project and to complete an initial phone screen. Parental consent and adolescent assent (for those under 18 years of age) were collected before data were collected; consent was collected from adolescents over 18 years of age. Data collection occurred over the months of August through December.

During the initial in-person visit, adolescents were given an ActiGraph wActi Sleep-BT accelerometer (ActiGraph LLC, Pensacola, FL) and were instructed to wear the accelerometer on their nondominant wrist every day for 24 hr. Because the accelerometer was waterproof, participants could wear the sensor all day, even when getting wet.

In addition to the accelerometer, each participant also received an Android smartphone (Google Nexus 4). A mobile application (APP), which was developed for the current study, was downloaded on each phone and was designed to deliver questionnaires that prompted participants with an alarm to report on affective and physical feeling states at four time points each day (each observation is called a *wave*). Notably, all affective and physical feeling states questions were given at each of the four time points. The study protocol required that survey times be at least 2 hr apart, and research staff encouraged participants to pick two survey times in the morning (e.g., before school, before lunch) and two survey times in the afternoon/evening (e.g., after school, early evening) during which it would be feasible to complete a 3–5-min survey. Research staff informed adolescents the surveys would be administered at the same time on weekdays and weekends and that they were allowed to choose survey times during school hours if they had free periods during which the use of a mobile device was appropriate. The chosen prompt times were fixed for each participant for each day throughout the duration of the study. The decision to allow participants to choose their preferred survey times was made in efforts to increase participants' opportunity for compliance with the protocol and maximize data acquisition. For example, it was anticipated that scheduling the surveys around after-school activities or sports practices increased the chances that when prompted, adolescents would complete the surveys with their full attention. Additionally, the decision to use four survey observations was made to obtain ecological momentary assessment (EMA) data that captured daily fluctuations of the variables of interest without being overly burdensome to participants. The measures included in this study were a part of a larger EMA project that evaluated the dynamic associations among physiological variables, psychological variables, and health behaviors in adolescents (Cushing, 2017).

At the end of the 20-day study period, participants attended another in-person visit in which they returned the equipment and completed post-assessment measures. Adolescents received up to $40 for participation in the study based on their compliance with the protocol. Specifically, they were compensated $25 for completing all four daily smartphone surveys on at least 17 of the 20 study days (i.e., 85% compliance). As part of the larger protocol not yielding data for the present study, participants also had the opportunity to earn $15 by wearing an additional heart rate monitoring device for 12 hr of each study day. The study procedures described above were approved by the local institutional review board prior to data collection.

Measures

Objective Measure of MVPA and Sedentary Behavior

The ActiGraph wActi Sleep-BT accelerometer (ActiGraph LLC, Pensacola, FL) was used as an objective measure of MVPA and sedentary behavior. This well-validated device records three planes of movement through a triaxial accelerometer. For the current study, accelerometers were initialized to sample movement at a rate of 30 Hz, and the participants were instructed to wear the ActiGraph on their nondominant wrist, as described in the current National Health and Nutrition Examination Survey (NHANES) protocol (Centers for Disease Control and Prevention, 2011).

The Actilife software v.6.10.2 was used to process the raw data into meaningful assessments of MVPA and sedentary behavior 30 min before and after EMA prompts to answer questions about affective and physical feeling states. Raw data were first binned into 60-s epochs. Next, sleep periods were flagged using the Sadeh algorithm (Sadeh, Sharkey, & Carskadon, 1994), and non-wear periods were flagged using the Troiano algorithm (Troiano et al., 2008). Sleep periods were considered non-wear time in the current processing procedures to ensure that only waking wear time was considered when determining activity estimates. Within waking wear time, participants were required to provide 10 consecutive hours of wear for data to be considered valid in a given day. All data that were considered waking wear time were then processed within a custom Python program using modified Chandler cut points (Chandler, Brazendale, Beets, & Mealing, 2015) for MVPA and sedentary behavior. The Chandler algorithm was chosen for cut points in the current study, as it was established using a sample of youth under 18 years of age wearing wrist-worn accelerometers (Chandler et al., 2015). Chandler et al. (2015) initially developed the cut points using 5-s epochs; however, these cut points were modified for the current study to account for the fact that the raw data were binned in 60-s epochs. As a result, the cut points in the current data processing procedures were as follows: sedentary (0–3660), light activity (3661–9804), and MVPA (9805 and above). Accelerometer data were linked with the EMA questionnaire responses using electronic time stamps. The MVPA and sedentary behavior variables were calculated by summing the total number of minutes for each variable respectively, occurring within the 30 min prior and immediately following each EMA questionnaire. Mean daily minutes of MVPA and sedentary behavior were also calculated and are reported in Table I.

Positive and Negative Affect

The short form of the Positive and Negative Affect Schedule (I-PANAS-SF; Thompson, 2007) was used to measure positive and negative affect. The I-PANAS-SF includes five items that assess positive affect (i.e., alert, inspired, determined, attentive, active) and five items that assess negative affect (i.e., upset, hostile, ashamed, nervous, afraid). Adolescents received prompts four times a day on the smartphone APP to indicate how much they currently felt each emotion on a 5-point Likert scale from 1 (“Never”) to 5 (“Always”). The I-PANAS-SF has been shown to have adequate psychometric properties (Thompson, 2007). The internal consistency of the positive affect subscale in the current sample was $\alpha = 0.83$, and the internal consistency of the negative affect subscale was $\alpha = 0.82$.

Table I. *Descriptive Statistics for Study Variables*

Variable	Mean	SD	Proportion rated 0 (%)
Minutes of MVPA per day	30.63	28.75	–
Minutes of SB per day	670.00	133.07	–
Minutes of MVPA 30 min pre-survey	1.14	2.79	64
Minutes of SB 30 min pre-survey	20.11	7.34	00.4
Minutes of MVPA 30 min post-survey	1.20	2.94	65
Minutes of SB 30 min post-survey	20.35	7.37	00.4
Positive affect	12.63	4.80	10
Negative affect	7.58	3.71	54.6
Energy	6.58	3.10	22.8
Fatigue	6.20	3.11	28.8

Note. Proportion rated 0 refers to the percentage of the responses that were at the floor of the scale—this aids in understanding the variability and distribution of the variables; MVPA= moderate-to-vigorous physical activity; SB= sedentary behavior.

Energy and Fatigue

Energy and fatigue were assessed using the three highest loading items for both the "Vigor-Activity" and the "Fatigue-Inertia" factors from Profile of Mood States (POMS; McNair, Lorr, & Droppleman, 1971). Adolescents received prompts four times a day on the smartphone APP to indicate how much they currently felt each physical feeling state since the last prompt on a 5-point Likert scale from 0 ("Not at all") to 4 ("Extremely"). To measure energy, participants were asked how much they currently felt energetic, full of pep, and vigorous. To measure fatigue, participants were asked how much they currently felt fatigued, exhausted, and worn out. The POMS has been extensively used to measure mood states in relation to athletic performance and activity (Beedie, Terry, & Lane, 2000; Berger & Motl, 2000). The internal consistency of the energy subscale in the current sample was $\alpha = 0.84$, and the internal consistency of the fatigue subscale was $\alpha = 0.88$.

Data Analysis Plan

First, descriptive statistics were conducted using IBM SPSS Statistics (Version 22) for all study variables. Next, a series of multilevel models were estimated using SAS PROC MIXED (SAS Version 9.4). Model comparisons were made sequentially for a fixed linear, random linear, fixed quadratic, and random quadratic effect of time. All modes were estimated using restricted maximum likelihood (REML) estimation; as such, the statistical significance of fixed effects was determined using $p < .05$, whereas the statistical significance of random effects was determined using likelihood ratio test based on the −2 Restricted Log Likelihood (−2LL). After establishing the model for time, hypothesized predictors were added. It is important to note that consistent with previous studies in this area (Dunton et al., 2014), no lagged analyses were conducted and models do not control for previous observations of the outcome variable. The between-person and within-person variability within each time-varying predictor was partitioned prior to analysis using person-mean-centering, such that between-person variability was represented by the person's mean across occasions, whereas within-person variability was represented by subtracting the user-entered value at each occasion from the person mean across occasions (Hoffman & Stawski, 2009). Because the analyses include both partitions of between- and within-person variability in our independent variable and we then also explain variability in the within-person component (i.e., random slopes), we are unable to provide pseudo-R^2 values as an indicator of effect size. Full results of all of the models are presented as online supplemental material.

Results

Preliminary Analyses

The average number of survey prompts completed by the participants was 70 surveys, equating to approximately 87.5% complete data. Regression models indicated that there was no significant effect of time on rate of survey completion. Participants provided valid accelerometer data on 75.3% of study days. Descriptive statistics for all study variables including proportion of zeroes (Stone, Broderick, Schneider, & Schwartz, 2012) are presented in Table I. On average, the adolescents in the current sample did not achieve the recommended guideline of 60 min of MVPA per day on average ($M = 30.63$, $SD = 28.65$); however, some adolescents did meet physical activity guidelines (14.54% of study days). Conversely, the adolescents in the current sample spent an average of 670 min per day ($SD = 133.07$) engaging in sedentary behavior.

Primary Analyses

Model Specification for Positive Affect as an Outcome

The unconditional time model for positive affect was a random linear time model; the addition of random linear time significantly improved model fit, $-2\Delta LL(\sim 2) = 40.4$, $p < .0001$. Although the fixed linear effect of time indicated a nonsignificant decrease of −0.02 per wave ($p = .1894$; 95% CI = −0.04 to 0.01), significant individual differences in the linear rate of change were indicated across waves such that 95% of the sample was expected to have linear time effect that ranged between −0.11 and 0.08.

Hypothesis Test for Positive Affect as an Outcome

When we added MVPA in the 30-min interval before the survey (pre30) to this model, the within-person effect of MVPA was statistically significant such that for every one-unit increase in MVPA beyond their usual level at a given wave, positive affect increased by an average of 0.12 points at the wave ($p = .0052$; 95% CI = 0.03 to 0.19). When we added sedentary time (pre30) to this model, the fixed effect of within-person sedentary time was statistically significant such that for every one-unit increase in sedentary time beyond their usual level at a given wave, positive affect decreased by an average of 0.10 points at that wave ($p = .001$; 95% CI = −0.16 to −0.05). Further, the addition of random within-person sedentary time significantly improved model fit, $-2\Delta LL(\sim 3) = 15.5$, $p = .0014$, such that 95% of the sample was expected to have an effect of within-person sedentary time between −0.29 and 0.09.

Model Specification for Negative Affect as an Outcome

The unconditional time model for negative affect was a random linear time model; the addition of random linear time significantly improved model fit, $-2\Delta LL(\sim 2) = 13.0$, $p = .0015$. Although the fixed linear effect of time indicated a nonsignificant decrease of 0.01 per wave ($p = .3275$; 95% CI = −0.02 to 0.01), significant individual differences in the linear rate of change were indicated across waves such that 95% of the sample was expected to have linear time effects ranging between −0.05 and 0.04.

Hypothesis for Negative Affect as an Outcome

Neither MVPA (pre30) nor sedentary time (pre30) was associated with negative affect.

Model Specification for Energy as an Outcome

The unconditional time model for energy was a random linear time model; the addition of random linear time significantly improved model fit, $-2\Delta LL(\sim 2) = 32.5$, $p < .0001$. Although the fixed linear effect of time indicated a nonsignificant decrease of 0.002 per wave ($p = .8327$; 95% CI = −0.02 to 0.02), significant individual differences in the linear rate of change were indicated such that 95% of the sample was expected to have linear time effects ranging between −0.06 and 0.06.

Hypothesis Test for Energy as an Outcome

When we added MVPA (pre30) to this model, the within-person fixed effect of MVPA was statistically significant such that for every one-unit increase in MVPA beyond their usual level at a given wave, energy increased by an average of 0.06 units at that wave ($p = .0402$; 95% CI = 0.003 to 0.11). When we added sedentary time (pre30) to this model, the fixed effect of within-person sedentary time was statistically significant such that for every one-unit increase in sedentary time beyond their usual level at a given wave, energy decreased by 0.05 units at that wave ($p < .0001$; 95% CI = −0.07 to −0.03).

Model Specification for Fatigue as an Outcome

The unconditional time model for fatigue was a random linear time model; the addition of random linear time significantly improved model fit, $-2\Delta LL(\sim 2) = 22.2$, $p < .0001$. Although the fixed linear effect of time indicated a nonsignificant decrease of 0.001 per wave ($p = .9112$; 95% CI = −0.02 to 0.01), significant individual differences in the linear rate of change were indicated such that 95% of the sample was expected to have linear time effects ranging between −0.05 and 0.05.

Hypothesis Test for Fatigue as an Outcome

When we added MVPA (pre30) to this model, the within-person fixed effect for MVPA (pre30) of −0.02 was not statistically significant ($p = .6787$; 95% CI = −0.09 to 0.06); however, the addition of random within-person MVPA (pre30) significantly improved model fit, $-2\Delta LL(\sim 3) = 10.3$, $p = .0162$, such that 95% of the sample expected to have within-person MVPA effect ranging between −0.19 and 0.16. Sedentary time (pre30) was not associated with fatigue.

Model Specification for MVPA (post30) as an Outcome

For MVPA in the 30-min window after the survey (post30), there were no fixed or random effects of time.

Hypothesis Test for MVPA (post30) as an Outcome

Although the fixed effect of within-person effect of positive affect of 0.07 was not statistically significant ($p = .1563$; 95% CI = −0.03 to 0.17), the addition of random within-person positive affect significantly improved model fit, $-2\Delta LL(\sim 2) = 14.8$, $p = .0006$, such that 95% of the sample was expected to have a within-person positive affect effect ranging between −0.29 and 0.43. Further, although the fixed effect of within-person negative affect of −0.05 was not statistically significant ($p = .5761$; 95% CI = −0.23 to 0.14), the addition of random within-person negative affect significantly improved model fit, $-2\Delta LL(\sim 2) = 39.3$, $p < .0001$, such that 95% of the sample was expected to have a within-person negative affect effect ranging between −0.73 and 0.63. Similarly, the fixed effect of within-person energy of 0.18 was not statistically significant ($p = .1851$; 95% CI = −0.10 to 0.47), but the addition of random within-person energy significantly improved model fit, $-2\Delta LL(\sim 2) = 23.7$, $p < .0001$, such that 95% of the sample was expected to have a within-person energy effect ranging between −0.97 and 1.34. Finally, the fixed effect of within-person fatigue of −0.23 was not statistically significant ($p = .4717$; 95% CI = −0.29 to 0.14); however, the addition of random within-person fatigue significantly improved model fit, $-2\Delta LL(\sim 2) = 23.7$, $p < .0001$, such that 95% of the sample was expected to have a within-person fatigue effects ranging between −0.92 and 0.77.

Model Specification for Sedentary Behavior (post30) as an Outcome

For sedentary time (post30), there were no fixed or random effects of time.

Hypothesis Test for Sedentary Behavior (post30) as an Outcome

The fixed effect of within-person positive affect of −0.16 was statistically significant ($p = .009$; 95% CI = −0.28 to −0.04). The fixed effect of within-person negative affect of 0.29 was statistically significant ($p = .0022$; 95% CI $= 0.10$ to 0.47). Neither energy nor fatigue was related to sedentary time.

Discussion

The findings in the current study partially comport with previous literature and study hypotheses (Dunton et al., 2014; Liao et al., 2015). That is, a portion of the sample demonstrated a significant relationship between all four predictor variables and MVPA. However, the significant within-person random effects revealed marked heterogeneity in the slopes. *That is, the slope for each predictor and MVPA is both positive for some participants and negative for others in this sample*. Therefore, it appears that each of the four affect and feeling variables (positive/negative affect, energy, and fatigue) are important for understanding MVPA. However, much more investigation is needed to determine what type of person will have a positive or negative association with each variable. This is a critically important concept that has been missing from psychology broadly and from studies of physical activity in particular (Molenaar, 2004). Indeed, if our results are confirmed in larger more representative studies, the field will need to begin thinking not about affect and physical feelings predicting MVPA, but *for whom* do those constructs predict activity. This study is a tentative and preliminary step in that direction.

Consistent with hypotheses, the results from the current study suggested that when an individual experienced higher levels of negative affect than were typical for him or her, there was an associated increase in sedentary behavior in the subsequent 30-min window. In addition, the current study did find support for the hypothesis that higher levels of positive affect than typical were associated with decreased sedentary behavior in the subsequent 30-min window. These findings are in contrast to those observed for MVPA in that both the positive and negative affect associations with sedentary behavior are fixed effects and can be interpreted as representing the group. That is, for this sample, feeling changes from one's own baseline positive or negative affect were associated with a subsequent change in sedentary behavior. This finding is novel and answers the call from Liao et al. (2015) to investigate the effect of sedentary behavior on time-varying variables.

In line with previous literature and hypotheses (Dunton et al., 2014; Liao et al., 2015), when participants accumulated higher levels of MVPA than typical, an associated increase in positive affect was observed in the subsequent 30-min window; the results also indicate the inverse relationship with sedentary behavior, as hypothesized. The finding for MVPA and positive affect is consistent with findings from both laboratory tasks (Schneider & Schmalbach, 2015; Subramaniapillai et al., 2016) and EMA studies (Dunton et al., 2014). However, our findings go beyond previous conceptions of these constructs in that we observed a significant random effect for sedentary behavior on positive affect. This means that for some participants, more sedentary behavior than typical decreases positive affect, whereas for others, the relationship is the opposite. However, it is important to note that the undesirable impact of sedentary behavior is stronger (-0.29) than any mood-enhancing effects (0.09). Unexpectedly, there was no prospective association between activity and negative affect.

Also consistent with previous literature and hypotheses (Dunton et al., 2014; Liao et al., 2015), when an individual participated in higher MVPA than was typical for him or her, there was an associated increase in energy. Similarly, engaging in more sedentary behavior than was typical for him or her was associated with a decrease in energy. For clarity, we note again that these are fixed effects and can be taken to represent the group. As a practical matter, if this finding holds up under replication, it would mean that a clinician could suggest that getting plenty of activity and avoiding sitting too much should leave a patient feeling more energetic, and be correct for most of their patients.

Finally, the observed random effect of within-person MVPA predicting fatigue may help to explain why previous work did not observe an association between physical activity and fatigue (Dunton et al., 2014). Specifically, the 95% confidence band that represents the association is -0.19 to 0.16. This implies that a given participant may, indeed, feel fatigued after exercise, whereas another will feel less fatigue. Without a random effect in the model, the association would most likely be reduced to nonsignificance, which was the case with the fixed effect in our data. As we have suggested above, the challenge to the field moving forward is to better determine the traits of an adolescent that moderate the effect of physical activity on fatigue. To highlight the value in this finding, consider the common suggestion, "exercise will make you feel less tired." Indeed, our data indicate that this is appropriate admonishment for some, but entirely inappropriate for other members of this sample.

When considering how best to extend and capitalize on the findings presented here, it seems that digital technology offers some of the best potential. It has been established that digital mediums are effective for influencing adolescent health behaviors (Cushing & Steele, 2010). Another exciting avenue within the digital space is the promise of smartphone-delivered adaptive interventions (Brannon, Cushing, Crick, & Mitchell, 2016). For example, in the case of the fixed effects here, if a smartphone can conduct an assessment that reveals high negative affect, then it can be reasonably assumed that the adolescent is at risk for engaging in sedentary behavior. In this case, an app running on an adolescent's smartphone could attempt to modulate negative affect in real time to make the conditions less optimal for sedentary behavior. If the current findings are upheld, the real challenge will be in promoting MVPA. This is because the current data suggest that each patient may be different in their associations between affect and feeling and MVPA. If these results hold, there are two types of studies that have potential moving forward. First, larger samples than the one presented here may be able to use between-person predictors to explain the random effects observed in the current data. For instance, it has been established that the single-nucleotide polymorphism rs6265 (aka Val66Met) moderates the effect of exercise on positive affect (Bryan, Hutchinson, Seals, & Allen, 2007) in adults. This is a biological example of the kind of trait that may help to explain random effects in the current study. However, other psychosocial traits such as self-efficacy for exercise, outcome expectancies, and social support for exercise also have value and should be explored (Babic et al., 2014; Craggs, Corder, van Sluijs, & Griffin, 2011; Lowry, Lee, Fulton, Demissie, & Kann, 2013; Van der Horst, Paw, Twisk, & Van Mechelen, 2007). The second avenue that holds potential as a future direction is more novel and ambitious. Simply put, it may be possible to personalize an intervention algorithm to every patient. That is, even the best models developed from using between-person moderators will only be effective for some people who possess the moderating trait. An alternative to traditional approaches is to gather intensive longitudinal data from each patient, model their data to find idiographic predictors of physical activity, and use those predictors to govern the behavior of an intervention system. We have shown that it is possible to gather the volume of data necessary to create such models (Brannon et al., 2016). Whether it is statistically or computationally feasible to do so remains an open question. Regardless, the findings from the current study suggest that the predictors of these health-promoting behaviors are personalized in adolescents. It makes sense that the interventions should similarly follow a precision medicine approach as well (Collins & Varmus, 2015; Riley et al., 2011).

Findings from the current study must be interpreted within the context of several limitations. First, there are characteristics of the sample that limit generalizability of the results. For example, the sample included adolescents who were primarily Caucasian and middle-class from a small and rural Midwestern community in the United States. Therefore, the findings of the current study may not generalize to adolescents from other demographic groups. Additionally, the current study collected data at four time points a day, and the assumption was made that the 30-min windows before and after the prompts were representative of the association between the predictor and dependent variables. Future studies could increase the density of data points throughout the day to more accurately characterize the associations. Physical activity and sedentary behavior are complex constructs, and there are likely additional predictors and consequences that are not present in the current model. Therefore, future studies with a larger sample size and appropriate array of covariates are needed to confirm and extend these findings. The current manuscript used PROC MIXED to analyze the multilevel data, as has been the convention across multilevel physical activity studies (Dunton et al., 2012, 2014). However, these results should be considered pilot findings that may be overturned in future more quantitatively rigorous studies. For instance, it has been suggested that two-part models may be needed to deal with the expected skew in physical activity data (Baldwin et al., 2016). However, it is currently unclear in the physical activity literature exactly how these two-part models should be specified, and what assumptions should be tested. We used PROC MIXED for the current study despite the positive skew in our data because it is the convention in the field and we, therefore, determined it appropriate for our pilot study. Future studies should be conducted to determine the optimal advanced quantitative approach to modeling skewed physical activity data. In addition to the limitations noted above, there are levels of nestedness that are not accounted for in the current analysis (i.e., observations within day, within week, within participants). However, a four-level model is impractical with the current data, and important conceptual questions must be left for future studies. Two of the many questions are: *Does time of day matter? Is there an effect of day of the week?* Future research should examine other factors, such as environmental, social, and contextual factors, that might predict MVPA and sedentary behavior and should examine other physical and psychosocial consequences of the behaviors.

The present study provides a starting place for researchers interested in understanding the reciprocal relationships among affective and physical feeling states and free-living MVPA and sedentary behavior in adolescents. Building a knowledge base in this area can help encourage additional basic research, inform clinical recommendations, and answer the call for research to inform the development of mobile apps that incorporate the research evidence (Brannon & Cushing, 2015).

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