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Examining acute bi-directional relationships between affect, physical feeling states, and physical activity in free-living situations using electronic ecological momentary assessment

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Abstract

Background—Current knowledge about the relationship of physical activity with acute affective and physical feeling states is informed largely by lab-based studies, which have limited generalizability to the natural ecology.

Methods—This study used ecological momentary assessment (EMA) to assess subjective affective and physical feeling states in free-living settings across 4 days from 110 non-physically active adults (Age M = 40.4, SD = 9.7). Light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA) were measured objectively by an accelerometer. Multilevel modeling was used to test the bi-directional associations between affective and physical feeling states and LPA/MVPA minutes.

Results—Higher positive affect, lower negative affect and fatigue were associated with more MVPA over the subsequent 15 minutes, while higher negative affect and energy were associated with more LPA over the following 15 and 30 minutes. Additionally, more LPA and MVPA were associated with feeling more energetic over the subsequent 15 and 30 minutes, and more LPA was additionally associated with feeling more negative and less tired over the subsequent 15 and 30 minutes.

Conclusions—Positive and negative affective states might serve as antecedents to but not consequences of MVPA in adults' daily lives. Changes in LPA may be predicted and followed by negative affective states. Physical feeling states appear to lead up to and follow changes in both LPA and MVPA.

Introduction

There is strong evidence for the health benefits of physical activity, including reduced rates of heart disease, metabolic syndrome, breast and colon cancers, depression, as well as

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increased cardiorespiratory and muscular fitness, and improved cognitive functioning (Haskell et al., 2009; Warburton et al., 2010). However, available data suggest that 31% of the world's population is not meeting the minimum recommendations for physical activity (Hallal et al., 2012). Although the United States released the first-ever national guidelines for physical activity in 2008, more than 80% of U.S. adults still do not meet these guidelines (U.S. Department of Health and Human Services, 2013). The prevalence of physical inactivity and its associated negative health consequences set the stage for the promotion of regular physical activity as a global public health priority.

According to several behavioral theories, individuals will be more likely to engage in a behavior when they derive pleasure from it (e.g., the greatest happiness principle; Bentham, 1962), or when they anticipate a positive emotional response from engaging in it (e.g., the subjective expected pleasure theory; Mellers, 2000). Acute affective responses during and immediately after a behavior may influence decisions regarding whether or not to repeat that behavior in the future (Kahneman et al., 1993). Previous research has shown that positive affective responses during structured exercise predicted greater free-living physical activity levels 6 and 12 months later (Williams et al., 2008). Likewise, there are biological and psychological bases for the role of feeling states in predicting immediate subsequent behaviors. Individuals' current affective and physical feeling states may reflect their physical and mental readiness for engaging in a near-term behavior (Seo et al., 2004; Schwarz, 1990). Positive emotions may influence future behaviors by building psychological resources (e.g., coping, social support; Salovey, Rothman, Detweiler, & Steward, 2000) or increasing appetitive motivation to participate in those behaviors (Updegraff, Gable, & Taylor, 2004), while negative emotions may trigger a motivational state of behavioral avoidance (Leone, Perugini, & Bagozzi, 2005). Recently, the role of affective and physical feeling states in influencing free-living physical activity has received increasing attention (Liao et al., 2015). A study in working adults found that greater positive affective states predicted more time spent in subsequent MVPA, while greater negative affective states predicted less time spent in subsequent MVPA (Niermann et al., 2016). Another study among college students revealed that increased positive affect and feeling energized were associated with a decrease in physical activity levels over the following 45 minutes (Kanning & Schoebi, 2016).

A number of studies have attempted to elucidate how individuals feel emotionally during and after engaging in physical activity. However, most of these studies were carried out in controlled laboratory settings (i.e., people were asked to perform prescribed activities in a laboratory, or were otherwise in a setting that was not part of their normal life; Bixby et al., 2001; Ekkekakis et al., 2000; Petruzzello et al., 2001). Lab studies may make assumptions that the activity being measured is representative of the behavior performed in daily life, however, such artificial settings, coupled with the fact that participants are cognizant of being watched, could induce very different behaviors, and affect the physiological and psychological processes from the physical and social contexts which would otherwise occur in normal daily life (Bussmann et al., 2009). For example, lab-based studies usually involve structured exercises such as treadmill activities that offer limited verisimilitude to free-living activities like walking for transportation and so on. These different contexts may influence physical activity and affective states differently. Additionally, for people that are unfamiliar with laboratory settings and/or exercise equipment, unpleasant emotions such as anxiety may be present (Kerr & Kuk, 2001; McAuley et al., 1996). Finally, lab-based studies often control for physical activity volume and in doing so provide little insight as to participant's decision-making processes about whether and how much physical activity to perform. Therefore, in order to more accurately understand whether physical activity and feeling states acutely influence each other, there is value in investigating their bi-directional relationship in free-living settings.

Although a few studies have examined how physical activity influences subsequent affective states in free-living settings, existing work suffers from a number of methodological limitations as discussed by Kanning and colleagues (Kanning, Ebner-Priemer, & Schlicht, 2013). For example, most studies relied on participants' self-reported physical activity, which might have low reliability (this is especially true for studies that only used one item to assess physical activity level). Second, although the majority of these studies used ecological momentary assessment (EMA) to assess affective and/or physical feeling states, not all of them utilized electronic EMA methods. EMA is a viable alternative to survey methodologies because it can reduce retrospective recall and memory bias, facilitate ecological validity, and offer opportunities to disentangle within- and between-person processes and temporal dynamics (Shiffman et al., 2008). The use of electronic devices to deliver and record momentary assessments has been shown to be more reliable than paper-pencil diaries, especially in terms of higher compliance (Green et al., 2006; Piasecki et al., 2007). Further, electronic EMA is able to give an exact time stamp when each assessment is completed. The latter feature is especially useful when linking EMA data with other types of real-time data (e.g., accelerometer data).

Most of the existing studies focused on moderate-to-vigorous physical activity (MVPA). However, the non-exercise activity thermogenesis (NEAT) hypothesis has drawn increasing attention because it suggests that low-level activities have potential health benefits (e.g., lower risk of metabolic syndrome; Uemura et al., 2013). In the past, NEAT has proven difficult to measure using traditional instruments such as recall-based self-reports because it can occur intermittently. Using objective measurement, such as accelerometry, NEAT may be operationalized as light physical activity (LPA), or activity intensity that is between sedentary activity and MVPA. Few studies have examined whether feeling states might predict subsequent MVPA and LPA differently. There are several theories addressing the dose-response relationship between activity intensity and acute affective responses; for example, some have suggested that the affective responses to physical activity are non-linear, and the optimal psychological benefits occur following moderate, but not low or high intensity activity (e.g., the inverted-U curve, Ojanen, 1994). Nevertheless, empirical evidence does not yield consistent results (i.e., Reed & Ones, 2006).

Overall, while there have been several recent studies investigating the acute relationships between physical activity and feeling states, these studies only examined such relationships in one direction (i.e., either affect predicting subsequent physical activity or affective responses after physical activity). Very few studies have examined the acute relationships between physical activity and feeling states in both directions at the same time, which might offer new insights about the dynamic associations between the two. To address the current research gaps, the present study used real-time data that was collected in free-living environments to examine the acute bi-directional relationship between physical activity and feeling states. Participants' affective and physical feeling states were assessed using electronic EMA methods, and physical activity was objectively measured via accelerometer. Together, these real-time data collection methods offer a more ecologically valid and reliable way to test the acute associations between different intensities of physical activity and feeling states. The current study aimed to test the acute bi-directional relationships between MVPA and feeling states, and to explore the acute bi-directional relationship between feeling states and LPA. For MVPA, it was hypothesized that (1) having a more positive affective and physical feeling state would be associated with more subsequent minutes spent in MVPA, (2) having a more negative affective and physical feeling states would be associated with less subsequent minutes spent in MVPA, and (3) more minutes spent in MVPA would be associated with more subsequent positive and less negative affective and physical feeling states.

Methods

Participants

This study used baseline data from Project Measuring Our Behaviors in Living Environments (MOBILE), which investigated the effects of environmental and intrapersonal factors on health behavior decision-making processes (Dunton et al., 2012). Participants were low-active (i.e., engaged in <150 minutes/week physical activity) adults living in Chino, California, or one of the surrounding communities. Individuals were excluded if they (a) did not speak and read English fluently; (b) had annual household income greater than $210,000; or (c) had physical disabilities limiting physical activity. All participants were required to be able to answer electronic EMA surveys while at work. A total of 117 participants were recruited to participate in the study. This study was reviewed and approved by the Institutional Review Board at the University of Southern California.

Study Protocols

Data collection—Eligible participants were scheduled for a data collection appointment at a local community site or their home. Participants received monitoring equipment with verbal and written instructions. Height and weight were measured by study staff using an electronically calibrated digital scale (Tanita WB-110A) and professional stadiometer (PE-AIM-101). Participants also filled out a paper-pencil survey, which assessed their demographic information.

EMA—Electronic EMA surveys were delivered through an HTC Shadow mobile phone (T-Mobile USA, Inc.). A custom software program (MyExperience) was installed in each phone as a platform to randomly prompt the EMA survey and store the survey responses. All other functions of the mobile phone were disabled. Eight EMA surveys were prompted each day from Saturday to Tuesday (up to 32 total surveys total). Each EMA survey was prompted at a random time within eight pre-programmed windows (between 6:30 am to 10:00 pm) to ensure adequate sampling spacing across the day. EMA surveys were prompted using an auditory signal. Upon receiving the signal, participants were instructed to complete a short question sequence on the display screen. If a survey prompt was not answered (i.e., no response entry was made), the mobile phone emitted up to three reminder signals at 5-minute intervals. After the third reminder, the EMA survey became inaccessible until the next prompt. Each prompted EMA was time-stamped.

Accelerometry—The Actigraph, Inc., GT2M model (firmware v06.02.00) accelerometer was used as an activity monitor to objectively measure participants' physical activity. This device was attached to an adjustable belt and placed on participants' right hip. Participants were instructed to wear this belt during their waking hours for 7 consecutive days, which encompassed the 4-day EMA monitoring period. This device continuously recorded participants' activity intensity (as expressed in activity counts) every 30 seconds. The 30-second epoch was chosen because of its ability to capture shorter bursts of activities (as compared to the 60-second epoch) and is consistent with other large population-based studies (e.g., Glazer et al., 2013; Treuth et al., 2012). Each accelerometer recording was time-stamped. Sixty minutes of consecutive zero activity counts were considered as accelerometer non-wear and were excluded from all analyses. This threshold maximizes the detection of sedentary behavior in adults (Cain & Geremia, 2012) and has been used by other national studies (Troiano et al., 2008).

Measures

Affective and Physical Feeling States—The current study used EMA items that assessed current positive affect, negative affect, energy, and fatigue (see Figure 1 for sample screenshots for EMA items). To reduce participant burden, each set of question(s) was designed to appear in a randomly programmed 6 out of the 8 daily question sequences (75% of sequences). Items for affective states were chosen based on the two fundamental dimensions of affect suggested by the circumplex model (i.e., valence and arousal; Posner, Russell, & Peterson, 2005), the positive affect scale included items that represent activated (happy, cheerful) and deactivated (calm or relaxed) pleasure (Cronbach's $\alpha = .837$). The negative affect scale included items that represent activated (anxious, stressed) and deactivated (depressed, angry) displeasure (Cronbach's $\alpha = .865$). Physical feeling states were represented by the assessment of energy and fatigue. Energy was assessed through one item asking about how energetic they were feeling. Fatigue was assessed through one item asking about how tired they were feeling. Response choices for all the items were “1=not at all, 2=a little, 3=moderately, 4=quite a bit, 5=extremely”. Therefore, “improved/better feeling states” refer to higher scores for positive affect, lower negative affect, higher energy, and lower fatigue.

Physical Activity—Activity counts from the accelerometer were converted to minutes spent in light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA). The cut-point for MVPA was defined as 2,020 activity counts per minute, which is consistent with national surveillance studies (Troiano et al., 2008). LPA was defined as the time that was not spent in MVPA and sedentary activity (i.e., less than 100 counts per minute; Healy et al., 2008).

Weight Category—Body mass index was calculated as kg/m^2. Weight category was classified as normal weight (BMI<25), overweight (25≤BMI<30), and obese (BMI≥30).

EMA Time Variables—In addition to the exact time when the participant answered a prompt, each EMA prompt was also coded for day of the week (i.e., weekdays vs. weekend days), and time of day (i.e., morning [6:30 am to 11:59 am], afternoon [12:00 pm to 5:59 pm], vs. evening [6:00 pm to 10:00 pm]).

Real-time Window

The internal clocks of the mobile phone and accelerometer were synchronized to the same computer each time before giving out to participants. Thus, data points from the two devices were time-matched. To test the acute relationships between physical activity and feeling states, 15-minute and 30-minute time windows were created before and after each answered EMA survey. Minutes of LPA and MVPA were then summarized within each of the time windows (see Figure 2 for illustration of the 15-minute time window summarizing the total MVPA minutes within each window). Thus, any amount of LPA and MVPA that occurred within each time window was captured.

Statistical Analysis

Only the answered EMA prompts were included in the analyses. A total of zero activity counts within 60 minutes surrounding (i.e., 30-minute before and 30-minute after) each EMA prompt was considered as accelerometer non-wear (i.e., invalid accelerometer data), and that EMA entry was excluded from analyses. Analyses of missing data pattern were conducted using multilevel modeling to examine whether EMA compliance and accelerometer non-wear differed across demographic variables, day of the week, and time of the day.

To test whether affective and physical feeling states acutely predict subsequent physical activity, multilevel models were used with physical activity level (i.e., total LPA or MVPA minutes within the 15- and 30-minute window *after* each EMA prompt) as the outcome, and feeling state (i.e., negative affect, positive affect, tired, energetic) at each prompt as the predictor. Each pair of outcome and predictor variables was tested in a separate multilevel model. Prior to data analyses, between-person (i.e., how individuals were different from each other; BP) and within-person (i.e., how individuals fluctuated within him/herself across prompts; WP) effects were disaggregated (Curran & Bauer, 2011). Disaggregation was accomplished by computing the mean of the prompt-specific feeling states within each individual (i.e., $\overline{\mathrm{AFFECT}}_i$), which is denoted as $AFFECT_{BP}$. Next, that person-specific mean was subtracted from each individual's prompt-specific feeling states to obtain $AFFECT_{WP}$. Finally, both $AFFECT_{BP}$ and $AFFECT_{WP}$ were used as predictors in the regression model. Further, we controlled for the total LPA or MVPA minutes, respectively, within the 15- and 30-minute window *before* the EMA prompt. Doing so allowed us to test how acute feeling states lead to changes in activity levels. Potential confounders for physical activity were screened for significance (defined as p<.05) in all models, one at a time. These potential confounders were determined a priori, which included both person-level variables (i.e., age, gender, ethnicity, annual household income, and weight category) and prompt-level variables (i.e., day of the week, time of the day, and time in the study). These person-level demographic and biological variables were selected for potential inclusion in the statistical models because they have been found to be correlated with daily physical activity

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levels in previous studies (Trost et al., 2002). For example, annual household income, which reflects socioeconomic status, has shown to be a consistent predictor of lower levels of physical activity (McNeill, Kreuter, & Subramanian, 2006). Significant confounders were retained as a covariate in the final model.

The following equation represents a generic multilevel linear regression model as outlined above:

$$PA_{ti}=\beta_{0i}+\beta_{1i}\ \mathrm{AFFECT}_{WP}+\beta_{2i}\ \mathrm{Prompt}_{ti}+\beta_{3i}\ PA_{\mathrm{before}}+\beta_{4i}\ \mathrm{COV}_{ti}+r_{ti} \quad \text{level-1}$$

$$\begin{array}{c}\beta_{0i}=\gamma_{00}+\gamma_{01}\ \mathrm{AFFECT}_{BP}+\gamma_{02}\ \mathrm{COV}_{i}+u_{0i}\\ \beta_{1i}=\gamma_{10}+\gamma_{11}\ \mathrm{COV}_{i}\end{array} \quad \text{level-2}$$

Total MVPA minutes within the 15- and 30-minute windows were not normally distributed. Therefore, log-transformations were performed for these outcomes. However, a large amount of observations had zero MVPA minutes, which led to missing data after log-transformation. To address this problem, a two-piece model was fit. The Piece 1 Model was a multilevel logistic regression model predicting the probability of engaging in some MVPA (i.e., non-zero MVPA minutes) versus no MVPA (i.e., zero MVPA minutes). The Piece 2 Model was a multilevel linear regression model predicting the log-transformed non-zero MVPA minutes. The two-piece models were evaluated using Mplus (Version 6). For LPA minutes, as log-transformation was unnecessary, SAS PROC MIXED was used to run the multilevel linear regression models.

To test whether physical activity acutely associated with subsequent affective and physical feeling states, multilevel linear regression models were used. The outcome variables were scores for the concurrent feeling state at the end of a 15- or 30-minute window. The predictor variable was total LPA or MVPA minutes within the 15- or 30-minute window *before* the EMA prompt. Each pair of outcome and predictor was tested in a separate multilevel model. Negative affect was not normally distributed. Therefore, it was log-transformed before fitting into the multilevel linear regression models. To preserve the "acute" nature of the research question, if the closest answered prior EMA prompt fell into the day before that EMA prompt was excluded from the analyses. All models testing the associations between physical activity and subsequent affective and physical feeling states were fit using SAS PROC MIXED.

For significant effects that were obtained from SAS PROC MIXED, Cohen's f^2 was also calculated to represent effect size following Selya and colleagues' method (Selya et al., 2012).

Results

Descriptive Statistics

Of the 117 participants recruited for the study, EMA data were unavailable for 3 participants due to data downloading problems. Of the remaining 114 participants, 2 participants lost the accelerometer device, and accelerometer data downloading problems occurred for 2 participants. Therefore, a total of 110 participants had available EMA and accelerometer data (see Table 1 for their demographic characteristics). On average, participants answered 82% (range 25 – 100%) of the EMA prompts. Of these answered EMA prompts, 86% had valid accelerometer data. The likelihood of answered vs. unanswered EMA prompts did not vary as a function of day of the week, time of day, gender, age, race/ethnicity, or weight category. However, male participants had more accelerometer non-wear rates than females (19 % vs. 12% non-wear rate; coef. = -.54, $p = .01$), and obese participants were more likely to have accelerometer non-wear compared to normal weight participants (17% vs. 11%; coef. = .54, $p = .03$). Further, compared to evening prompts (9% non-wear rate), accelerometer non-wear was more likely to occur in morning prompts (27% non-wear rate; coef. = 1.35, $p < .01$), and less likely to occur in afternoon prompts (5% non-wear rate; coef. = -.69, $p < .01$).

The person-level average for positive affect was 3.06 (SD = 0.63) on a 5-point scale; for negative affect was 1.44 (SD = 0.41); for energy was 2.63 (SD = 0.67); for fatigue was 2.04 (SD = 0.61). On average, during the 30-minute window before each answered prompt, participant spent 6.78 (SD = 2.54) minutes in LPA and 0.72 (SD = 0.85) minutes in MVPA. During the 15-minute window before each prompt, participants spent an average of 4.12 (SD = 1.35) minutes in LPA and 0.36 (SD = 0.43) minutes in MVPA (85.7% of the prompts had 0 MVPA minutes). During the 30-minute window after each prompt, participants on average spent 7.19 (SD = 2.36) minutes in LPA and 0.70 (SD = 0.83) minutes in MVPA (66.3% of the prompts had 0 MVPA minutes). Participants on average spent 3.49 (SD = 1.25) minutes in LPA and 0.33 (SD = 0.41) minutes in MVPA during the 15-minute window after each answered prompt.

Bi-directional Relationships between Feeling States and MVPA

Table 2 shows the results from multilevel models using MVPA minutes as the outcome, and feeling states as the predictors, controlling for prior activity level and significant covariates as indicated for each specific model. In summary, at both WP and BP level, affective and physical feeling states were not associated with the probability of engaging in some MVPA minutes versus no MVPA minutes in the subsequent 15-minute window (Piece-1 models; $ps > .05$). For participants who did engage in some MVPA minutes within the subsequent 15-minute window (Piece-2 models; Level-2 N = 105, Level-1 n = 394), feeling more positive than one's usual level (i.e., the WP effect) was associated with more MVPA minutes (coef. = .084, SE = .038, $p = .027$); feeling more tired than one's usual level (i.e., the WP effect) was associated with less MVPA minutes (coef. = -.083, SE = .039, $p = .033$) during the subsequent 15-minute window. Feeling more negative than one's usual level (i.e., the WP effect) was associated with less subsequent MVPA minutes within the 15-minute window (coef. = -.165, SE = .068, $p = .016$); however, participants who on average, felt more negative compared to other people in the study, engaged in more MVPA minutes within the 15-minute window (i.e., the BP effect; coef. = .186, SE = .092, p =.043). For the subsequent 30-minute window, only feeling more energetic was associated with a higher probability of engaging in some MVPA minutes than no MVPA minutes (coef. = .141, SE = .063, p = .025) in Piece-1 models. For participants who did engage in some MVPA minutes within the subsequent 30-minute window (Piece-2 models; Level-2 N = 108, Level-1 n = 926), all the effects observed in the 15-mintue window were no longer significant, except for the positive BP effect for negative affect (coef. = .336, SE = .097, p = .001).

Table 3 shows the results from the multilevel linear regression models using feeling state as the outcome and MVPA minutes as the predictor; controlling for significant covariates as indicated for each specific model. Engaging in more MVPA minutes than one's usual level during a 15-minute window prior to an EMA prompt (i.e., the WP effect) was associated with feeling more energetic at the end of this window (coef. = .071, SE = .022, p = .001, f^2 = .007). Similar effect was also found for the 30-minute window (coef. = .042, SE = .013, p < .001, f^2 = .008). MVPA minutes were not associated with any other subsequent affective and physical feeling states for both 15- and 30-minute windows.

Bi-directional Relationships between Feeling States and LPA

Table 2 shows the results from multilevel models using LPA minutes as the outcome, and feeling states as the predictors, controlling for prior activity level and significant covariates as indicated for each specific model. Feeling more energetic than one's usual level was associated with more subsequent LPA minutes in the 15-minute window (WP coef. = .263, SE = .075, p < .001, f^2 = .076); further, participants who on average, felt more energetic compared to other people in the study, engaged in more subsequent LPA minutes (BP coef. = .263, SE = .116, p = .025, , f^2 = .001). These positive associations between feeling energetic and subsequent LPA minutes were also found for the 30-minute window (WP coef. = .501, SE = .144, p < .001, f^2 = .033; BP coef. = .489, SE = .217, p =.026, f^2 = .001). In addition, feeling more negative than one's usual level (i.e., the WP effect) was associated with engaging in more subsequent LPA minutes within both 15- and 30-minute windows (coef. = .326, SE = .130, p = .012, f^2 = .025; coef. = .619, SE = .244, p = .011, f^2 = .015; respectively). No significant relationship was found for positive affect or fatigue and subsequent LPA minutes.

Table 3 shows the results from the multilevel linear regression models using feeling state as the outcome and LPA minutes as the predictor; controlling for significant covariates as indicated for each specific model. When participants engaged in more LPA minutes than one's usual level during a 15-minute window (i.e., the WP effect), they reported higher negative affect (coef. = .012, SE = .002, p < .001, f^2 = .019), energetic (coef. = .046, SE = .008, p < .001, f^2 = .029), and lower fatigue (coef. = -.039, SE = .007, p < .001, f^2 = .036) at the end of this window. Similarly, significant WP effects for negative affect, energetic, and fatigue were also found for the 30-minute window (coef. = .006, SE = .001, p < .001, f^2 = .014; coef. = .030, SE = .004, p < .001, f^2 = .038; coef. = -.027, SE = .004, p < .001, f^2 = .029; respectively). LPA was not associated with subsequent positive affect for both 15- and 30-minute windows.

Table 4 summarizes the acute bi-directional associations between affect, physical feeling states, and physical activity.

Discussion

Feeling States Predicting Subsequent Physical Activity

For individuals who engaged in at least some minutes of MVPA, feeling more positive, less negative, and less tired than one's usual level at the moment were associated with more MVPA minutes over the subsequent 15-minute window. However, these associations were not found for the 30-minute window. These results suggest that, while more positive affective states might predict higher physical activity level, such effect may not last very long. This might partially explain why previous studies that examined a much longer time window (i.e., 90 minutes) found no association between affective or physical feeling states and subsequent physical activity (Mata et al., 2012). However, the significant associations found in the current study had a small effect size in general (Cohen's f^2 ranging from .001 to .076).

Interestingly, results from this study suggest that when engaged in MVPA, people who generally felt more negative affect tended to engage in more MVPA minutes than people who felt less negative affect. The fact that the BP effect of negative affect was in the opposite direction of the WP effect demonstrates the importance of disentangling these relationships when analyzing time-intensive multilevel data. While the WP effect of negative affect followed in the direction as expected (i.e., feeling less negative affect was associated with more subsequent MVPA minutes), the BP effect contradicts cross-sectional and longitudinal evidence suggesting that more depressed and stressed individuals are less physically active (Song et al., 2012; Gudmundsson et al., 2015; Paluska & Schwenk, 2000; Sherwood & Jeffery, 2000; Mouchacca et al., 2013). Nevertheless, most of these studies measured individuals recalled usual (i.e., chronic) perceived stress or depression over the past week or month whereas the current study examined individual's negative feeling states captured “in the moment.” It is possible that people who experienced acute types of stressors (e.g., daily hassles and stressful events) might more often use physical activity as a strategy to cope with stress (Nguyen-Michel et al., 2006; Austin et al., 2005; Berger, 1994).

Although feeling more energetic in the moment was not associated with subsequent MVPA minutes, it increased the probability of engaging in at least some MVPA minutes vs. no MVPA minutes at all. Further, feeling more energetic was associated with more subsequent LPA minutes for both 15- and 30-minute windows. Together, these results suggest that, although feeling more energetic at the moment might not lead to high intensity activity, it may predict less time in sedentary activity up to 30 minutes later. Previous studies have shown a positive relationship between physical activity and feeling energetic. However most of these studies were cross-sectional, and a temporal relationship could not be established (Puetz, 2006). Further, the positive relationship between feeling of energy and LPA found in this study was also observed at the BP level. This result suggests that people who, on average, feel more energetic during their everyday lives might spend less time in sedentary activity than people who feel less energetic.

Contrary to the findings for MVPA, results from this study suggest that feeling more negative affect than one's usual level was associated with more LPA minutes over the subsequent 15- and 30-minute windows. One possible explanation is that performing errands, or other daily activities that individuals do not necessarily enjoy, require a certain level of light activity. Further, unlike MVPA, momentary positive affect and fatigue were not associated with subsequent LPA minutes. This finding suggests that the effects of momentary affective states might only be relevant with higher intensity of subsequent activities.

Physical Activity Predicting Subsequent Feeling States

Results from this study suggested an increase in feeling energetic after engaging in more physical activity than one's usual level. This positive relationship between energetic feelings and physical activity was found for both MVPA and LPA, and for both 15- and 30-minute windows. This finding is consistent with previous free-living studies that showed a significant increase in energy following physical activity bouts (Kanning, 2013; Gauvin et al., 1996). In addition, the current study showed that spending more time in LPA than one's usual level within the past 15- and 30-minute period was inversely associated with feelings of fatigue. However, no association was found between fatigue and MVPA. This null finding is consistent with previous studies that examined change in physical exhaustion before and after self-reported physical activity bouts (Gauvin et al., 1996).

Spending more minutes in MVPA than one's usual level was not associated with subsequent positive or negative affect. These null findings are consistent with several other studies that also examined the affective response from physical activity in free-living settings (Wichers et al., 2012; Kanning, Ebner-Priemer, & Schlicht, 2015; Mata et al., 2012). Nevertheless, there are several studies that found a significant increase in positive affect (e.g., Gauvin et al., 1996; Carels et al., 2007) and decrease in negative affect (e.g., Gauvin et al., 1996; LePage & Crowther, 2010) after engaging in free-living physical activity. These inconsistencies could be due to the different methods used to capture physical activity levels (objectively measured vs. self-reported). Another possible explanation could be that free-living physical activity varies greatly across individuals from the type of exercise to physical and social contexts of exercise (Liao, Intille, & Dunton, 2015) These differing conditions could potentially influence people's affective feelings. For instance, people exhibited more positive moods when with friends compared to being alone (Larson, 1990); also, greater mental benefits were found for outdoor physical activity than for indoor (Thompson Coon et al., 2011). Some recent studies also showed physical and social contexts moderate affective responses to physical activity (Dunton et al., 2015). Notably, the current study found that more LPA minutes in the past 15 and 30 minutes were associated with an increase in negative affect. Again, as discussed above, it is possible that engaging in light activities might imply running errands, dealing with hassles, and handling other stressful events that happen in people's daily lives, which may result in an increase in negative affective states.

Limitations

Despite the combined use of electronic EMA to assess current feeling states and accelerometer to objectively measure physical activity in free-living settings, this study has several limitations. First, physical activity was summarized through real-time windows that were artificially created surrounding EMA prompts, rather than by examining the naturally occurring beginning and ends of activity bouts or episodes. It is possible that we captured partial physical activity sessions (e.g., the last 5 minutes of a 20-minute running session). Overall, a majority of participants of this study did not engage in recommended levels of physical activity. On average, 43.5% of the participants engaged in more than 20 minutes of daily MVPA, and only 28.7% engaged in more than 30 minutes of daily MVPA. Therefore, findings from this study might not be generalizable to more active adults. It is also possible that we might have included affective responses *during* physical activity in our analyses. To help elucidate this possible confounding effect, we have re-run all the analyses excluding EMA responses where the participants reported engaging in physical activity as their current main activity, and all results remained the same.

Secondly, the EMA protocol was not designed to capture feeling states *before* an exercise bout. Therefore, we might have failed to capture the changes in feeling states due to exercise. A set of ancillary analysis were conducted to include feeling states at the previous EMA prompt as a covariate in the model, and all results remained the same except for the association between LPA 30 minutes and subsequent negative affective state became marginally significant.

Thirdly, this study only collected data over the course of 4 days. Although these 4 days encompassed both weekdays and weekend days, this short monitoring period might not be fully representative of adults' usual daily behaviors and feeling states. Additionally, since 2 of the 4 days were weekend days, weekday behaviors might be underrepresented in this study. Furthermore, we found systematically missing patterns for accelerometer non-wear. Thus, results from this study might not be representative of males, obese people, and activities that occurred in the morning.

Lastly, we did not examine the contextual information (e.g., at work vs. at home) or other time-varying moderators that might limit individuals' ability to engage in physical activity. These time-varying barriers to physical activity could potentially attenuate the effect between feeling states and subsequent physical activity levels.

Implications and Future Directions

This study showed that momentary affective and physical feeling states could predict subsequent physical activity level. Future studies might explore some potential mediators of this relationship. For example, affective and physical feeling states might influence an individual's cognitive states (e.g., motivation, self-efficacy, intention), which then affect the subsequent physical activity level (Rhodes & Nigg, 2011; Loehr et al., 2014). Lastly, the current study suggested that feeling more energetic was associated with being more physically active; and being more physical active was associated with feeling more energetic. Nevertheless, in order to test whether this positive feedback loop exists, a more systematic statistical approach is needed. For example, the dynamical system modeling method would be able to examine the potential time-varying, nonlinear relationship between physical activity and affective and physical feeling states (Riley et al., 2011).

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Figure 1.
EMA items assessing current affective and feeling states.

Figure 2.
Illustration of 15-minute time windows summarizing total minutes spent in moderate-to-vigorous physical activity (MVPA) before and after each random EMA prompt in one day.

Table 1

Participant demographic characteristics (N=110)[1].

Age	Mean (SD)
	40.4 (9.74)
Gender	**n (%)**
Male	30 (27.5)
Female	79 (72.5)
Race/Ethnicity	
Hispanic/Latino	33 (30.3)
Non-Hispanic/Latino	76 (69.7)
Annual Household Income	
Less than $40,000	25 (25.8)
$40,000 - $70,000	24 (24.7)
$70,001 - $90,000	27 (27.8)
Above $90,000	21 (21.7)
Weight Category	
Underweight/Normal Weight	42 (38.2)
Overweight	34 (30.9)
Obese	34 (30.9)

Note:

[1]Age was missing for three participants. Gender and ethnicity information was missing for one participant. Thirteen participants refused to disclose their annual household income or left the answer blank.

Table 2

Associations between feeling states and subsequent minutes in moderate-to-vigorous physical activity (MVPA) and light physical activity (LPA)

Predictors		15 Minute Window		30 Minute Window		15 Minute Window (LPA minutes)	30 Minute Window (LPA minutes)
		Piece 1 Model (Some vs. zero MVPA minutes)[1]	Piece 2 Model (MVPA minutes)[2]	Piece 1 Model (Some vs. zero MVPA minutes)[3]	Piece 2 Model (MVPA minutes)[4]		
		Coefficient Estimate (SE)	Coefficient Estimate (SE)	Coefficient Estimate (SE)	Coefficient Estimate (SE)	Coefficient Estimate (SE)	Coefficient Estimate (SE)
Positive Affect	WP Effect	-0.102 (0.087)	**0.084 (0.038)***	-0.047 (0.085)	0.050 (0.036)	0.047 (0.089)[a]	0.161 (0.171)[a]
	BP Effect	-0.107 (0.137)	-0.021 (0.069)	-0.068 (0.128)	-0.055 (0.063)	0.243 (0.123)	0.359 (0.232)
Negative Affect	WP Effect	0.170 (0.114)	**-0.165 (0.068)***	0.185 (0.108)	-0.108 (0.069)[a]	**0.326 (0.129)***	**0.619 (0.244)[a]***
	BP Effect	-0.002 (0.170)	**0.186 (0.092)***	-0.085 (0.237)	**0.336 (0.097)[b]****	-0.221 (0.189)	-0.373 (0.376)
Energy	WP Effect	0.091 (0.073)	0.068 (0.042)	**0.141 (0.063)***	0.053 (0.031)	**0.263 (0.075)[a]****	**0.501 (0.144)[a]****
	BP Effect	0.020 (0.122)	0.045 (0.063)	0.097 (0.107)	0.016 (0.056)	**0.263 (0.116)***	**0.489 (0.217)***
Fatigue	WP Effect	-0.080 (0.073)	**-0.083 (0.039)***	-0.088 (0.061)	-0.054 (0.040)	-0.114 (0.077)	-0.194 (0.145)[c]
	BP Effect	-0.188 (0.186)	-0.026 (0.061)	-0.192 (0.165)	0.028 (0.065)	-0.187 (0.130)[b]	-0.417 (0.243)

Note: WP, within-person; BP, between-person. All models controlled for prior activity (i.e., MVPA/LPA minutes in the prior corresponding 15-/30-minute window). Boldface indicates statistical significance (*p<0.05, **p<0.01).

[1] Multilevel logistic regression model predicting the probability of engaging in some MVPA minutes vs. no (i.e., zero) MVPA minutes. Level-2 N = 110, Level-1 n = 2747.

[2] Multilevel linear regression model predicting the log-transformed non-zero MVPA minutes. Level-2 N = 105, Level-1 n = 394.

[3] Multilevel logistic regression model predicting the probability of engaging in some MVPA minutes vs. no (i.e., zero) MVPA minutes. Level-N = 110, Level-1 n = 2747.

[4] Multilevel linear regression model predicting the log-transformed non-zero MVPA minutes. Level-2 N = 108, Level-1 = 926.

[a] Indicates the model additionally controlled for time of day.

[b] Indicates the model additionally controlled for weight category.

[c] Indicates the model additionally controlled for the chronological order of each prompt (i.e., time in the study).

Table 3

Associations between physical activity[1] and subsequent feeling states

Predictors		Positive Affect Coefficient Estimate (SE)	Negative Affect[2] Coefficient Estimate (SE)	Energy Coefficient Estimate (SE)	Fatigue Coefficient Estimate (SE)
Total MVPA Minutes in 15-Minute Window	WP Effect	0.030 (0.018)[a]	0.002 (0.007)[b]	**0.071 (0.022)**[b]*	-0.011 (0.022)[b]
	BP Effect	-0.211 (0.162)	-0.010 (0.007)	-0.113 (0.172)	0.097 (0.160)
Total MVPA Minutes in 30-Minute Window	WP Effect	0.016 (0.010)[a]	0.001 (0.004)[b]	**0.042 (0.013)**[b]**	-0.009 (0.012)[b]
	BP Effect	-0.070 (0.081)	-0.024 (0.030)	-0.024 (0.086)	-0.006 (0.080)
Total LPA Minutes in 15-Minute Window	WP Effect	0.001 (0.006)[a]	**0.012 (0.002)****	**0.046 (0.008)**[b]**	**-0.039 (0.007)**[b]**
	BP Effect	0.031 (0.047)	-0.013 (0.017)	0.066 (0.049)	-0.009 (0.045)
Total LPA Minutes in 30-Minute Window	WP Effect	0.003 (0.004)[a]	**0.006 (0.001)****	**0.030 (0.004)**[b]**	**-0.027 (0.004)**[b]**
	BP Effect	0.021 (0.025)	-0.009 (0.009)	0.040 (0.027)	-0.009 (0.024)

Note: WP = within-person, BP = between-person. All models controlled for prior affect and time between current affective state and prior affective state.

[1] Physical activity refers to either total minutes spent in moderate-to-vigorous physical activity (MVPA) or light physical activity (LPA) within a 15-minute or a 30-minute window prior to the assessment of feeling states.

[2] Log transformation was applied.

[a] Indicates the model additionally controlled for the chronological order of each prompt (i.e., time in the study).

[b] Indicates the model additionally controlled for time of day.

Table 4

Summary of the acute bi-directional associations between affect, physical feeling states, and physical activity

		Feeling States Predicting Subsequent Physical Activity			
		MVPA 15-Minute[1]	**MVPA 30-Minute[1]**	**LPA 15-Minute**	**LPA 30-Minute**
Positive Affect	WP Association	+	*n.s.*	*n.s.*	*n.s.*
	BP Association	*n.s*	*n.s*	*n.s.*	*n.s.*
Negative Affect	WP Association	-	*n.s*	+	+
	BP Association	+	*n.s*	*n.s.*	*n.s.*
Energy	WP Association	*n.s*	+	+	+
	BP Association	*n.s*	*n.s*	+	+
Fatigue	WP Association	-	*n.s*	*n.s.*	*n.s.*
	BP Association	*n.s*	*n.s*	*n.s.*	*n.s.*
		Physical Activity Predicting Subsequent Feeling States			
		Positive Affect	Negative Affect	Energy	Fatigue
MVPA 15-Minute	WP Association	*n.s*	*n.s*	+	*n.s*
	BP Association	*n.s*	*n.s*	*n.s*	*n.s*
MVPA 30-Minute	WP Association	*n.s*	*n.s*	+	*n.s*
	BP Association	*n.s*	*n.s*	*n.s*	*n.s*
LPA 15-Minute	WP Association	*n.s*	+	+	-
	BP Association	*n.s*	*n.s*	*n.s*	*n.s*
LPA 30-Minute	WP Association	*n.s*	+	+	-
	BP Association	*n.s*	*n.s*	*n.s*	*n.s*

Note: WP = within-person, BP = between-person, MVPA = moderate-to-vigorous physical activity, LPA = light physical activity, n.s. = no significant association, + = significant positive association, - = significant negative association.

[1] Only included occasions when non-zero MVPA minutes were spent within the corresponding time window.