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ORIGINAL RESEARCH

Individual Differences in Negative Affectivity and Physical Activity in Adolescents: An Ecological Momentary Assessment Study

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Abstract

To examine the bi-directional relationships between negative affectivity (i.e., depression, anxiety, and anger) and adolescents' physical activity in nearly real time. Twenty-six adolescents ($M_{age} = 15.67 \pm 1.56$ years; 57.7% male) were asked to complete 80 self-report measures of their negative affect (depression, anxiety, and anger) via a smartphone app and wear an accelerometer as an objective assessment of their physical activity over 20 consecutive days. Negative fixed effects emerged for within-person depression and moderate-to-vigorous physical activity (MVPA) as well as for within-person anger and MVPA. Further, there were significant random effects for each of the within-person negative affect variables and MVPA. Study findings highlight the importance of considering individual differences in the association between negative affect constructs and physical activity.

Keywords Physical activity · Ecological momentary assessment · Adolescent · Negative affect

Physical activity is critically important for optimal health and well-being (Janssen and Leblanc 2010; Penedo and Dahn 2005). Adolescents who engage in adequate physical activity are at lower risk for a variety of chronic illnesses and injuries, and have healthier self-esteem and body image than those who are not physically active (Hallal et al. 2006; Sothern et al. 1999). Despite these benefits, the majority of adolescents do not engage in sufficient physical activity (i.e., ≥60 min of moderate-to-vigorous physical activity [MVPA] per day; Centers for Disease Control and Prevention 2014; World Health Organization 2015). Notably, it appears that younger children typically engage in adequate physical activity, but this habit declines steeply during middle adolescence (Nader et al. 2008; Trost et al. 2002). This pattern is troubling because adolescent behaviors are commonly carried forward into adulthood, when the health consequences of inadequate physical activity become more severe and are often accompanied by economic burden (Chenoweth and Leutzinger 2006; Kohl et al. 2012). Thus, adolescence is a critical developmental period for the study of physical activity.

Efforts to understand the correlates of adolescents' low engagement in physical activity may yield high-value intervention targets. Generally, higher levels of physical activity have been associated with decreases in dimensions of negative affect, such as anxiety, depression, and anger in both pediatric and adult populations (Driver and Ede 2009; Dunn et al. 2001; Motl et al. 2004). These commonly assessed facets of negative affect can be conceptualized as either time-invariant (between subjects, trait-like variables, e.g., Öztekin and Tezer 2009) or time-varying (within subjects, state-like variables, e.g., O'Reilly et al. 2015). Much is currently known about the associations between physical activity and trait anxiety and depression in adolescent populations (e.g., Cannon and Weems 2010; Motl et al. 2004). However, less is known about acute associations and even less still is understood about how fluctuations in state negative affectivity influences physical activity in adolescence.

Several adult studies offer support for time-varying relationships between physical activity and dimensions of negative affect (e.g., Aggio et al. 2017; Haas et al. 2017). For instance, Hass et al. (2017) found that young adults reported less depressed and angry evening affect but not anxious affect on days they engaged in more physical activity than was

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typical for them. Similarly, Aggio et al. (2017) found that young adults reported less depressed affect but not anxious affect on days they engage in more physical activity than usual. Recent studies have hypothesized that varying levels of arousal (ranging from deactivated to activated; Posner et al. 2005) among negative affect dimensions may help explain their unique associations with physical activity (Aggio et al. 2017; Hass et al 2017; Rebar et al. 2015). Specifically, these studies hypothesized that daily physical activity may enhance activation, and therefore, lead to a greater reduction of deactivated negative affect dimensions (i.e., sad or depressed, frustrated or angry) than activated negative affect dimensions (i.e., nervous or anxious, stressed; Aggio et al. 2017; Haas et al. 2017; Rebar et al. 2015). However, studies have yet to consider how deactivated and activated negative affect dimensions may impact engagement in daily physical activity.

While adult studies have identified notable differences in the acute relationships between physical activity and dimensions of negative affect, researchers have yet to examine whether these associations extend to adolescent samples. Rather, existing studies in children and adolescents have largely relied on an aggregate score of negative affect when examining daily fluctuations in physical activity and affect (Cushing et al. 2017; Dunton et al. 2014). For instance, one ecological momentary assessment (EMA) study found feeling states to predict physical activity levels, and subsequently, children's affective states (Dunton et al. 2014). Specifically, findings indicated that physical activity was associated with subsequent lower levels of negative affect. However, a recent meta-analysis that included this study found inconclusive and inconsistent support for physical activity predicting negative affect in the subsequent time window (Liao et al. 2015). Thus, further investigation is warranted in order to develop understanding of the acute relationships between physical activity and negative affect, and how these processes may be unique in adolescents.

While it is reasonable to consider physical activity as a preventative variable in the development of problems related to anxiety, depression, and anger, the concept of decreased physical activity as a consequence of negative affect also merits attention. Da Silva et al. (2012) found support for these bidirectional associations between physical activity and depression symptoms in an adult sample; in addition to finding that regular physical activity was associated with lower depressive symptoms, the authors found that adults with anxious or depressive symptoms were less likely to meet recommendations for physical activity (Da Silva et al. 2012). Studies in adolescent samples have also found depressive symptoms to be associated with lower subsequent physical activity over the course of one to six years (Jerstad et al. 2010; Stavrakakis et al. 2012). Other findings suggest that trait level anger is associated with lower of levels of aerobic exercise in adults (Anton and Miller 2005). It reasonable to speculate that anxious, depressed, or angry affect could diminish reward seeking and inhibit engagement in physical activity (Salmon 2001) and that building self-regulation skills, such as in cognitive behavioral therapy (Cooper et al. 2004), might improve individuals' ability to engage in physical activity. Considering the past research and speculations above, it is important that we further understand how these respective negative affect states are related to subsequent physical activity, as findings may be relevant to preventative efforts addressing lack of physical activity in adolescents.

Our previous work has established that the influence of acute unidimensional negative affect on physical activity varies significantly from adolescent to adolescent (Cushing et al. 2017). However, it is still unknown whether there is added benefit to modeling separate dimensions of negative affectivity (i.e., anger, anxiety, and depression) to account for each dimension's unique effect. The current study seeks to address gaps in the literature by examining anxiety, depression, and anger separately as time-varying mood states within adolescents and in relation to physical activity. Consistent with previous studies of youth (Cushing et al. 2017; Dunton et al. 2014), the current study relied on the accumulated physical activity in the 30 min prior and immediately following EMA prompts assessing dimensions of negative affect. Furthermore, the current study uses a 20-day study period, an objective measure of physical activity, and multiple smartphone survey items to inform each affect construct. These components may allow results of the present study to contribute evidence to the scant literature regarding the proposed reciprocal influence of adolescents' activity levels on mood states.

The aim of the current study is to test the acute bidirectional effects of physical activity with the negative affectivity constructs of anxiety, depression, and anger through the following between-person and within-person hypotheses: (1) Adolescents who report anxious, depressive, or angry states that are higher than their typical levels will engage in less MVPA than they typically do in the subsequent 30 min; (2) there will be within-person heterogeneity in the slopes between MVPA and negative affect variables; (3) consistent with adult studies, adolescents who engaged in more MVPA than typical would report lower levels of depressed and angry affect than usual in the subsequent 30 min.

Method

Participants

Participants were recruited through flyers, direct emails, and a social media campaign in a small Midwestern college

town. Participants included 26 adolescents between 13 and 18 years old ($M = 15.67$, $SD = 1.56$). Participants were 57.7% male, 69.2% Caucasian, 15.4% American Indian, 11.5% Hispanic, and 3.8% Asian. The majority of participants (56%) indicated having an annual family income of greater than $60,000, while others reported family income between $50,000–$60,000 (16%), between $30,000–$50,000 (20%), or between $20,000–$30,000 (8%). To be eligible, adolescents had to be between the ages of 13 and 18, and able to read and write at grade level in English. Adolescents with significant visual impairments or activity-limiting physical maladies were excluded from the study.

Procedures

This paper presents data from a pilot study of an intensive ecological momentary assessment protocol to examine relationships between biopsychosocial variables and health behaviors. (For a complete description of procedures, please see Brannon et al. 2016). All study procedures were approved by the local Institutional Review Board (IRB). Participant assent and parental consent was collected for all adolescents. Participants then completed a demographic questionnaire and computer-based surveys. Following the surveys, participants were trained to use study equipment, including a smartphone and accelerometer. Participants were informed that they would be compensated up to $40, based on compliance with the study protocol (see Brannon et al. 2016 for full information about study compensation). At the end of the 20-day study period, participants returned all equipment and completed questionnaires on a computer.

Smartphone app

The smartphone used in this study was programmed to deliver questionnaires four times per day via an application (PETE app). Participants selected four times, separated by at least 2 h, that they would be able to answer surveys during the 20-day study period (e.g. 7:00 a.m., 11:30 a.m., 3:30 p.m., 7:00 p.m.). Participants were informed that surveys would be administered at the same time on weekdays and weekend days and that each survey would take approximately 3 min to complete. The PETE app notified participants to answer surveys at the designated times.

Accelerometer

The Actigraph wActi Sleep-BT accelerometer (Actigraph LLC, Pensacola, FL) is a validated wireless monitor that allows for objective measurements of physical activity. The device uses a triaxial accelerometer, which can measure accelerations in three planes of movement in the range of 0.05 to 2 G's using a band-limited frequency of 0.25 to 2.5 Hz. Participants were instructed to wear the accelerometer on their nondominant wrist for the duration of the study period (24 h per day), noting that it was waterproof and would not need to be charged.

Measures

Physical activity

Physical activity was measured through accelerometer records of motor movement. Accelerometers were initialized to sample at 30 Hz and raw accelerometer file were downloaded using Actilife v.6.10.2. Data were binned into 60 s epochs. The Sadeh (Sadeh et al. 1994) algorithm was used to flag sleep periods. Non-wear time was flagged using the Troiano algorithm (Troiano et al. 2008), and sleep periods were also counted as non-wear in order to ensure that only waking wear time was counted in estimates of MVPA. In the next step, data flagged as waking wear time were processed using a custom Python program that applied the Chandler (Chandler et al. 2016) cut points for MVPA. This algorithm was selected because the study incorporated wrist-worn accelerometers in a sample under the age of 18, making it relevant to the current investigation. In the initial validation study Chandler (2016) used 5 sec epochs to create cut points. In the current data processing, we used the cut points adjusted for a 60 sec epoch. Therefore, thresholds for activity were sedentary (0–3660), light (3661–9804), and MVPA (9805 and above).

Negative affect

Negative affect was assessed using clinical constructs of anxiety, depression, and anger. Each of these constructs was measured through inclusion of three items with the highest factor loadings from the Profile of Mood States (POMS; McNair et al. 1981). The items for each construct consisted of the following: Anxiety: *nervous, restless, on edge* ($\alpha = .79$); Depression: *miserable, sad, hopeless* ($\alpha = .83$); Anger: *peeved, angry, annoyed* ($\alpha = .89$). Participants were prompted to rate the extent to which they experienced each emotion "since the last beep went off." Participants indicated responses on a 5-point Likert scale. For example, a question would ask, *Since the last beep went off how PEEVED have you been feeling? (1: Not at all, 2: A little, 3: Moderately, 4: Quite a bit, 5: Extremely).*

Data Analyses

Data from the PETE app surveys and from the Actigraph accelerometer were downloaded from the smartphone and analyzed using PROC MIXED (SAS Version 9.4). Scores on items for the respective constructs of anxiety, depression,

and anger were averaged to create mean variables across all observations for each participant. To center the affect variables, the person mean was then subtracted from each observation (Hoffman and Stawski 2009). Thirty-minute time windows of the accelerometer data before and after survey observations were specified for observation of MVPA.

Testing assumptions

All data analysis was conducted using full information maximum likelihood (FIML) estimation (Enders 2001) to account for missing data. The interclass correlation coefficient (ICC) was calculated using the formula ICC = (Random Intercept Variance/Total Variance)*100 for each variable of interest (anxiety, depression, anger, MVPA 30 min before, MVPA 30 min after) and used to determine between-person variability. The ICC–100 was then used to calculate within-person variability represented by each variable of interest.

To test whether each variable of interest changed over observations, each was tested in a model with a linear effect of time, and additionally tested with alternate models of time: random, quadratic, and random quadratic. Fit statistics were compared using the −2 Restricted Log Likelihood (−2LL) and chi-square for significance testing.

Evaluating hypotheses

After testing assumptions, MVPA in the 30 min prior to survey responses was entered as a predictor, with each affect construct as a dependent variable. Then, depression, anxiety, and anger, respectively, were tested as predictors of MVPA in the 30 min following survey responses. Random effect models were tested for all corresponding significant within-person fixed effects.

Results

On average, adolescents completed 70 out of the 80 surveys prompts, resulting in ~13% missing survey data. Participants provided valid accelerometry data for 75.3% of study days. Descriptive statistic for all study variables are presented in Table 1. On average, adolescents did not achieve the recommended 60 min of MVPA per day (30.63 ± 28.75 min). Participants engaged in 1.14 ± 2.79 of MVPA in the 30-minute window before a survey and 1.20 ± 2.94 in the 30-min window after a survey.

After establishing a random effect of time, no between-person associations were observed. However, given that only 9.63% of the variability in MVPA is between-persons, the within-person effects are considerably more meaningful.

Table 1 Descriptive statistics

Variable	Mean	SD
MVPA (daily average)	30.63	28.75
MVPA (30 min post-survey)	1.20	2.94
MVPA (30 min pre-survey)	1.14	2.79
Depression	4.28	2.29
Anxiety	4.76	2.40
Anger	5.14	2.83

MVPA moderate-to-vigorous physical activity

Negative within-person associations were found between depression and MVPA and anger and MVPA, while no significant fixed effect was observed for anxiety and MVPA. However, all three predictors did have a significant random effect in the final model. For depression, the 95% confidence interval around the fixed effect was −.25, .77 which suggests that there is considerable variability in the slopes that characterize this association. Similarly, the 95% CIs were −.40, .30 and −.56, .26 for anxiety and anger, respectively. These findings suggest that in order to effectively model the relationship between three distinct domains of negative affect and MVPA it is necessary to gather intensive longitudinal data, and include random effects in the final models. Moreover, these findings support the idea that there are individual differences in the association between negative affect constructs and MVPA. Table 2 contains the information from the multilevel models. MVPA was not a significant predictor of negative affect at the within-person or between-person level (see Table 3).

Discussion

No significant differences were found when considering negative affectivity and MVPA between participants. Importantly, this means that the common way of conceptualizing a research question, "is a higher negative affectivity score relative to the group associated with higher MVPA relative to the group?" shows no association. However, when examined as within-person variables, or, "is higher negative affectivity relative to a given adolescent's typical level of negative affectivity associated with more MVPA than usual for that adolescent?" does demonstrate an association for some of the participants in the sample. It is equally important to note that in the case of all three negative affect variables there are within-person associations that are significantly negative, significantly positive, and nonsignificant in this dataset. This finding supports assertions made elsewhere (Cushing et al. 2017) that

Table 2 Association of negative affect variables and MVPA minutes in the following 30-min window

	Fixed Association with MVPA β (SE)	*p*	CI for random slope
Depression ($n = 26$)			
Intercept	.27 (.78)	.73	
PM	.22 (.17)	.24	
WP	−.13 (.06)	.03	−.25, .77
Anger ($n = 26$)			
Intercept	.90 (.78)	.26	
PM	.06 (.15)	.68	
WP	−.12 (.05)	.01	−.40, .30
Anxiety($n = 26$)			
Intercept	.25 (.81)	.77	
PM	.20 (.16)	.24	
WP	−.05 (.05)	.34	−.56, .26

MVPA moderate-to-vigorous physical activity, *PM* person mean, *WP* within person

Table 3 Association of negative affect variables and MVPA minutes in the preceding 30-min window

	Depression		Anger		Anxiety	
	β (SE)	*p*	β (SE)	*p*	β (SE)	*p*
MVPA						
Intercept	4.10 (0.50)	<.001	5.10 (.64)	<.001	4.80 (.61)	<.001
PM	.06 (.19)	.75	.18 (.48)	.70	.11 (.45)	.82
WP	−.01 (.01)	.27	−.03 (.02)	.14	−.00 (.02)	.85

MVPA moderate-to-vigorous physical activity, *PM* person mean, *WP* within-person

adolescents are more unique than they are similar when it comes to the associations between negative affectivity and MVPA. The current study extends our previous work by demonstrating that different dimensions of negative affect may have different associations with MVPA. Moreover, these findings open the possibility that a given adolescent could have a significant association between one dimension of negative affect and MVPA, but not effect or the opposite effect for another dimension.

Adolescence is a pivotal developmental period where individuals' opportunity and likelihood of engaging in MVPA decreases significantly. Intense negative mood states, particularly feelings of anxiety, depression, and anger, may themselves be related to normative developmental processes of adolescence. It fits that negative mood states generally decrease an adolescent's opportunity to engage in physical activity (McAuley and Blissmer 2000; Nelson et al. 2009). However, these data suggest that it is not always the case that negative affect always results in less MVPA. In fact, sometimes, participants engage in more MVPA when they experience negative affect. These findings highlight the importance of understanding the individual differences in behavioral responses to internal affective states.

The heterogeneous findings elicit speculation that negative affectivity may be more physiologically activating for some adolescents relative to others, relating to a lack of decreased likelihood for engaging in MVPA. Research suggesting that respective negative mood states are associated with unique cardiovascular responses may be relevant in exploring these speculations (Kreibig 2010). Future studies may benefit from obtaining additional heart rate data, which may add value in identifying physiological traits that serve to explain the heterogeneity in the associations.

In addition to adding clarity by understanding the interactions between physiology and affect, future studies should integrate the wealth of cross-sectional data on person-level influencers of MVPA. There are a range of theoretical models that have received support (see Cushing and Steele 2010). It will be important for future studies to determine how social support, self-efficacy, perceived behavioral control, and outcome expectancies interact with negative affect to influence MVPA. For instance, it may be that an adolescent who experiences high levels of anger could still engage in MVPA if they also have high social support for exercise. Related, it may be that some dimensions of affect interact with some person-level traits while others do not. For instance, an adolescent who has high self-efficacy for MVPA may be able to overcome anger to be active because they are already physiologically activated (i.e., feeling energetic) while feeling depressed could be too burdensome due to the associated fatigue.

It is notable that MVPA was not found to be a significant predictor of depressive, anxious, or angry affective states at the within-person or between-person level. Our within-person findings are inconsistent with adult studies that have found less depressed and angry affect following physical activity (Aggio et al. 2017; Haas et al. 2017). However, these discrepancies may be explained by differences in measurement intervals, given that adult studies have focused on evening affect, whereas our study examined more immediate outcomes (MVPA 30 min prior to affect survey) across the day. The literature examining the impact of physical activity on subsequent negative affect in children and adolescents has been inconsistent and inconclusive. In line with some studies, our findings show no associations between MVPA and subsequent negative affect (for a review see Liao et al. 2015) and, therefore, further clarify and extend previous findings by demonstrating that these associations do not appear to differ across negative affect dimensions in adolescents.

Limitations

Limitations of this study include small sample size and lack of racial/ethnic diversity among the participants. Further research examining these intrapersonal processes in a larger sample of individuals could provide clarity regarding whether the proposed bidirectional relationships exist, as well as their implications for clinical interventions. However, adolescents in this study were non-treatment seeking, meaning that they did not have clinical diagnoses related to anxiety, depression, or anger. Therefore, it is assumed that their levels of impairment would differ from a clinical sample. Future research should enhance efforts to recruit more diverse samples in order to increase external validity of findings. Additionally, given the complex nature of physical activity, it is likely that additional factors not assessed in the present study also serve as predictors and consequences of physical activity. Future studies with a larger sample and additional covariates are necessary to confirm and extend the present findings. While, the current study focused on adolescents' daily MVPA, studies of adults have identified differences in negative affect when accounting for exercise and non-exercise activity (Reichert et al. 2017), as well as when activity transitions from aerobic to anaerobic levels (for a review see Ekkekakis et al. 2011). Future studies should consider whether similar relations emerge in adolescent samples. Lastly, while successfully employing an ecological momentary assessment approach, additional surveys throughout the day, use of random EMA prompts, or considering additional windows for observation of physical activity, would add to the comprehensiveness of this continuous data.

Implications and Future Direction

The particular findings from this study suggest importance for screening adolescents for levels of anger and depression. Awareness of these mood states may allow for the opportunity to educate adolescents about health behavior and how physical exercise may serve to improve physical and mental health, as well as prevention and early intervention of clinical conditions. The emphasis on within-person variability in this study's findings draws attention to the importance of considering state-like factors (e.g., negative affect, having a "bad day") that may influence engagement in physical activity. It remains to be determined, however, which participants are likely to demonstrate this association. Future studies should determine what person-level traits may explain the variability in these associations. It may be that physical characteristics such as weight-status or psychological traits such as self-efficacy help to account for the variability in negative affectivity and MVPA association. Once baseline characteristics are identified, they can be used as grouping variables in adaptive intervention designs (Noser et al. 2017). Future research should also explore the value of mood profiles as predictors of MVPA (Cushing et al. 2017). That is, it may be that combinations of negative affectivity (e.g., depressed-anxious) may be more powerful predictors of MVPA for some adolescents than a single dimension of negative affect.

Ecological momentary assessment has proven valuable in obtaining information about individual adolescents and their "real-time" physical and emotional states that would not typically be available through standard self-reported data collection procedures (Brannon et al. 2016; Dunton et al. 2005). Considering that the majority of teenagers (about 75%) own or have access to use of a smartphone (Pew-Lenhart 2015), continued use of ecological momentary assessment data capture through smartphones opens the possibility of developing a precision medicine approach (i.e. a health care system tailored to the needs of individual patients) to health behavior change (U.S. Department of Health & Human Services). Precision medicine emphasizes the integration of multiple data sources across time and could be particularly relevant in the context of adolescents' developing physical and mental health (Kieling 2015). Such data capture strategies hold promise for identifying psychobehavioral processes that can be used to optimize already promising mHealth intervention modalities (Fedele et al. 2017) in understanding reciprocal relationships between physical, behavioral, and mental health.

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Author Contributions C.C.C.: obtained funding for the project; conceptualized the work; provided substantial original writing; conducted the statistical and methodological design; conducted the statistical analyses; collected the data; editing the work; and supervised/mentored C.M.B., T.B.M., & A.E.N. C.M.B., T.B.M., & A.E.N.: collaborated in the conceptualization of the work, provided substantial original writing, and edited the work. C.J.C.: collaborated in the conceptualization of the work, designed the PETE app and oversaw its use, and edited the work.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of

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Informed Consent Informed consent was obtained from all individual participants included in the study.

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