

## **Within-Person Link between Physical Activity and Depressed Affect in Adolescents: An Intensive Longitudinal Approach**

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We thank Hannah Jöckel, Lea Köhler, Katrin Molsen, Marie Landenberger, and Annika Plambeck for their assistance with participant recruitment and data collection, Dale Esliger and Lauren Sherar for processing the accelerometry data, and Matthew Riccio for his helpful comments on the manuscript.

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Within-Person Link between Depressed Affect and Moderate-to-Vigorous Physical Activity  
in Adolescence: An Intensive Longitudinal Approach

Abstract

**Background:** During adolescence, young women and men frequently show low physical activity and elevated depressed affect. This study aimed to examine the within-person link between moderate-to-vigorous physical activity (MVPA) and depressed affect in everyday life. **Methods:** Within an intensive longitudinal approach, adolescents ( $N = 72$ ; 37% young women;  $M$  age = 17.36 years; age range: 12-26 years; mid-90% age range: 13-22 years) wore accelerometers to assess their daily MVPA and reported next-morning and same-evening depressed affect in diaries over eight consecutive days. The within-person link between MVPA and depressed affect on the next morning (time-lagged prediction) and the same evening (same-day link) was analyzed with mixed-effects models. **Results:** More-than-usual MVPA significantly predicted less next-morning depressed affect on weekdays in young women, to the extent that a 60-min increase in MVPA over the person mean significantly predicted 50% lower next-morning depressed affect. **Conclusions:** This study encourages the development of individually-tailored physical activity interventions that could help adolescents enhance their daily amount of unstructured, self-initiated MVPA to reduce depressed affect. This approach may be particularly suitable for young women who have the highest risk for an inactive lifestyle and elevated depressed affect.

**Keywords:** moderate-to-vigorous physical activity, accelerometry, depressed affect, adolescence, within-person link, intensive longitudinal design

## Introduction

Adolescence<sup>1</sup> is a high-risk period for elevated depressed affect (Thapar, Collishaw, Pine, & Thapar, 2012) and developing an inactive lifestyle (Kann et al., 2014). During this period depressed affect<sup>2</sup> becomes increasingly prevalent (Bertha & Balázs, 2013; Thapar et al., 2012), particularly in young women (Thapar et al., 2012; Wesselhoeft, Sørensen, Heiervang, & Bilenberg, 2013), and can be associated with severe social problems (Verboom, Sijtsema, Verhulst, Penninx, & Ormel, 2014), educational impairments (Verboom et al., 2014), and morbidity (Thapar et al., 2012).

During the same developmental period, everyday moderate-to-vigorous physical activity (MVPA) decreases by approximately 40 min per day each year (e.g., Nader, Bradley, McRitchie, Houts, & O'Brien, 2008). On weekend days, young women and men spend less time with MVPA compared to weekdays possibly due to competing weekend priorities and fewer opportunities for participation in MVPA (Compte et al., 2013; Corder et al., 2014; Nader et al., 2008; Ortega et al., 2013). Notably, MVPA decreases even sharper and more rapidly in young women than men (Hallal et al., 2012; Nader et al., 2008). Overall, the decline of MVPA during adolescence leads to various short- and long-term consequences for physical and mental health such as poorer cardiometabolic parameters (Ekelund et al., 2012) and higher levels of anxious and depressed affect (e.g., Janssen & LeBlanc, 2010).

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<sup>1</sup> In this article we follow the suggestion of Sawyers and colleagues (2012) who defined “adolescence” as the period between ages 10 and 24; thus, we use the terms adolescents and young women and men to refer to this age group.

<sup>2</sup> When using the term depressed affect researchers generally refer to a core symptom of depression (i.e., being sad, discouraged, downhearted, or hopeless). Within intensive longitudinal studies, depressed affect is mostly conceptualized as transient episodes occurring frequently in everyday life that can be readily changed by social, psychological, and environmental contexts (Cranford et al., 2006).

Although there is ample evidence that enhanced physical activity is associated with lower depressed affect (Brown, Pearson, Braithwaite, Brown, & Biddle, 2013; Cooney, Dwan, & Mead, 2014; Larun, Nordheim, Ekeland, Hagen, & Heian, 2006; Mammen & Faulkner, 2013), the underlying mechanisms are still poorly understood (Josefsson, Lindwall, & Archer, 2014). Possible explanations for the antidepressant effect associated with activity include immediate-to-short-term and longer-term physiological mechanisms (e.g., increased synthesis of norepinephrine and serotonin, increased blood circulation, Buckworth, Dishman, O'Connor, & Tomporowski, 2013; increased synthesis of endorphins, dopamine, and endocannabinoids, Ekkekakis, 2013; neuroimmune modulation, i.e., reduced inflammation and oxidation stress, Eyre & Baune, 2012; enhanced energy and lower fatigue, Loy, O'Connor, & Dishman, 2013; circadian rhythm reset through natural light exposure, Stephenson, Schroder, Bertschy, & Bourgin, 2012) as well as psychological mechanisms (e.g., better sleep quality, Brand et al., 2014; van Zundert, van Roekel, Engels, & Scholte, 2015; distraction from worries, subjective expectations, physical activity enjoyment, social participation and support, Salmon, 2001; enhanced control beliefs, Buckworth et al., 2013; improved physical self-concept, self-efficacy, and self-esteem, Babic et al., 2014).

In sum, studying the link between everyday MVPA and depressed affect within person seems very promising to see if MVPA could be used as an intervention to prevent depressed affect.

### **Previous Studies on the Link between Physical Activity and Depressed Affect in Adolescence**

To date, most studies involving young women and men have focused on linking differences in physical activity and depressed affect *between* individuals (between-person link). The majority of these studies followed cross-sectional designs and showed small to moderate negative associations between activity and depressed affect (e.g., Janssen &

LeBlanc, 2010). The few existing mid- and long-term longitudinal studies examining this association over months or years predominantly showed that higher activity levels are prospectively related to lower depressed affect (Mammen & Faulkner, 2013). Moreover, randomized controlled trials (RCTs) suggest that activity interventions reduce depressed affect in adolescents (Brown et al., 2013; Larun et al., 2006).

Despite the valuable contributions of cross-sectional and longitudinal studies, and RCTs to understanding the physical activity-depressed affect link in adolescence, these studies are not without limitations. First, particularly cross-sectional and longitudinal studies generally used self-reports assessing past activity instead of motion sensors (i.e., accelerometers or pedometers) measuring concurrent activity, potentially resulting in recall bias and overestimation of the actual amount of activity (Adamo, Prince, Tricco, Connor-Gorber, & Tremblay, 2009). Second, especially in RCTs, activity is usually conceptualized as prescribed, structured, and supervised exercise under laboratory conditions and not as self-initiated, unsupervised everyday activity in real-world settings, thereby reducing the generalizability of results. Third, by focusing almost entirely on between-person effects, previous studies are mostly unable to capture fluctuations over time *within* individuals (within-person link; Kanning, Ebner-Priemer, & Schlicht, 2013). Since results at the between-person level do not necessarily translate to those at the within-person level (Hamaker, 2012) the question of whether more activity is related to lower depressed affect *within* young women and men remains largely unanswered (Biddle & Asare, 2011; Hume et al., 2011).

### **Intensive Longitudinal Studies on the Within-Person Link between Physical Activity and Affect in Adolescence**

To examine psychological processes occurring at the within-person level from day to day and within the same day, intensive longitudinal designs are considered the method of

choice (Bolger & Laurenceau, 2013). These designs include sequences of repeated measurements taken on individuals in everyday contexts to examine change processes within individuals. Studies with intensive longitudinal designs have two key advantages over studies with cross-sectional, mid- and long-term longitudinal, as well as intervention designs. First, researchers can systematically examine naturally occurring processes on a day-to-day basis in real-world settings, thereby enhancing the ecological validity and reducing recall bias (Reis, 2012). Second, the focus on within-person processes has the advantage that only a few time-varying constructs with similar timing could be alternative explanations. Thus, researchers can rule out explanations through stable between-person differences such as socioeconomic status. Intensive longitudinal studies enable researchers to study if more MVPA indeed precedes less depressed affect within the same person, thus providing the basis for claiming a temporal order—a precondition for causality which, then, has to be tested within experiments.

So far, there are very few intensive longitudinal studies of the physical activity-affect link. In adults, two intensive longitudinal studies (Mata et al., 2012; Wichers et al., 2012) showed within-person links between activity and positive affect, but not negative affect, possibly due to the measurement approach for activity (self-report) and for negative affect (heterogeneous items with low sensitivity to change and partially low within-person reliability). Hence, these studies cannot convincingly rule out a within-person link between activity and negative affect in adults due to methodological restrictions. With regard to childhood and adolescence, there are three intensive longitudinal studies, all of them using sensor-based assessment of activity (Dunton et al., 2014; Gawrilow, Stadler, Langguth, Naumann, & Boeck, 2013; Kühnhausen, Leonhardt, Dirk, & Schmiedek, 2013). Neither Dunton and colleagues (2014) nor Kühnhausen and colleagues (2013) could show a within-person link between activity and negative affect in elementary school children, possibly due methodological restrictions such as participants' young age, item selection, scale reliability,

and for Kühnhausen and colleagues low mean levels and variability of affect. Gawrilow and colleagues (2013) showed that boys and girls in early adolescence reported less evening depressed affect on days when they had taken more-than-usual steps. In sum, the activity-affect link has been investigated with mixed results, and only a handful of studies focused on adolescence and early adulthood.

### **Research Questions and Hypotheses**

We addressed the following two research questions: Does accelerometer-assessed MVPA on one day predict (a) next-morning and (b) same-evening depressed affect<sup>3</sup> within person? We hypothesized that young women and men with more-than-usual physical activity throughout the day (i.e., over the person mean) would show (a) less depressed affect on the next morning (time-lagged prediction) and (b) the same evening (same-day link). We focused on MVPA because this intensity level showed the strongest impact on depressed affect in previous research (Brunet et al., 2013). Since activity and depressed affect differ considerably between young women and men (i.e., more activity in young men, higher depressed affect in young women) and weekdays and weekend days (i.e., more activity and higher depressed affect on weekdays; Cranford et al., 2006; Hallal et al., 2012; Nader et al., 2008), we examined gender and weekday vs. weekend day as moderators of within-person links.

## **Methods**

### **Design and Procedure**

This study had an intensive longitudinal design with a baseline questionnaire, seven consecutive days of daily physical activity and depressed affect assessment (i.e., five weekdays, two weekend days), and a follow-up questionnaire. Participants were recruited from two public secondary schools (Grades 7-12) and one vocational school (Grades 10-12)

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<sup>3</sup> In the current study, we used three items of the Profile of Mood States (sad, discouraged, hopeless; Cranford et al., 2006; McNair, Lorr, & Droppleman, 1992) to define depressed affect.

in a large urban area in Germany. Trained research assistants explained the study procedure in the classroom, handed out a written study description, and assured them that their participation would be voluntary and that their answers would remain completely confidential. Participants and their parents (for those under 18) provided written informed consent.

Participants completed the baseline questionnaire on single desks in the school hall. Subsequently, in pairs of two students, participants were shown how to wear the accelerometer and received paper-and-pencil morning and, if requested, paper-and-pencil evening diaries for all days. Those participants who had chosen the online format for filling out evening diaries were instructed that they would receive a link to each evening diary at 7 pm every day via e-mail. For the following seven consecutive days, participants wore an accelerometer on their right waistband during waking hours on all days except during water-based activities (Day 1 to 7). On Day 2 to 8, participants reported their morning depressed affect within one hour of waking up via paper-and-pencil diaries (using this format allowed all participants to integrate their ratings into their daily morning routine). On Day 1 to 7, participants reported their evening depressed affect within one hour of going to sleep depending on participants' preference via paper-and-pencil diaries (78% of participants) or online diaries (22%). On Day 8, participants completed a follow-up questionnaire, and research assistants collected accelerometers and paper-and-pencil diaries. All data were collected between September and December 2011. The research protocol was approved by the local Institutional Review Board.

### **Measures**

**Daily physical activity.** We measured daily physical activity using GT3X+ accelerometers by ActiGraph (Pensacola, FL, US). The sampling rate was set to 60 Hz and the non-wear time was determined as 60 min of consecutive zeros of activity counts allowing for two min of non-zero interruptions. Days with wear times of 10 or more hours were



considered as valid days (Colley, Connor Gorber, & Tremblay, 2010). All participants with at least one valid day of activity (and affect) assessment were included in the analyses (see Appendix B for sample composition).<sup>4</sup> Data were downloaded and aggregated into 15-s epochs by using ActiLife 5. After scanning for spurious data, epochs were aggregated to MVPA min per day using KineSoft version 3.3.67 (KineSoft, Saskatchewan, Canada; <http://www.kinesoft.org>). We used well-established MVPA cut points ( $\geq 2020$  counts per min, cpm; Troiano et al., 2008)<sup>5</sup>. Detailed information on valid days, wear time, and MVPA min are given in Table 1.

**Morning and evening depressed affect.** Depressed affect was assessed in morning and evening diaries with three items (sad, discouraged, hopeless) from the POMS (Profile of Mood States; Cranford et al., 2006; McNair, Lorr, & Droppleman, 1992). These items were particularly designed for use in intensive longitudinal studies and are a reliable measure of within-person change (Cranford et al., 2006); they were previously pilot tested for adolescents (Gawrilow et al., 2013) as recommended by Shrout and Lane (2012). In the morning and evening, participants rated their *current* depressed affect (“How do you feel *right now*?”) using a 5-point scale ranging from 0 (*not at all*) to 4 (*extremely*). For each individual we computed a mean score for each morning and evening (Table 1). The within-person reliability (Shrout & Lane, 2012) for morning and evening depressed affect was good ( $\alpha = .80$  and  $\alpha = .79$ , respectively).

**Retrospective report on depressed affect.** To describe the sample, we assessed depressed affect retrospectively with the German 20-item Center for Epidemiologic Studies –

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<sup>4</sup> Participants with only one day of physical activity assessment do not contribute to estimating the within-person effect but to estimating the other effects in the model.

<sup>5</sup> Cut-points for all physical activity intensity levels published by Troiano and colleagues (2008): sedentary ( $< 100$  cpm), light ( $\geq 100 < 2020$  cpm), moderate ( $\geq 2020 < 6000$  cpm), and vigorous activity ( $\geq 6000$  cpm).

Depression Scale (CES-D; Hautzinger, Bailer, Hofmeister, & Keller, 2012). Items were rated with regard to the past week using a 4-point scale ranging from 0 (*rarely or none of the time*) to 3 (*most or all of the time*). The CES-D composite score can vary between 0 and 60, with values  $\geq 23$  indicating elevated depressed affect (Hautzinger et al., 2012). The internal consistency of the scale was good (Cronbach's  $\alpha = .83$ ).

**Socio-demographic characteristics.** We asked participants to indicate their age, gender, grade, country of origin, and intended highest education level as well as their parents' country of origin and education level (Table 1).

### **Analyses**

All analyses were conducted with IBM SPSS Statistics 21. Concerning MVPA only Day 1 to 7 (i.e., days with full-day physical activity assessment) were selected for analyses; participants' morning (Day 2 to 8) and evening depressed affect (Day 1-7) were also incorporated. We analyzed the within-person link between MVPA and next-morning depressed affect (time-lagged prediction) and same-evening depressed affect (same-day link) using mixed-effects models (Bolger & Laurenceau, 2013). Gender and weekend were included as moderators in the model. By centering all time varying variables within-person we ruled out that the current findings can be explained by between-person differences in these variables. For all analyses, a probability level of  $p < .05$  indicated significance. For more details on the analyses of the time-lagged prediction and the same-day link including an exemplary equation see supporting online information (Appendix A).

## **Results**

### **Descriptives and Sample Characteristics**

Eighty-seven out of 124 participants wore the accelerometer for at least 10 hours on at least one day, with an average of six accelerometer days available per participant. Of these, 72 adolescents (37% young women;  $M$  age = 17.36 years; age range: 12-26 years; mid-90%

age range: 13-22 years) also provided daily ratings of depressed affect at least once and completed nearly all morning and evening diaries (6.75 and 6.13, respectively, out of 7.00 possible entries). In total, we analyzed 362 valid days for the time-lagged prediction and 346 valid days for the same-day link, where valid daily assessments of both physical activity and depressed affect were available. For more details on sample size and sample composition, and dropout analysis see Appendices B and C.

Participants provided valid data for MVPA on 5.38 days (out of 7.00 possible days) with an average daily wear time of approximately 16.00 hours, with young women providing more valid days and longer wear time on weekdays and weekend days than young men. On weekdays, young women were engaged in MVPA for approximately 1.00 hour per day; young men were active for approximately 1.00 hour and 20 min per day. Similar to weekdays, on weekend days, the average amount of MVPA varied equally between young women (0.75 hours per day) and men (1.00 hours per day). On weekdays and weekend days, young women and men did not differ in their person mean of next-morning and same-evening depressed affect (see Table 1). On weekdays and weekend days, young women and men did not significantly differ in their day-to-day variability of next-morning and same-evening depressed affect.

Over 90% of participants were aiming for a university-entrance exam. Most of them (87%) were born in Germany and 41% had at least one parent with another country of origin. Two thirds of participants had at least one parent who had passed the university-entrance exam and 41% of parents obtained a university degree. Further details on descriptives including a comparison of sample characteristics between young women and men (a probability level of  $p < .05$  indicates significance) are displayed in Table 1 (see Appendix D for between-person correlations of descriptives and sample characteristics).

### **Does Moderate-to-Vigorous Physical Activity Predict Less Next-Morning Depressed Affect?**

With dummy-coded gender (0 = women, 1 = men) and day of the week (0 = weekday, 1 = weekend day), the intercept indicates the average next-morning depressed affect for young women on weekdays ( $\gamma_0 = 0.46, p < .001$ ); young men did not differ from young women in average next-morning depressed affect ( $\gamma_1 = 0.02, ns$ ). Young women did not differ in next-morning depressed affect between weekdays and weekend days ( $\gamma_2 = -0.07, ns$ ), and young men's weekdays-weekend days difference in depressed affect was not significantly weaker or stronger than women's difference ( $\gamma_3 = -0.07, ns$ ). Next, we found the following four activity-affect links: For young women on weekdays, a 60-min increase in MVPA over the person mean predicted 50% lower next-morning depressed affect ( $\gamma_4 = -0.24, p = .03$ ). Young men's activity-affect link on weekdays differed from young women's ( $\gamma_5 = 0.26, p = .05$ ); simple slope analysis showed that on weekdays in men, a 60-min increase in MVPA over the person mean did not predict lower next-morning depressed affect ( $-0.24 + 0.26 = 0.02$ ). Young women differed in their activity-affect link between weekdays and weekend days ( $\gamma_6 = 0.37, p = .03$ ); simple slope analysis showed that for young women on weekend days higher MVPA did not predict lower next-morning depressed affect ( $-0.24 + 0.37 = 0.13$ ). Young men's difference in the activity-affect link between weekdays and weekend days did not differ from young women's difference ( $\gamma_7 = -0.26, ns$ ); simple slope analysis showed that for young men on weekend days higher MVPA did not predict lower next morning depressed affect ( $-0.24 + 0.26 + 0.37 - 0.26 = 0.13$ ). In sum, there was a lagged-time prediction of next-morning depressed affect by MVPA on weekdays for young women but not young men (see Figure 1; see Appendix E for effects in within-person correlations). We tested the effects of potential confounding variables (studyday, wear time) on next-morning depressed affect. Because studyday and wear time did not change the pattern of results in

sensitivity analyses, we report the more parsimonious model.

[Table 2 here]

### **Does Moderate-to-Vigorous Physical Activity Predict Less Same-Evening Depressed Affect?**

There was no same-day link between MVPA and evening depressed affect on weekdays or weekend days neither in young women nor men (see Figure 1; see Appendix E for effects in within-person correlation metric). For details on findings of the same-day link see Appendix F. Studyday and wear time did not change the pattern of results in sensitivity analyses; thus, we report the more parsimonious model.

[Figure 1 here]

### **Discussion**

In the present intensive longitudinal study, we examined the within-person links between accelerometer-based daily MVPA and next-morning and same-evening depressed affect in young women and men. More-than-usual MVPA predicted significantly less next-morning depressed affect on weekdays in young women but not in men. In young women in our sample on weekdays, a 60-min increase in MVPA over the person mean significantly predicted 50% lower next-morning depressed affect. In young men on weekdays, more-than-usual MVPA did not predict less next-morning depressed affect. On weekend days, neither young women nor men showed an activity-affect link. More-than-usual MVPA did not predict less same-evening depressed affect, regardless of gender or weekday vs. weekend day. To our knowledge, there are no comparable studies that have investigated this time-lagged prediction in this age group.

There are several possible explanations for the weekday vs. weekend day effect found (i.e., time-lagged prediction on weekdays but not weekend days). First, one reason could be the higher amount of MVPA on weekdays compared to weekend days in our study. This

higher amount on weekdays is possibly due to more opportunities for structured physical activity (e.g., in sports clubs and physical education classes) on weekdays than on the weekend (Comte et al., 2013; Ortega et al., 2013)<sup>6</sup>. Second, because we included five weekdays but only two weekend days for analyses in this study, the weekday effect of activity on depressed affect was estimated with higher precision than the weekend effect, and studies with longer duration are needed to deliver a more definitive answer regarding this weekday–weekend discrepancy.

Explanations for the gender effect found (i.e., time-lagged prediction for young women but not men) could be due to (a) differences in assessment of depressed affect and physical activity, (b) developmental differences in self-esteem, physical self-concept, and motivation, and (c) dose-response differences. First, regarding depressed affect, we found no significant differences in mean depressed affect or variability of depressed affect between young women and men that could explain this finding. Instead, differences in activity may be a more likely explanation: As we measured activity with accelerometers but not with additional questionnaires, we could not study the influence of activity type (individual vs. team sports; cooperative vs. competitive) or environment (outdoor vs. indoor). These context factors, however, are associated with activity enjoyment (Burton, Khan, & Brown, 2012) and might influence depressed affect. For example, we could not investigate whether young men were predominantly engaged in competitive activities (“win-or-lose”, “fight-or-flight”) whereas young women were mostly engaged in cooperative activities (supportive, “tend-and-befriend”; Asztalos et al., 2012) with potentially different effects on depressed affect. Through cooperative activities young women could attempt to satisfy their need for affiliation (due to pubertal changes in hormone regulation; Patton & Viner, 2007), leading to

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<sup>6</sup> Higher activity on weekdays compared to the weekend days was not an artifact of higher accelerometer wear time on weekdays vs. weekend days, as we found uniformly high wear time of 16 hours per day.

reduced depressed affect. As shown by Lewis and colleagues (2015), young women who lack this emotional connectedness tend to report more depressed affect than young women who have more satisfactory relationships. Second, during puberty, physical changes vary considerably by gender (tripled vs. double total body fat mass in young women vs. men; Siervogel et al., 2003) and may contribute to gender differences in the activity-depressed affect link. Thus, particularly in young women, differences between internalized ideal body shape and real body shape may lead to increased body dissatisfaction (e.g., Tiggemann, 2011). Improving self-esteem and physical self-concept through more activity (Babic et al., 2014; Dishman et al., 2006) may lead to increased body satisfaction particularly in young women (Greenleaf, Boyer, & Petrie, 2009) and, thus, to lower depressed affect. Taken together, more negative psychological reactions to bodily changes of young women compared to men during adolescence may explain the positive impact of activity on depressed affect in young women (Patton & Viner, 2007). Third, motives for activity (e.g., appearance, competition, or companionship; Ingledew, Markland, & Strömmer, 2014) or motivational regulation (e.g., external or internal motivation; Deci & Ryan, 2002) could also have differed between young women and men and might have contributed to the gender effect found. Fourth, it could be possible that young women require lower doses of activity than men to experience benefits for affect; thus, these thresholds should be examined in future studies (Dunn, Trivedi, & O'Neal, 2001).

Explanations for the missing same-day link could be due to (a) temporal dynamics between physical activity and depressed affect and (b) the impact of sleep duration and quality on the activity-depressed affect link. First, because depressed affect reported the same evening was comparable to reports the next morning in level and variability, again, depressed affect is an unlikely explanation of this finding. Instead, this finding raises the interesting question about temporal dynamics in the activity-depressed affect link. On the same day, do

the immediate effects of MVPA on depressed affect occur within a short time window (e.g., within the next three hours after activity; see Wichers et al., 2012) and vanish across the day due to other emotional experiences (Wrzus, Müller, Wagner, Lindenberger, & Riediger, 2013) or increasing fatigue (Kim, Kikuchi, & Yamamoto, 2013)? Second, the effect of activity on next-morning depressed affect could emerge due to better sleep after an active day. Few intensive longitudinal studies have investigated the association between activity and sleep during adolescence. A cross-sectional study showed (Brand et al., 2014) that more activity throughout the day was associated with better sleep during the following night in this age group. Prior research on the effect of sleep on negative affect showed that adolescents who sleep less the previous night reported more negative affect the next day (Wrzus, Wagner, & Riediger, 2014). Moreover, poorer sleep quality during the night has been shown to predict more negative affect the next day—and this association was strongest in young women (van Zundert et al., 2015).

### **Limitations and Strengths**

The study has several limitations. First, since we measured depressed affect only twice per day, we cannot draw conclusions about causality. However, the significant time-lagged prediction shown in this study is a valuable starting point for investigating the cause-and-effect relationships linking physical activity and depressed affect within person. Future intensive longitudinal designs with higher sampling frequency may resolve this question. Second, we cannot answer the question which mediating mechanisms might have encouraged the decrease of next-morning depressed affect on weekdays in young women. Including promising process variables such as sleep quality would be an important contribution in future studies. In this regard, studying the impact of activity on other depressive symptoms (e.g., lack of energy or fatigue) could also be worthwhile, since activity has been shown to improve other depressive symptoms in young women than men (McKercher et al., 2013).



Third, at the time of the study a considerable subgroup of participants did not have reliable access to a home computer or smartphone and chose, therefore, to fill out paper-and-pencil evening diaries instead of online diaries to assess depressed affect, thus time stamps were only available for online evening diaries. However, participants showed high study commitment and wore their accelerometer assiduously. When attaching and removing the accelerometer, we assume participants were reminded to complete their morning and evening diaries. Thus, we assume that compliance didn't differ between the two modalities. Fourth, the current study design included only one weekend. To gain more power while studying the weekday vs. weekend effect on the within-person link, activity and depressed affect should be measured on more than one weekend.

Despite these limitations, the present study makes several important contributions. First, this is the first study that investigates the within-person link between physical activity and next-morning and same-evening depressed affect in young women and men. By capturing the within-person variability in adolescents' activity and depressed affect, this study contributes to the limited body of literature and improves our understanding of the day-to-day association between activity and depressed affect in this age group. Second, we measured depressed affect using three items previously proved to be reliable and valid to assess within-person change (Cranford et al., 2006); we also showed adequate reliability of these items for measuring within-person change within this sample of adolescents. Third, we measured young women's and men's activity by using accelerometers which are considered the gold standard in activity research because self-report questionnaires tend to overestimate the amount of activity (e.g., Corder, Ekelund, Steele, Wareham, & Brage, 2008). As recommended by Cain, Sallis, Conway, Van Dyck, and Calhoun (2013), we monitored activity for seven consecutive days including weekend days to obtain reliable estimates for young women's and men's habitual activity. Fourth, by measuring unstructured, self-initiated

activity in everyday life, that is, activity as it naturally occurs, we enhanced the ecological validity of our results. Our findings, taken together, are an important step towards understanding the temporal paths between activity and depressed affect in adolescents' everyday life.

### **Implications and Directions for Future Research**

Further studies are needed to better understand the physical activity-depressed affect link in young women and men. To address the dynamics between activity and depressed affect, future research could measure depressed affect multiple times per day. Additionally, future research should study neurobiological mechanisms (e.g., neurotransmitter and endorphins) as possible mediators (for a review, see Dishman, Heath, & Lee, 2013). Intervention studies that enhance adolescents' activity through self-regulation strategies (Hynynen et al., 2014; Stadler, Oettingen, & Gollwitzer, 2009) seem to have a great potential to decrease depressed affect on a day-to-day basis in this age group.

### **Conclusion**

This study provides evidence that it is feasible to use an intensive longitudinal design for school-based research on physical activity and depressed affect in young women and men. Given that adolescents are at high risk for developing an inactive lifestyle, this study encourages the development of individually-tailored activity interventions using an intensive longitudinal approach that could help adolescents enhance their daily amount of unstructured, self-initiated activity and reduce depressed affect. This approach may be particularly suitable for young women who have the highest risk for an inactive lifestyle and elevated depressed affect.

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Table 1

*Descriptives and Sample Characteristics (N = 72)*

Variables	All	Young women	Young men
Activity, number of valid days <sup>a</sup> , <i>M (SD)</i>	5.38 (2.00)	6.04 (1.56)*	5.00 (2.16)*
Mean accelerometer wear time <sup>b</sup> , hours ( <i>SD</i> )			
Weekday	15.93 (2.35)	16.76 (2.13)*	15.49 (2.37)*
Weekend day	15.40 (2.25)	15.93 (2.00)	15.01 (2.38)
Mean activity <sup>b</sup> , hours ( <i>SD</i> )			
Weekday	1.28 (0.48)	1.05 (0.32)*	1.41 (0.52)*
Weekend day	0.92 (0.75)	0.73 (0.61)	1.06 (0.83)
Depressed affect, number of diaries <sup>c</sup>			
Next-morning, <i>M (SD)</i>	6.75 (0.83)	6.88 (0.43)	6.67 (1.00)
Same-evening, <i>M (SD)</i>	6.13 (1.59)	6.88 (0.33)*	5.71 (1.87)*
Depressed affect, daily rated <sup>b</sup> , <i>M (SD)</i>			
Next-morning			
Weekday	0.49 (0.65)	0.45 (0.58)	0.52 (0.71)
Weekend day	0.39 (0.54)	0.43 (0.55)	0.38 (0.55)
Same-evening			
Weekday	0.47 (0.55)	0.47 (0.56)	0.47 (0.55)
Weekend day	0.39 (0.57)	0.45 (0.66)	0.36 (0.51)
No intraindividual variation of depressed affect <sup>d</sup> , %			
Next-morning			
Weekday		20.00	32.43
Weekend day		47.06	47.37
Same-evening			
Weekday		24.00	35.29
Weekend day		38.89	57.89
Depressed affect, retrospectively rated <sup>e</sup> , <i>M (SD)</i>	15.24 (7.85)	15.96 (8.47)	14.88 (7.62)
Depressed <sup>f</sup> , %	11.80	12.00	11.90
Mean age, years ( <i>SD</i> )	17.36 (3.38)	16.27 (2.59)*	18.01 (3.67)*
Gender, %		36.62	63.38
Grade			
7-9, %	30.99	36.00	28.89
10-12, %	69.01	64.00	71.11
Higher education entrance qualification, intended %	93.06	88.46	97.78
Other country of origin than Germany, %	12.86	12.00	13.33
Parents with another country of origin than Germany <sup>g</sup> , %	41.43	32.00	46.66
Parents with a higher entrance qualification <sup>g</sup> , %	60.29	62.50	59.09
Parents with a university degree <sup>g</sup> , %	40.91	37.50	42.86

*Note.* Activity = moderate-to-vigorous physical activity measured by accelerometers.

<sup>a</sup>Valid day: accelerometer wear time  $\geq$  10 hours per day. <sup>b</sup>Person mean of accelerometer wear time, activity, and depressed affect (measured through POMS-15, scale range: 0-4).

<sup>c</sup>Maximum number of diaries amounts to seven morning and evening diaries each. <sup>d</sup>Based on intraindividual standard deviations (ISDs); percentage of adolescents showing no intraindividual variation of depressed affect (e.g., only ratings of being *moderately depressed*) across all studydays. <sup>e</sup>Depressed affect was retrospectively reported for the study period on Day 8 (measured through CES-D, scale range: 0-3). <sup>f</sup>Based on CES-D cut-off  $\geq 23$ . <sup>g</sup>Information refers to at least one parent.

\* Statistically significant gender differences ( $p < .05$ ).

Table 2

*Gender, Weekday vs. Weekend Day, and Physical Activity as Predictors of Next-Morning and Same-Evening Depressed Affect, Fixed and Random Effects*

Fixed effects of predictors	Depressed affect					
	Next morning: Time-lagged prediction ( <i>N</i> = 67)			Same evening: Same-day link ( <i>N</i> = 68)		
	Estimate		<i>SE</i>	Estimate		<i>SE</i>
Intercept $\gamma_0$	0.46	*	0.11	0.44	*	0.19
Men $\gamma_1$	0.02		0.15	-0.01		0.12
Weekend $\gamma_2$	-0.07		0.10	-0.04		0.11
Men x weekend $\gamma_3$	-0.07		0.13	0.05		0.16
Activity $\gamma_4$	-0.24	*	0.11	-0.17		0.14
Activity x men $\gamma_5$	0.26	*	0.13	0.29		0.17
Activity x weekend $\gamma_6$	0.37	*	0.17	0.19		0.19
Activity x men x weekend $\gamma_7$	-0.26		0.23	-0.34		0.26
Random effects (variances)						
Level 2 (between-person)						
Intercept	0.25	*	0.06	0.12	*	0.04
Level 1 (within-person)						
Residual	0.28	*	0.03	0.35	*	0.03
AR1 $\rho$	0.19	*	0.08	0.14		0.08

*Note.*  $\gamma_0$  = average depressed affect for young women on weekdays (intercept);  $\gamma_1$  = difference in average depressed affect between young men and women on weekdays;  $\gamma_2$  = weekdays-weekend days difference in depressed affect for young women;  $\gamma_3$  = Do young men differ in their weekdays-weekend days difference in depressed affect from young women?  $\gamma_4$  = activity-affect link in young women on weekdays;  $\gamma_5$  = Do young men differ in activity-affect link on weekdays from young women?  $\gamma_6$  = Do young women differ in the activity-affect link between weekdays and weekend days?  $\gamma_7$  = Do young men differ in activity-affect link between weekdays and weekend from young women? Men = young men (0 = young women, 1 = young men); Weekend = weekend day (0 = weekday, 1 = weekend day); Activity = moderate-to-vigorous physical activity measured by accelerometers, centered at the person mean, in 60 min units; Estimate = unstandardized regression coefficients; *SE* = standard error.

\*  $p < .05$ .