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REGULAR ARTICLE

Bidirectional Associations of Momentary Affect with Physical Activity and Sedentary Behaviors in Working Adults

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Abstract

Background Affective experiences and movement-based behaviors form a system that has been shown to influence exercise adherence and mental health outcomes. Little is known about the naturalistic dynamics of the reciprocal associations in this system.

Purpose We examined the time intervals at which momentary affect precedes and follows movement-based behaviors in everyday life.

Methods A community sample of working adults (n = 111) completed ecological momentary assessments (EMA) asking about current affect states (sad, happy, tired, and interested) six times a day for three consecutive days. Ratings were used to generate scores for momentary affective arousal and valence. Participants also wore an activity monitor. Total activity counts and sedentary duration in the shorter to longer time intervals (5–120 min) before or after EMA were used as indicators of movement-based behaviors.

Results Multilevel modeling showed that current affective arousal predicted higher subsequent activity counts in the longer time intervals (120 min) and less subsequent sedentary behavior in the shorter to longer time intervals (5, 60, and 120 min). For the reversed sequence, neither movement-based behavior predicted subsequent momentary arousal or valence. Affective valence was unrelated to movement-based behaviors in either temporal direction.

Conclusions Some naturally occurring affective experiences (i.e., arousal) might precede, rather than follow, movement-based behaviors. Understanding affective arousal may contribute to improved management of subsequent movement-based behaviors in everyday life.

Keywords Physical activity · Sedentary behaviors · Arousal · Valence · Ecological momentary assessment

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Introduction

Affect and health behavior form a system of bidirectional influence in everyday life. Affective experiences have been linked to exercise adherence and regular physical activity has been linked with a variety of improved affective outcomes [1]. The Affect and Health Behavior Framework elaborates on pathways by which affective processes may influence health behaviors, including movement-based behaviors such as physical activity and sedentary behavior [2]. In turn, these movement-based behaviors can impact subjective affective experiences and long-term mental health outcomes [3]. Both affect and movement-based behaviors are dynamic, suggesting the need for intensive longitudinal data to test their sequential relations [4] and to inform health behavior change efforts [5]. However, little is known about the timing of relations in this affect–behavior–affect system. This study combined data from ecological momentary assessment (EMA) of affect and ambulatory monitoring of behavior to characterize the reciprocal relations between affect and behavior across a variety of time intervals.

Physical activity, which is defined as "any bodily movement produced by skeletal muscles that results in energy expenditure" [6], has been associated with numerous health benefits on physical and psychological health outcomes, for example, heart diseases and stress [7, 8]. Wearable devices, particularly accelerometers, are increasingly used by researchers to measure physical activity and estimate the intensity, duration, frequency, and the type of a person's movement over a given period of time in daily life [9, 10]. Total activity counts can be used to represent physical activity volume, reflecting the total amount of activity accumulated over a specified period of time [11]. Minute-level activity data can also be used to identify sedentary behavior [12–15]. Sedentary behavior refers to low energy expenditure (<1.5 metabolic equivalents [METs]) during activities completed in a seated or reclined posture [12]. Many studies have shown that spending excessive time engaged in sedentary behaviors may have a negative impact on physical health [14–17] and mental health [18, 19] outcomes.

For several decades, the relations between affect and physical activity have been studied. One line of work focused on affective dynamics during and immediately after acute and regular exercise in laboratory settings [20]. Other studies focused on within-person associations between affect states measured using EMA and physical activity in the natural context of everyday life [21]. The studies examining affect and subsequent physical activity have typically found that higher positive affect generally predicted physical activity over the next few hours [22–25], whereas negative affect has—more inconsistently—predicted physical activity [22, 24, 26]. On the other hand, some work suggests that physical activity predicts affect states, but these studies have conflicting results on the association of physical activity with positive/negative affect [23, 25, 27, 28].

Subjective affective experiences can largely be summarized by two basic dimensions of arousal and valence [29]. Arousal describes subjective experiences along a continuum ranging from deactivated to activated, whereas valence describes subjective experiences along a continuum ranging from unpleasant to pleasant. In previous research on affect and movement-related behaviors, higher energetic arousal predicted subsequent physical activity [26, 30] but valence did not predict subsequent physical activity [26]. In research on movement-based behaviors and affect, physical activity predicted higher subsequent energetic arousal, albeit in different time intervals [26, 31, 32]. However, these studies have found equivocal results on the association of physical activity with subsequent valence [31, 33]. Prior work has also noted that it is important when studying the associations between affect and physical activity to classify affect as either incidental or integral [2]. Incidental affect describes subjective affective experiences "not caused by the target behavior but may influence the target behavior," whereas integral affect refers to subjective affective experience that are produced during or immediately following a particular context or behavior, such as physical activity [2]. The present study reflects the use of *incidental affect* because our affect measures were not directly tied to the physical activity (e.g., exercise sessions).

The literature reviewed above indicated that affective experiences predict subsequent physical activity and physical activity predicts subsequent affect. However, findings varied and few studies have systematically examined the reciprocal relations between movement-based behaviors and affect. Three unresolved issues complicate progress in this area. First, it is unclear whether relations are due to variability in physical activity, the displacement of sedentary behavior with physical activity, or both. That is, no research of which we are aware has examined the role of affect in relation to both total physical activity volume and sedentary behavior in everyday life. Second, it is not clear whether effects in each direction are fast (appearing and possibly disappearing in a matter of minutes) or relatively slow (only appearing after a delay perhaps as long as 2 hr). Finally, the choice of the time window of behavioral data preceding or following an affect assessment plays an important role in the investigation of the sequential association, such as whether movement-based behaviors precedes or follows changes in current affect states. To the best of our knowledge, no research has compared relations across different time windows to understand the timing of relations. Intensive longitudinal studies (e.g., studies using EMA or ambulatory assessment) with repeated measures of reported affect, along with concurrently assessed physical activity, become necessary to systematically examine the temporality.

In this study, we applied an assessment of momentary affect (broadly adapted from a circumplex model, attempting to distinguish between affective valence and affective arousal) to examine if distinct indicators of arousal and valence precede and/or follow movement-based behaviors such as physical activity and sedentary behaviors in a community sample of working adults. Four models were tested: in Model 1, current affective states (arousal and valence) were modeled as predictors of subsequent physical activity; in Model 2 current affective states (arousal and valence) were modeled as predictors of sedentary behaviors; in Model 3, preceding behaviors (physical activity and sedentary behavior) were modeled as predictors of current arousal; and in Model 4, preceding behaviors were modeled as predictors of current valence. In addition, we tested the temporal coincidence on the relations by aggregating movement-based behaviors across a variety of time intervals before/after each affect assessment. There are two approaches to determine the size of time windows: one is using the specific time windows based on confirmatory hypotheses from scientific evidence or theories; the other may be a systematic examination using exploratory attempts by varying the length of the time windows. Given the lack of empirical evidence regarding the former (especially bidirectionally), we chose the latter in this study to test the relatively transient, medium, and relatively long association between affect and physical activity with 5–120-min time intervals [34].

We hypothesize that bidirectional associations exist between affect and physical activity. Specifically, both higher arousal and higher (more positive) valence will be significant predictors of (greater) physical activity and (less) sedentary behaviors. We expect symmetrical associations in the other direction; that is, that (greater) physical activity and (less) sedentary behaviors will be related to higher arousal and more positive valence. Given the dearth of an empirical basis upon which to make specific predictions, we do not a priori predictions regarding the time frame over which these associations will be stronger or weaker; accordingly, we address this research question in an exploratory manner.

Methods

Participants

We used a dataset from the Work and Daily Life (WDL) study examining how workplace daily experiences were associated with health and well-being among full-time employed adults (see ref. [35] for additional details). A community sample of full-time employed working adults (n = 122) from the greater metropolitan area of a mid-sized city in the Northeast was recruited via random calls from a local telephone directory and from public listings on a university e-mail news alert and local event websites. Exclusion criteria consisted of the following: younger than 18 years of age; not currently employed Monday through Friday with regular working hours between 6:00 AM and 7:00 PM; employed on weekends; unable to come to the research laboratory on a Wednesday evening and the following Monday; not fluent in English; pregnant; and having a psychiatric therapy or drug treatment change within the prior three months. Of the 122 participants, 7 participants who did not complete EMA data collection were excluded from the analysis. Of the remaining 115 participants, physical activity data for 4 participants were unavailable. Thus, 111 participants were analyzed in this study. Participants had a mean age of 41.3 (SD = 11.6, range: 19–63) and were predominantly Caucasian (69.1%; Non-Hispanic Black 8.2%; Asian 4.6%; Others and N/A 18.2%) and female (76.4%). The average body mass index (BMI) of participants was 27.6 (SD = 7.4, range: 17.8–53.7).

Procedures

The initial session was completed in a laboratory setting. After being screened for eligibility, participants were trained on how to use a provided palmtop device to complete the EMAs. For the ensuing three consecutive days (Thursday to Saturday, thus two work days and one nonwork day), participants completed six measurements a day with measurements occurring randomly via a beep signal within roughly two and a half hour intervals (excluding the first and last 15 min of each interval to ensure assessment spacing) during waking periods. A maximum of 18 assessments per person was possible; participants averaged 16.1 (SD = 2.3, range: 8–18) assessments. Also, all participants were trained to wear an ActiHeart device (CamNtech Ltd., Cambridge, UK) on the left side of their chest (attached to the skin using two ECG electrodes) throughout the study period, except while bathing, showering, or any other activity likely to damage the device. At the end of the three days, participants returned the EMA and ActiHeart devices and data from both devices were downloaded by study staff.

Measures

As part of the larger study, assessments of affective states and physical activity were concurrently obtained during the study period (Fig. 1). Current affect was measured with four items (sad, happy, tired, and interested) rated on a Likert-type response scale ranging from 0 (Not at all) to 6 (Very much). These affect items were chosen to efficiently capture affect (i.e., a small number of items to keep respondent burden low) and reflect affective experiences thought to be important in the workplace context. Following approaches used in previous work, these ratings were used to generate momentary circumplex dimensions, arousal and valence [36]. To estimate affective arousal, we combined responses to the interested and tired (reversed) items (Arousal = [Interested + (6 − Tired)]/2). To estimate affective valence, responses to the happy and sad (reversed) items were averaged (Valence = [Happy + (6 − Sad)]/2). The correlation between "interested" and reverse-coded "tired" was .36 (p < .01), and that between "happy" and reverse-coded "sad" was .48 (p < .01).

The ActiHeart device has been validated in prior studies [11, 37, 38] and combines a heart rate monitor with a piezo-electronic accelerometer capable of detecting small changes in bodily acceleration, allowing it to register even slight movements in daily life. Also, activity and heart rate parameters are used to generate activity energy expenditure, with the equivalent of 3.5 mL O_2/kg/min used to define one MET on the device [39]. In this study, activity counts and energy expenditure accumulated in 1-min epochs were used. This device does

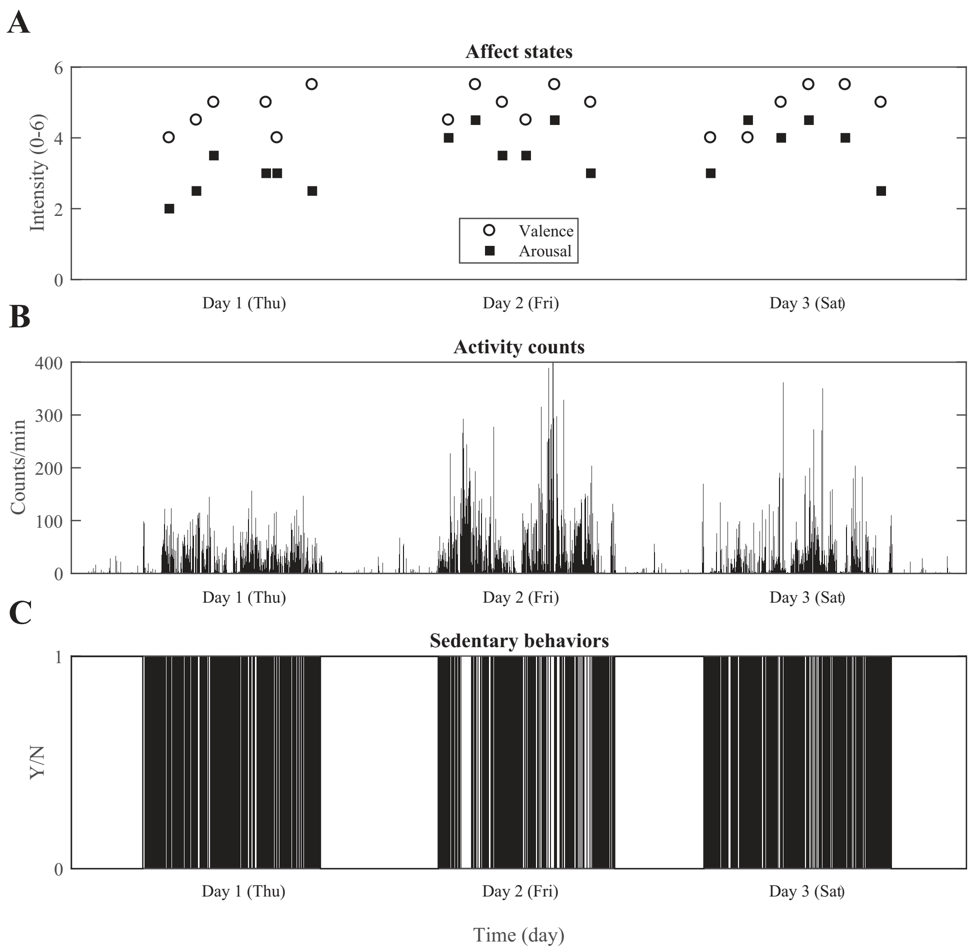

Fig. 1. Example of simultaneous assessments of affect states and physical activity. (A) Circles and filled squares indicate valence and arousal scores respectively assessed by ecological momentary assessment for three consecutive days. (B) Activity counts per minute are also obtained by an objective measure accelerometer during the study period. (C) Sedentary behaviors are defined at every minute (Yes = 1/No = 0) based on the prespecified cut-off value (<1.5 metabolic equivalents) which derived from combined heart rate and movement. The accelerometer data for (B) and (C) were excluded from the analysis when sleeping and not wearing the activity monitor.

not display any data (e.g., activity levels) to participants during use.

Analytic Plan

Days when participants wore the ActiHeart device less than 10 hr were excluded from the analysis (5 days from four participants). To examine how distinct indicators of arousal and valence predict subsequent movement-based behaviors and vice versa, we used activity counts and sedentary duration for various time windows before or after the EMA beep. As a measure of physical activity, mean activity counts per minute were calculated for each time window. Sedentary behavior was estimated as the proportion of minutes within each time window when the device indicated energy expenditure below 1.5 METs based on heart rate and movement data (Fig. 1).

For the primary analysis, mean activity counts and time spent in sedentary behaviors were calculated using transient (5 min), medium (1 hr), and relatively long (2 hr) time windows before/after each EMA to reflect transient to enduring effects. Further, we used 24 different lengths of time windows, 5 min up to 120 min with a 5-min interval before/after each EMA and the results using these various time windows are briefly provided (Figs. 2 and 3). For example, when the epoch size of activity counts obtained by accelerometer is 1-min, 60-min local mean of activity counts is computed from 60 data points, whereas 5-min local statistics are computed from five data points. Accelerometer data were excluded from the analysis when the heart rate was missing (i.e., presumably not wearing the device) as well as sleep which was defined by EMA reports (i.e., data between evening and morning survey was considered as sleep).

We estimated multilevel models using SAS PROC MIXED (SAS 9.4, SAS Institute Inc., Cary, NC) because the present study produced a hierarchically structured data set in which the EMA for affective states and

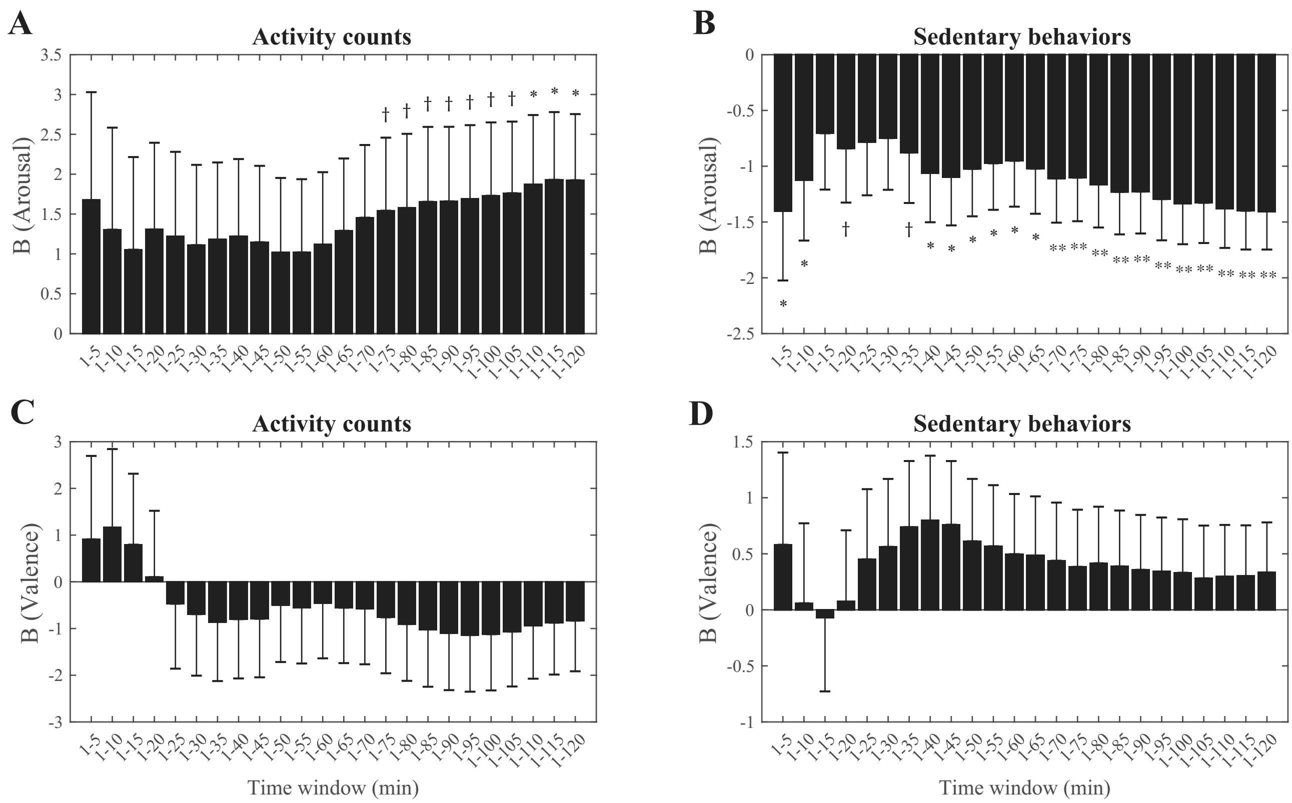

Fig. 2. Within-person B coefficient of affect states for the dependent variable *subsequent* movement-based behaviors as a function of the different length of time windows: (A) Coefficient of Arousal for Activity counts, (B) Coefficient of Arousal for Sedentary behaviors, (C) Coefficient of Valence for Activity counts, and (D) Coefficient of Valence for Sedentary behaviors. The length of the time windows was from 5 to 120 min with a 5-min interval (e.g., 1–20 means physical activity was calculated from the time window 1 min to 20 min *after* ecological momentary assessment [EMA] beep). Activity counts and Sedentary behaviors were calculated from 24 different time windows after EMA. Error bars indicate standard error of the B coefficients. The double asterisk, asterisk, and dagger indicate significant cases at the 0.01, 0.05, and 0.10, respectively.

the corresponding local statistics of movement-based behaviors were nested within persons. All models were estimated with three levels including day level (i.e., beep, day, and person) with the full-information maximum likelihood method, the between-within method for the denominator degrees of freedom option, and the unstructured variance-covariance matrix for the random effects and residuals. We used the deviance test to compare the goodness-of-fit of the models including a random or fixed effect for slope [40]. After this comparison, the multilevel model, in which intercept addressed as a random effect and predictors as a fixed effect, was used in this study. A $p < .05$ was considered significant. A false discovery rate (FDR) procedure [41] was performed to test the probability that the significance at $p < .05$ is a reliable effect for the multiple comparisons.

Predictors were centered at their person-mean to focus on the within-person variability in each of four models. The person-mean of predators were also included in the models to adjust for between person differences in mean values. General demographic variables (i.e., age, gender, race-ethnicity, and BMI) were included as covariates in each of four models to control for individual mean differences in predicting dependent variables. Age and BMI were treated as continuous variables, whereas race-ethnicity (Non-Hispanic White vs. Others) and gender (Male vs. Female) was addressed as categorical.

Results

The person-level mean, standard deviation (*SD*), and range of affective states and physical activity used for the primary analyses are summarized in Table 1. The mean of arousal was 3.8 (*SD* = 0.9, range = 1.5–5.8), whereas the mean of valence was 4.8 (*SD* = 0.7, range = 2.0–6.0), each on 0–6 scale. Averaged activity counts aggregated from 1 to 5, 1 to 60, or 1 to 120 min prior to EMA ranged from 28.1 to 30.7. Those aggregated following EMA ranged from 25.2 to 29.9 across the same interval lengths. As for time spent in sedentary behaviors, the range in the time windows before/after EMA was from 83.0 to 84.9%. Physical activity in the transient time window (i.e., 1–5 min) showed a lower level of activity counts or

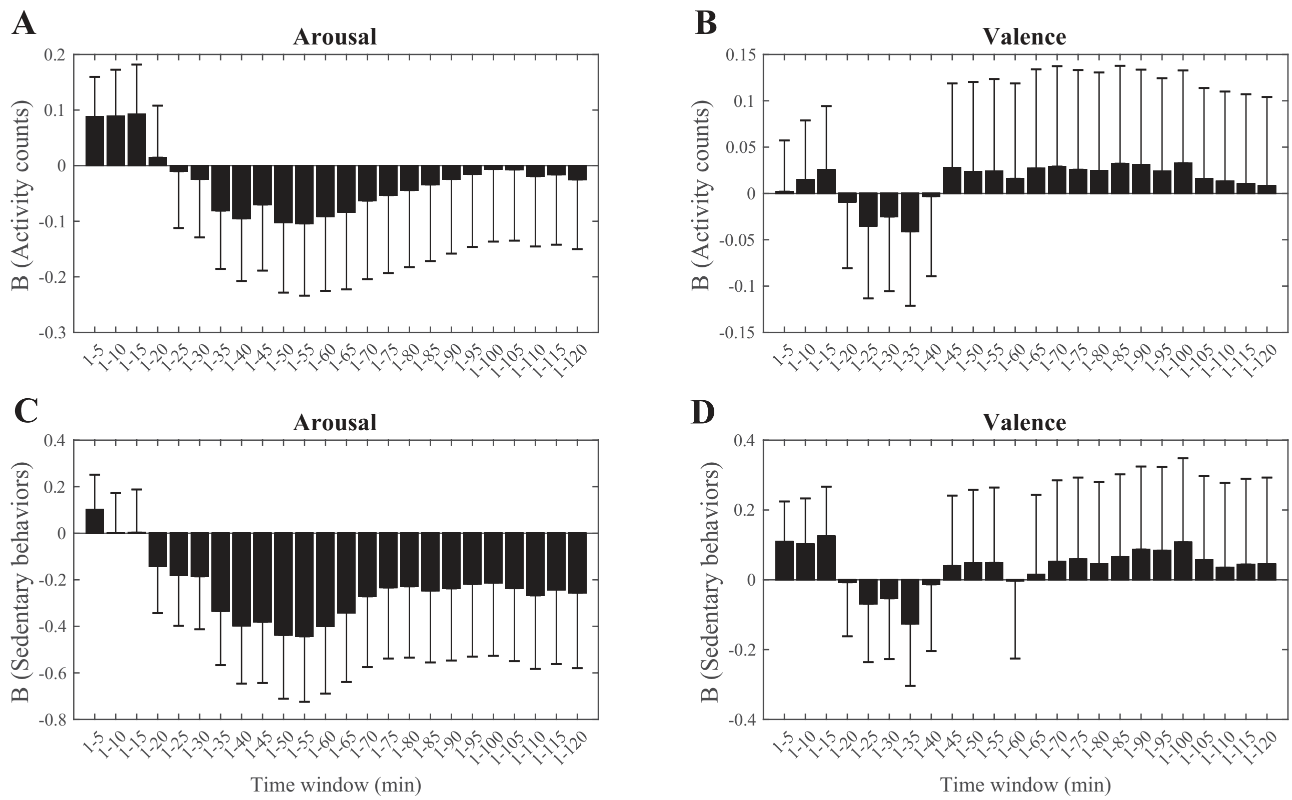

Fig. 3. Within-person B coefficient of *antecedent* physical activity for the dependent variable current affect states as a function of the different length of time windows: (A) Coefficient of Activity counts for Arousal, (B) Coefficient of Activity counts for Valence, (C) Coefficient of Sedentary behaviors for Arousal, and (D) Coefficient of Sedentary behaviors for Valence. The length of the time windows was from 5 to 120 min with a 5-min interval (e.g., 1–20 means physical activity was calculated from the time window 1 min to 20 min *before* ecological momentary assessment [EMA] beep). Activity count and Sedentary behaviors were calculated from 24 different time windows before EMA. Error bars indicate standard error of the B coefficients. B coefficient and standard error values are multiplied by 100 for convenience.

a higher proportion of time spent in sedentary behaviors. As expected, due to the smaller number of data points, the shorter time window had a higher *SD* with a wider range of activity counts and sedentary behaviors.

Current Affect Predicting Subsequent Movement-Based Behaviors

Estimates from Model 1, affect predicting subsequent mean activity counts in 5, 60, and 120 min time windows, are shown in Table 2. As hypothesized, at moments when participants reported greater affective arousal than their person-mean (i.e., higher relative to their usual affect states), they subsequently exhibited higher activity counts for the next 120 min (B = 1.92, *SE* = 0.83, *p* = .02), but not the next 5 min and 60 min. Contrary to expectations, affective valence was unrelated to subsequent activity counts over the 5-, 60-, or 120-min time windows.

Additional analyses were conducted with a range of time windows (5–120 min with a 5-min bin) for physical activity, and the B coefficients representing within-person associations between current affect and subsequent movement-based behaviors of those models were shown in Fig. 2. The B coefficients of arousal on activity counts were consistently positive values (between 1.02 and 1.93) across a wide range of time windows lasting from 5 to 120 min but showed significance only in longer time windows from 110 to 120 min (Fig. 2A). The FDR procedure indicated that the significant results in Fig. 2 are likely to be valid at a *q* value 0.2 (i.e., valid four out of five times). Affective valence was consistently unrelated to activity counts across any time window lasting from 5 to 120 min (Fig. 2C).

Estimates for Model 2, affect predicting subsequent sedentary behaviors, are shown in Table 3. As hypothesized, higher-than-usual arousal predicted less sedentary behaviors in the next 5-min (B = −1.40, *SE* = 0.62, *p* = .02), next 60-min (B = −0.95, *SE* = 0.41, *p* = .02), and next 120-min time windows (B = −1.41, *SE* = 0.34, *p* < .01). Inconsistent with our prediction, affective valence was unrelated to subsequent sedentary behaviors over the 5-, 60-, or 120-min time windows.

Additional analyses were conducted with a range of time windows (5–120 min with a 5-min bin) for sedentary behavior. The B coefficients for arousal on sedentary behaviors were consistently negative values (between −1.41 and −0.70) and were also significant across a wide range of

Table 1 Descriptive Statistics of Affect States and Physical Activity

Variables	Mean	*SD*	Min	Max
Arousal (0–6)	3.8	0.9	1.5	5.8
Interested	3.9	0.9	1.4	6.0
Tired	2.2	1.1	0.0	5.0
Valence (0–6)	4.8	0.7	2.0	6.0
Happy	4.3	0.8	2.2	6.0
Sad	0.8	0.8	0.0	4.3
Activity counts (per min)				
Previous 120 min	30.7	16.3	9.7	83.8
Previous 60 min	29.9	17.0	8.1	89.8
Previous 5 min	28.1	19.5	5.8	93.0
Next 5 min	25.2	20.4	1.4	116.3
Next 60 min	29.9	16.8	7.2	90.9
Next 120 min	29.9	17.1	8.3	88.9
Sedentary behaviors (% of time spent)				
Previous 120 min	83.0	9.7	39.6	97.3
Previous 60 min	83.1	10.2	38.9	98.1
Previous 5 min	84.9	11.2	31.3	100.0
Next 5 min	86.0	12.6	48.2	100.0
Next 60 min	83.3	9.9	45.4	98.0
Next 120 min	83.4	9.8	47.1	97.1

Note. Affect states were assessed with the scale ranged from 0 (not at all) to 6 (very much). Activity counts represent counts per minute averaged during each time duration.

Table 2 Multilevel Model Predicting Subsequent Activity Counts from Current Arousal and Valence

	Activity counts		
	Next 5 min	Next 60 min	Next 120 min
Intercept	41.76 (22.42)	37.61 (16.97)*	39.91 (17.15)*
Arousal centered at person-mean arousal	1.67 (1.35)	1.12 (0.91)	1.92 (0.83)*
Valence centered at person-mean valence	0.91 (1.79)	−0.45 (1.19)	−0.83 (1.08)
Person-mean arousal	−7.84 (3.65)*	−0.43 (2.76)	−0.81 (2.79)
Person-mean valence	5.75 (5.05)	3.27 (3.81)	2.31 (3.85)
Age	−0.11 (0.21)	−0.07 (0.16)	−0.02 (0.16)
BMI	−0.29 (0.34)	−0.71 (0.26)**	−0.70 (0.26)**
Gender	−2.65 (5.39)	−0.96 (4.08)	1.14 (4.13)
Race-ethnicity (Non-Hispanic White vs. Others)	0.17 (6.27)	0.46 (4.75)	−0.03 (4.80)

Note. B coefficients and standard errors of the multilevel model (Model 1) are shown. Arousal/Valence centered at person-mean shows within-person association. Mean activity counts per minute of physical activity and percentage of time spent in sedentary behaviors are calculated from each time window: 1–5, 1–60, or 1–120 min after EMA. Asterisks indicate whether the coefficients significantly differ from zero (*$p < .05$, **$p < .01$).

time windows (5–10 and 40–120 min; Fig. 2B). Affective valence did not predict subsequent sedentary behaviors across any time window lasting from 5 to 120 min.

Prior Behavior Predicting Current Affect

No hypotheses for this direction of associations were supported. Estimates for Model 3, arousal regressed on prior movement-based behaviors in 5-, 60-, and 120-min time windows, are shown in Table 4. Arousal was not associated with movement-based behaviors in any preceding time windows (see also Fig. 3A and C).

Estimates for Model 4, valence regressed on prior movement-based behaviors in 5-, 60-, and 120-min time windows, are shown in Table 5 (Model 4). We did not find any significant associations between affective

Table 3 Multilevel Model Predicting Subsequent Sedentary Behaviors from Current Arousal and Valence

	Sedentary behaviors		
	Next 5 min	Next 60 min	Next 120 min
Intercept	76.60 (13.07)**	75.78 (9.7)**	74.54 (9.56)**
Arousal centered at person-mean arousal	−1.40 (0.62)*	−0.95 (0.41)*	−1.41 (0.34)**
Valence centered at person-mean valence	0.58 (0.82)	0.50 (0.54)	0.33 (0.45)
Person-mean arousal	3.95 (2.13)	0.68 (1.58)	0.96 (1.55)
Person-mean valence	−3.83 (2.94)	−1.46 (2.18)	−1.31 (2.15)
Age	0.16 (0.12)	0.08 (0.09)	0.08 (0.09)
BMI	0.19 (0.20)	0.31 (0.15)*	0.32 (0.15)*
Gender	2.77 (3.15)	1.98 (2.34)	1.02 (2.31)
Race-ethnicity (Non-Hispanic White vs. Others)	−1.05 (3.65)	−1.17 (2.71)	−0.64 (2.67)

Note. B coefficients and standard errors of the multilevel model (Model 2) are shown. Arousal/Valence centered at person-mean shows within-person association. Mean activity counts per minute of physical activity and percentage of time spent in sedentary behaviors are calculated from each time window: 1–5, 1–60, or 1–120 min after EMA. Asterisks indicate whether the coefficients significantly differ from zero (*$p < .05$, **$p < .01$).

Table 4 Multilevel Model Predicting Current Arousal from Antecedent Activity Counts and Sedentary Behaviors

	Arousal		
	Previous 5 min	Previous 60 min	Previous 120 min
Intercept	3.79 (1.60)*	2.22 (2.18)	2.66 (1.79)
AC centered at person-mean AC†	0.09 (0.07)	−0.09 (0.13)	−0.03 (0.13)
SB centered at person-mean SB†	0.10 (0.15)	−0.40 (0.29)	−0.26 (0.32)
Person-mean AC	0.00 (0.01)	0.01 (0.01)	0.01 (0.01)
Person-mean SB	0.00 (0.02)	0.02 (0.02)	0.01 (0.02)
Age	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
BMI	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)
Gender	−0.27 (0.20)	−0.28 (0.20)	−0.28 (0.20)
Race-ethnicity (Non-Hispanic White vs. Others)	−0.66 (0.23)**	−0.63 (0.23)**	−0.64 (0.23)**

Note. *AC* activity counts; *SB* sedentary behaviors. B coefficients and standard errors of the multilevel model (Model 3) are shown. AC/SB centered at person-mean shows within-person association. Mean activity counts per minute of physical activity and percentage of time spent in sedentary behaviors are calculated from each time window: 1–5, 1–60, or 1–120 min before EMA.

†B coefficient and standard error values on the within-person level are multiplied by 100 to rescale the estimates for presentation. Asterisks indicate whether the coefficients significantly differ from zero (*$p < .05$, **$p < .01$).

valence and either movement-based behavior at any preceding time intervals (see also Fig. 3B and D). B coefficient and standard error values on the within-person level in Model 3 and 4 are multiplied by 100 to rescale the estimates for presentation.

Discussion

The nature and timing of bidirectional relations, especially within-person associations, between momentary affect and movement and nonmovement behaviors in everyday life are not well understood. We systematically examined how within-person changes in affective reports were associated with those in movement and nonmovement behaviors preceding or following the affective assessments. Importantly, this approach uses each individual as their own control, thus removing any effects due to between-person differences and increasing confidence in interpreting the observed effects [42]. Using sensors to measure these behaviors with high granularity enabled us to investigate associations when behavior was aggregated across time windows ranging from 5 to 120 min. Momentary affective arousal levels greater than usual (i.e., higher than their person-mean) predicted subsequent active movement-based behaviors for at least 120 min after the affect assessment, but momentary affective valence ratings did not predict subsequent movement-based behaviors. For the reversed sequence, within-person movement-based behaviors (i.e.,

Table 5 Multilevel Model Predicting Current Valence from Antecedent Activity Counts and Sedentary Behaviors

	Valence		
	Previous 5 min	Previous 60 min	Previous 120 min
Intercept	4.29 (1.15)**	5.13 (1.57)**	4.27 (1.29)**
AC centered at person-mean AC†	0.00 (0.06)	0.02 (0.10)	0.01 (0.10)
SB centered at person-mean SB†	0.11 (0.12)	0.00 (0.22)	0.04 (0.25)
Person-mean AC	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)
Person-mean SB	0.00 (0.01)	0.00 (0.02)	0.00 (0.01)
Age	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
BMI	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)
Gender	−0.20 (0.15)	−0.19 (0.15)	−0.21 (0.15)
Race-ethnicity (Non-Hispanic White vs. Others)	−0.27 (0.17)	−0.31 (0.16)	−0.29 (0.16)

Note. *AC* activity counts; *SB* sedentary behaviors. B coefficients and standard errors of the multilevel model (Model 4) are shown. AC/SB centered at person-mean shows within-person association. Mean activity counts per minute of physical activity and percentage of time spent in sedentary behaviors are calculated from each time window: 1–5, 1–60, or 1–120 min before EMA.

†B coefficient and standard error values on the within-person level are multiplied by 100 to rescale the estimates for presentation. Asterisks indicate whether the coefficients significantly differ from zero (*$p < .05$, **$p < .01$).

being more or less active than typical for each individual) did not predict subsequent affective states across these time intervals.

As we hypothesized, momentary affective arousal preceded periods of physical activity and sedentary behavior. This finding was consistent with prior studies which showed that energetic arousal predicts subsequent physical activity [26, 30, 43]. We extended prior work by finding that affective arousal also predicted sedentary behavior. Multilevel models suggested that a one-point increase in arousal (0–6) over each participant's typical (average) level was associated with a 6.4% higher level of average activity counts over the next 120 or 1.7 min less sedentary behaviors during the next 120 min based on the results with a 2-hr window. These magnitudes seem modest in isolation, especially for sedentary behaviors, but the cumulative duration is more substantive. For example, the cumulative impact of a steady one-unit increase in affective arousal across one week would be estimated to reduce sedentary time by as much as 95.2 min (e.g., 1.7 min every 2 hr × 16 awake hours a day × 7 days a week). Also, prior studies suggest that merely interrupting extended periods of sedentary behaviors more frequently can improve physical and mental health outcomes [44, 45]. Thus, affective changes that alter the patterning of sedentary time may be valuable even if they do not greatly reduce the overall duration of sedentary time.

In contrast, we did not identify significant associations between current affect and previous movement-based behaviors. These findings suggest that momentary affective experiences (i.e., arousal) might precede physical activity and sedentary behavior rather than following those behaviors. Prior studies, however, have reported inconsistent results regarding whether or not affective arousal follows physical activity. Higher light and moderate-to-vigorous physical activity (MVPA) over shorter time windows (e.g., previous 10, 15, or 30 min) predicted higher reports of feeling energetic in inactive samples [26, 33]. A study in university students showed that higher physical activity 10 min prior to affect assessment predicts energetic arousal [31]. Higher MVPA in the previous 30 min predicted increased feeling energetic in children [32]. These discrepant results between prior studies and the present study might be due to different selections of affect items for arousal, measures of physical activity (e.g., intensity, duration, and frequency), or sample characteristics (e.g., age, fitness, etc.). It will be important to conduct further research using reliable affect measures and validated measures of movement-based behaviors in diverse samples. Given our methodology (stratified random sampling of EMA assessments), relatively infrequent events, such as MVPA, may be unlikely to temporally align with an EMA prompt. As such, any associations are difficult to estimate, and further so when such effects (e.g., MVPA effects on affect) are short-lived (e.g., dissipate within ~30 min). Further research will need to carefully tailor the timing/frequency of EMA prompts to align with various indicators of physical activity in accordance with the specific research question(s).

Another important finding was that associations between arousal and subsequent physical activity or sedentary behavior may be time-varying (Fig. 2A and B). Affective arousal was consistently associated with subsequent sedentary behaviors across a broad range of time windows, whereas affective arousal predicted subsequent activity counts only in longer time intervals. These results are broadly consistent with a prior study that feeling more energetic may not predict higher physical activity but predict less time spent in sedentary activity, although that study used shorter time windows up to 30 min [26]. We tested the relations with longer time windows up to 120 min and found that more affective arousal may predict both subsequent physical activity and sedentary behaviors. These findings suggest the need to characterize temporal characteristics when trying to identify affective determinants of activity patterns. Higher arousal may very quickly lead to a decrease of sedentary behaviors but it might not lead to acute physical activity in that same time interval. Future work may want to focus on developing strategies for reducing inactivity according to the temporal characteristics of different types of movement-based behaviors.

Contrary to our expectations, affective valence was unrelated to movement-based behaviors. Prior studies have demonstrated positive bidirectional associations between valence and physical activity over shorter time windows (e.g., 10 or 45 min) in university students [30, 31]. However, a study in inactive (i.e., exercising once a week or less) university students reported valence was not related to physical activity over a 15-min time window [33]. This suggests that differences in results might be due to different levels of physical activity across samples. Another explanation for these results is that the specific adjectives used to measure valence can influence findings [46]. In particular, we recognize that "happy" and "sad" are not comprehensive indicators of valence. If the present finding is replicated with other (and more diverse) measures of affective valence, researchers interested in movement-based behaviors might examine accounts of affect regulation or congruency that explain how people process their affective experiences to improve understanding of how those affective experiences influence physical activity and sedentary behavior in everyday life [2].

This study had several strengths that added rigor. First, both physical activity and sedentary behavior were monitored with wearable sensors instead of self-reports to remove the threat of recall and other reporting biases. The combination of repeated measures of affective experiences using EMA and the continuous stream of sensor data permitted a detailed investigation of bidirectional, sequential relations across varying time windows for both preceding and subsequent behavior. Second, we thoroughly examined the affect–behavior–affect sequence in this study using transient, medium, and relatively long time windows. To the best of our knowledge, this study is the first to compare different time windows for affect–behavior–affect relations.

Yet, there are also limitations to this study. First, we used only 4 items (i.e., interested, tired, happy, and sad) to derive dimensional measures of affective valence and arousal in this study and it is potentially insufficient to fully represent the whole circumplex. Specifically, there is no item that represents activated negative valence or deactivated positive valence because the terms "happy" and "sad" in Russell's circumplex [29] are neutrally activated (neither activated nor deactivated). Second, participants were all employed and mostly Caucasian females so the generalizability of these associations to other populations is unclear. Third, this study has a short study period (3 days) with a fixed order of study days (Thursday to Saturday). It is difficult to generalize our conclusions to nonsampled days as well as difficult to examine the day of week effects because affect and physical activity might vary from day to day in this employed sample, we do not sample all days, and the days of the week (the subset that was consistently sampled) are in a fixed order for all participants. Fourth, although we carefully established the affect–behavior–affect temporal ordering (i.e., 5 min up to 120 min with a 5-min interval before/after each EMA), findings on the relations between affect and subsequent behaviors were observational so strong causal inferences cannot be drawn from the present study. Also, multiple tests on the relations with a variety of time windows causes the potential increase in Type I error, although we tested the probability of the error using FDR procedure. Fifth, there is a possibility that the EMA study procedures may have impacted participants' behaviors. However, we believe this possibility is unlikely because the wearable sensor used for movement-based behaviors does not provide feedback to participants, and affect measures were collected on a random schedule and not collected in response to (i.e., triggered by) the behaviors. Lastly, we defined sedentary behaviors with time spent under 1.5 METs which derived from combined heart rate and movement obtained by a torso-worn monitor; although this allows us to characterize sedentary behaviors, this method has not been fully examined [39]. Future research should evaluate whether the present findings replicate when using more sophisticated devices—for example, those that are more sensitive to postural changes involved in sedentary behavior.

Conclusion

In this study, we showed that affective arousal preceded higher levels of physical activity and lower sedentary behavior. In contrast, affective valence was unrelated to either physical activity or sedentary behavior. As such, perhaps separating arousal and valence components out of affect measures when predicting physical activity or sedentary behaviors should be de rigueur in future research. This study extends our understanding of the dynamic interplay of affective experiences and movement-based behaviors in both "directions" (i.e., behaviors to affect, affect to behaviors) in everyday life. In addition, this study may be informative for the design and implementation of interventions targeting affective arousal to promote physical activity and help working adults to avoid inactivity in everyday life.

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Compliance with Ethical Standards

Conflict of Interest The authors declare no conflict of interest.

Authors' Contributions: J.M.S. designed the study and collected the data. All authors formulated the research questions and outlined the article. J.K. cleaned and analyzed the data. J.K. wrote the first draft of the manuscript. D.E.C. and J.M.S. revised the draft of the manuscript. All authors approved the final version of the manuscript.

Ethical Approval and Informed Consent All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee. Participants provided written informed consent.

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