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Relationships between incidental physical activity, exercise, and sports with subsequent mood in adolescents

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Physical activity is beneficial for human physical health and well-being. Accordingly, the association between physical activity and mood in everyday life has been a subject of several Ambulatory Assessment studies. This mechanism has been studied in children, adults, and the elderly, but neglected in adolescents. It is critical to examine this mechanism in adolescents because adolescence plays a key role in human development and adolescents' physical activity behavior translates into their behavior in adulthood. We investigated adolescents' mood in relation to distinct physical activities: incidental activity such as climbing stairs; exercise activity, such as skating; and sports, such as playing soccer. We equipped 134 adolescents aged 12-17 years with accelerometers and GPS-triggered electronic diaries to use in their everyday life. Adolescents reported on mood repeatedly in real time across 7 days, and these data were analyzed using multilevel-modeling. After incidental activity, adolescents felt better and more energized. After exercise, adolescents felt better but less calm. After sports, adolescents felt less energized. Analyses of the time course of the effects confirmed our findings. Physical activity influences mood in adolescents' everyday life, but has distinct effects depending on the kind of physical activity. Our results suggest incidental and exercise activities entail higher post-bout valence compared to sports in competitive settings. These findings may serve as an important empirical basis for the targeted application of distinct physical activities to foster well-being in adolescence.

KEYWORDS
accelerometry, adolescents, ambulatory assessment, ecological momentary assessment, exercise, mood, physical activity

1 | INTRODUCTION

Physical activity can improve well-being[1] and fosters physical health.[2] Nevertheless, 81% of adolescents globally (aged 11-17 years) do not reach the level of physical activity necessary to sustain health that is recommended by the World Health Organization.[1] Behavioral theories suggest positive feeling states (ie positive affective responses) after physical activity to drive individuals to repeat those activities.[3] As a long-term consequence, these positive feelings may lead to an active life style and thus improve well-being, promote health, and enhance quality of life.[1,3,4] Given that adolescents' physical activity behavior has been shown to translate into adulthood, the investigation of the association between physical activity and mood in adolescents constitutes a major priority. According to the broad definition of Williams et al,[6] the umbrella term "affect" describes an evaluative neurobiological state that includes core affect, emotion, and mood. Affect coordinates patterns of physiological and involuntary behavior changes (eg heart rate and facial expression) and subjective experiential feelings (eg pleasure, anger). Moods (eg feeling irritable, anxious, happy, or contented) share components with the construct of emotions but they are more diffuse, do not focus on a specific event or stimulus, and are less time-limited than emotions. For instance, anger may be an emotion that is related to a specific event and may pass quickly, but being in an irritable mood may not be related to an specific event and may last longer with no specific timepoint of beginning or ending[6] (for further discussion on the different affective constructs please refer to Williams et al[6]). Accordingly, post-bout mood has frequently been tackled in adults using daily life research (for further details please see the current review by Liao et al[7]).

The umbrella term "physical activity" describes different activities such as sports or exercise. Physical activities that occur in daily life are mostly done for an intended purpose (eg in the context of gardening, walking dogs, workplace) and are processed habitually, automatically, spontaneously, or incidentally (eg cleaning, running to the train).[8] We labeled these activities here as "incidental activities" (IA). The reason why a person is physically active depends on his or her motives (eg fitness, strengthening, health, enjoyment, competing). Exercise, as a sub-category of physical activity, can be defined as planned, structured, and repetitive movement with the main intention to improve physical fitness. Moreover, in contrast to exercise, participation in sports goes along with high physical exertion and with intentions of competition that has official rules and institutional characteristics. Additionally, some definitions imply sports are executed for internal or external rewards and require complex physical skills.[9]

To garner insights into how physical activity (ie incidental activity, exercise and sports) relates to mood in adolescents, intensive longitudinal data are crucial, since within-subject processes (derived from intensive longitudinal data) are conceptually,[11] methodologically,[11] and empirically[10] distinct from between-subject relationships (derived from cross-sectional data). One striking example that emphasizes the importance of this distinction is that people with generally higher physical activity levels showed habitually lower blood pressure (ie a negative between-subject correlation), but current higher physical activity coincided with higher blood pressure in everyday life, for example, when climbing stairs (ie a positive within-subject correlation).[12] This example shows that between-subject and within-subject findings are distinct from each other. Using a within-subject perspective to investigate mood is highly recommended since mood is known to fluctuate enormously across time within both healthy and clinical populations.[13]

Ambulatory Assessment (AA) is a state-of-the-art methodology that allows for the gathering of intensive longitudinal data in everyday life.[14] In particular, physical activity is measured objectively via accelerometers and mood is assessed repeatedly within persons in real time via electronic smartphone diaries.[14] Consequently, AA has many advantages, such as a high ecological validity compared to laboratory studies ("white coat effect"[15]), a high accuracy of physical activity measurement compared to retrospective self-reports,[16] and no or minimized recall biases compared to self-report methods.[16]

In the past decade, a few AA studies have provided evidence that physical activity and mood dimensions are interrelated within adults' everyday lives. For example, studies have investigated whether mood states in everyday life are related to preceding and subsequent physical activity levels[17] or whether there are differential effects for different physical activity types and different mood dimensions.[18] This issue has been studied mainly in adults,[17,18] and there are few investigations in children[19] and the elderly.[8] Thus, the effect of healthy adolescents' natural physical activity behavior on mood dimensions has so far been neglected. There is only one study investigating physical activity and mood in adolescents.[20] This lack of research is surprising given the above-mentioned importance of adolescence in physical activity behavior later on in adulthood.[5]

However, there is laboratory research on the relationship between physical activity and mood as well as studies on physical activity behavior in adolescents. In the laboratory, adolescents' physical activity was shown to be positively associated with mood dimensions, that is, energetic arousal and valence and negatively associated with calmness.[21] Accordingly, studies found distinct mood responses to sports vs exercises.[21,22] However, it has yet to be studied whether these findings translate into adolescents' everyday life (ecological validity) and whether there are distinct contextual effects (eg based on the type and setting of physical activity).

Despite the converging evidence from AA studies on the real-life association between physical activity and mood dimensions in children,[19] adults,[17,18] and the elderly,[8] the investigation of this psychological mechanism in adolescents has so far been neglected. Thus, we conducted an AA study applying accelerometry in combination with e-diaries on smartphones in 134 individuals aged 12-17 years to investigate specific influences of physical activity on mood in adolescent's everyday life. Based on the empirical findings reviewed above, our main hypothesis was that incidental activity (IA; such as climbing stairs) would increase valence (hypothesis 1) and energetic arousal (hypothesis 2), but also decrease calmness (hypothesis 3) within adolescents. Moreover, we conducted explorative analyses aiming to investigate whether sports (such as soccer and tennis) vs no activity (ie not moving at all) and exercise activities (such as jogging and skating) vs no activity (ie not moving at all) would show distinct effects on adolescent's subsequent mood. Additionally, we explored the time course of effects.

2 | MATERIALS AND METHODS

2.1 | Participants

Adolescents aged 12-17 years were recruited from December 2014 to January 2017 from the URGENCY study (Impact of Urbanicity on Genetics, Cerebral Functioning and Structure and Condition in Young People) in the psychiatric-epidemiological center at the Central Institute of Mental Health in Mannheim, Germany. Adolescents with acute diseases, mental disorders, cardiovascular disorders, or chronic endocrine or immunological diseases were excluded from the study in advance. For detailed information on the recruitment and methods, see Ref.18 Participants received monetary compensation.

We excluded 12 out of 134 datasets due to a large accelerometer non-wear time (ie <10 hours per day);[23] 6 out of 134 datasets were excluded because of missing accelerometer data, that is, lost devices, incomplete recordings (eg defect devices or the accelerometer ran out of battery). Furthermore, 3 datasets were excluded due to low e-diary compliance (<30%).[24] This process led to a final sample size of n = 113 participants (52% male, 48% female). The sample's mean age was 15.02 years (SD = 1.70), and the average BMI was 20.14 kg/m^2 (SD = 2.66). There were no meaningful differences between participants/datasets that were removed and those that were retained for analysis concerning gender ($\chi^2(1) = 0.620$, $P = .431$), age (mean included (n = 113) = 15.041, SD = 1.839; mean excluded (n = 21) = 14.407; SD = 1.242; $t\,(39) = 1.973$; $P = .056$), BMI (mean included (n = 113) = 20.143, SD = 2.657; mean excluded (n = 21) = 19.708; SD = 2.883; $t\,(132) = 0.680$; $P = .498$), and socioeconomic status (mean included (n = 110) = 16.646, SD = 2.740; mean excluded (n = 20) = 16.380; SD = 1.877; $t\,(36) = 0.537$; $P = .595$); for more details see (Appendix 1).

2.2 | Ambulatory assessment procedure

Prior to the study, each participant received thorough instructions on how to handle the study devices. Thereafter, the participant's physical activity was monitored objectively via an accelerometer (movisens Move-II or Move-III, movisens GmbH) in their everyday lives over seven consecutive days. The triaxial acceleration sensors measured IA with a sampling frequency of 64 Hz and a range of ±8 g on the right-hand side of the participants' hips. Participants were instructed to wear the accelerometers during waking hours but not while sleeping. Additionally, participants reported their mood via repeated ratings in e-diaries (Motorola Moto G) in real-time.

For assessing mood, Wilhelm and Schoebi[25] recommend either a two-dimensional construct that is beneficial for a between-subjective perspective (level two) or a three-dimensional model that is beneficial for a within-subject perspective (level one).[25] Wilhelm and Schoebi[25] revealed the following psychometric properties for their three-dimensional scale on the within-person level, that is, reliability coefficients for valence and calmness: 0.70; and for energetic arousal: 0.77. Therefore, their scales are used in many studies that investigate mood in the everyday life of adults. However, since youths' developmental stages reveal special social (eg rules, communication, moral concept, and interaction with others) and cognitive skills (eg verbal, theory of mind, and self-reflection) that have to be taken into account in the questionnaire structure, we used the first established and validated instrument by Leonhardt et al[26] for assessing mood in adolescents in our study. This instrument is based on the Multidimensional Mood Questionnaire[25] and uses a three-dimensional construct for assessing within-person effects, as recommended by Wilhelm and Schoebi.[25] Leonhardt et al[26] validated the mood dimensions valence (items: "content, cheerful, delighted, good, fantastic, unhappy, mad, afraid, miserable"); energetic arousal (items: "concentrated, active, interested, exhausted, tired, faint"); and calmness (items: "rested, pleasant, anxious, stressed, on edge") in youth. These items were presented on seven-point Likert scales with reversed polarity and in a mixed order. Leonhardt et al[26] showed that this three-dimensional approach is best suited to assess mood in youth on both the between- and within-subject levels.[26] We calculated psychometric properties for the final (three-dimensional) model using McDonalds Omega[27] to reveal within- and between-subject reliability (see Appendix 2). The movisensXS smartphone app (version

0.6.3658, movisens GmbH) triggered e-diary prompts between 16:00 and 20:30 on weekdays (to not disturb pupils) and 9:00 and 20:00 on weekend days and queried for mood levels. Within our sampling schema, participants were triggered based on location; that is, whenever participants exceeded a distance of 0.5 km, the location-based trigger prompted participants. Methodologically, these triggered e-diaries use an algorithm for real-time detection of situations of interest (ie when participants are physically active) to prompt e-diaries exactly at those moments. Thus, this state-of-the-art technology allows for the assessment of a maximum within-subject variance of the parameter of interest in comparison to traditional sampling schemas (triggering, eg at random time points).[14] Additionally, time-based triggers prompted participants at 16:30 and 20:20 (weekdays) or 9:30 and 19:50 (weekend days), resulting in 4-7 prompts/d on weekdays and 8-17 prompts/d on weekends. One prompt followed the other at 37 minutes (minimum trigger interval) at the earliest but not later than 77 minutes (time-out trigger). Participants had the choice to answer the alarm immediately or with a delay of 5, 10, or 15 minutes. Such mixed sampling strategies, for example, combining location-based and time-based triggers, have been shown to maximize the within-subject variance in the parameters of interest.[14] After their week of study participation, participants were asked to report the type, time point, and duration of their exercise activities by means of a procedure similar to the Day Reconstruction Method (DRM), which is described in detail elsewhere.[17] Participants were shown a digital map (movisens GmbH) displaying their whereabouts within the study week and were asked to label their sports and exercise locations to report the type of exercise, exercise time points, and durations.

2.3 | Data processing

2.3.1 | Incidental activity

To parameterize IA for our main analyses, we first used the software DataAnalyzer (version 1.6.12129, Movisens GmbH) to compute Movement Acceleration Intensity (MAI, [millig/min]). In particular, raw data (64 Hz) captured from the three accelerometer axes were aggregated to a minute resolution using vector addition. A high-pass filter (0.25 Hz) was used to eliminate gravitational components and artifacts were excluded using a low-pass filter (11 Hz) (for details, see Ref. 28). Second, to avoid the confounding effects of exercise activity with IA on mood (because both exercise activity and IA were entered into our multilevel model as predictors of interest; see below), we set the incidental activity variable to zero at all time points when participants had been exercising. Third, we aggregated MAI within a 15-minute time frame prior to each answered e-diary assessment because this time frame has been shown to be optimally suited to investigate associations of physical activity and mood.[29] Fourth, to investigate the time course of the potential effects of IA on mood, we aggregated the MAI within four additional time frames prior to the answered e-diary assessments. Specifically, we aggregated MAI in time frames ranging from 16-30, 31-45, 46-60, and up to 61-75 minutes. To differentiate between-person effects from within-person effects, we centered all incidental activity variables on the persons' mean within the study week.

2.3.2 | Exercise

To parameterize exercise activity for our explorative analyses, we used the data derived from the participants' reports on their exercise activity within the study week. In particular, we used the information on the time frame when participants had been exercising to compute a dichotomous variable indicating whether participants engaged in an exercise activity prior to each e-diary prompt [1] or not [0]. To analyze the time course of the potential effects of exercise activity on mood, we created five variables indicating whether exercise activity occurred within the 30, 60, 90, 120, or 240 minutes prior to each e-diary prompt. Thereafter, we used the participants' reports on exercise types to categorize the exercise activities as sports vs exercise. We defined sports as activities executed in the context of rules and with an international regulatory agency (ie basketball, tennis[30]) and exercise as activity with an increased energy expenditure based on personal interests and needs or with the intent of an improvement of fitness, physical performance, or health (ie skating, jogging[30]). We created categorical variables, that is, 0 represented "incidental activity," 1 represented "sports," and 2 represented "exercise."

2.3.3 | Multilevel analyses

To identify within-subject relationships between distinct exercise types (sports vs exercise), IA and the three mood dimensions valence, energetic arousal, and calmness, we conducted multilevel analyses nesting repeated mood ratings (ie level 1) within participants (ie level 2). We used the statistical software SPSS (version 24, IBM) and set the α-level to 0.05. We calculated intraclass correlation coefficients by estimating three null models for each mood dimension to identify the amount of within-subject variance in our data. We entered the predictors of interest, that is, exercise (parameterized as a categorical variable, ie no activity (ie not moving at all) [0], sports [1], and exercise [2]) and IA as a dimensional variable (parameterized as the mean MAI within the 15 minutes prior to each e-diary assessment). To control for conceivable effects of confounding parameters that have been shown to impact either physical activity or mood,[8,13,31] we entered age,[31] gender,[31] and BMI[8] (in level 2, respectively), as well as time and time-squared[13] (in level 1, respectively) as covariates of no interest into our three models (for model fit indices, refer to Appendix 3).The predictors time and time-squared were transformed, that is, we subtracted a value of 9 because adolescents received their e-diary prompts at the earliest time of 9:00. In particular, if an e-diary prompt was triggered at 14:26, the values 5.43 (time) and 29.49 (time-squared) were entered in our model. We added random effects for every level 1 predictor but kept only significant random effects for our three final models (eg equation 1). We modeled the data with a variance components matrix and estimated models with full maximum likelihood.[32] For evaluating the quality of the maximum likelihood estimators of the multilevel models, we performed bootstrapping[33] and reported the resulting estimates in the Appendix 4. Bootstrap estimates were generated using SAS Software (Version 9.4).

Equation 1: Predicting valence (main model 1)

$$Y(\text{valence})_{ij} = \beta_{00} + \beta_{01} \times \text{age}_j + \beta_{02} \times \text{gender}_j + \beta_{03} \times \text{BMI}_j + \beta_{10} \times \text{non exercise activity}_{ij} + \beta_{20}^{(k)} \times \text{exercise}_{ij}^{(k)} + \beta_{30} \times \text{time of day}_{ij} + \beta_{40} \times \text{time of day}_{ij}^2 + u_{0j} + u_{1j} \times \text{non exercise activity}_{ij} + u_{3j} \times \text{time of day}_{ij} + r_{ij}$$

We estimated within-subject effects on level 1. In particular, subscript j refers to participant j, and the subscript i refers to the mood assessment. Accordingly, Y_{ij} represents the estimated level of each mood dimension (ie valence, energetic arousal, and calmness, respectively) at the given time i in participant j. The beta coefficients (β) at level 1 represent the intercept as well as the effects of the level 1 predictors IA, exercise activity (where exercise$^{(k)}$ is a dummy variable coding for the three categories of exercise activity), time of the day, and time of the day squared, whereas r_{ij} represents the residuals. Moreover, we estimated between-subject effects on level 2. As stated above, we kept only the random effects showing significance in our final models, represented by u_{ij}. Significant random effects indicated that there is variation in the participants' individual slope estimates around the respective overall mean slope estimates.

Studies investigating physical activity and mood often use short periods for exploring short-term-effects of the predictor.[8] However, there is evidence that the effect is of long-term nature.[18,29] To explore the time course of the effects discovered in our main models, that is, investigate whether relationships among IA, exercise, sports, and mood dimensions are of short- vs long-term nature, we subsequently computed additional multilevel models. For any analyses on the time course of the effects, we used the models specified above (eg see equation 2 with modifications highlighted). However, we incorporated one adaptation: We refrained from modeling random slopes but rather considered random intercepts within these additional analyses. In particular, to explore the time course of the effects of IA on mood, we computed 12 models (3*4 for each mood dimension), incorporating IA averaged across distinct time frames prior to the mood ratings (ie 16-30, 31-45, 46-60, and 61-75). To explore the time course of the effects of exercise activity on mood, we again computed 12 models (3*4 for each mood dimension) incorporating exercise activities within distinct time frames prior to the mood ratings (ie 31-60, 61-90, 91-120, and 121-240). To compare the magnitude of

TABLE 1 Descriptive characteristics

	N	Minimum	Maximum	Mean	SD
Age (y)	113	11.50	17.88	15.02	1.70
BMI (kg/m^2)	113	14.10	29.40	20.14	2.66
Incidental activity (mg/participant/wk)	113	13.32	74.78	40.86	11.87
Valence (mean/participant/wk)[a]	113	4.10	6.95	5.59	0.54
Energetic arousal (mean/participant/wk)[a]	113	3.27	6.22	4.55	0.65
Calmness (mean/participant/wk)[a]	113	3.15	6.63	5.13	0.63
Compliance (%/wk)	113	42.86	100.00	81.95	14.24
Compliance (prompts answered/per day)	113	5.14	13.43	6.37	0.97

[a]Mood was assessed on Likert scales (1-7).

effects, we computed standardized beta coefficients following established procedures.[32]

Equation 2: Predicting valence in time course

within this e-diary entry. However, her or his calmness decreased on average by −0.117 (on seven-point Likert scales) within this e-diary entry.

$$\begin{aligned} Y(\text{valence})_{ij} &= \beta_{00} + \beta_{01} \times \text{age}_j + \beta_{02} \times \text{gender}_j + \beta_{03} \times \text{BMI}_j + \beta_{10} \\ &\times \text{non exercise activity}_{ij}\ (\text{lag}30;45;60;75) + \beta_{20}^{(k)} \\ &\times \text{exercise}_{ij}^{(k)}\ (\text{lag}60;90;120;240) + \beta_{30} \times \text{time of day}_{ij} + \beta_{40} \\ &\times \text{time of day}_{ij}^2 + u_{0j} + u_{1j} \times \text{non exercise activity}_{ij} + u_{3j} \times \text{time of day}_{ij} + r_{ij} \end{aligned}$$

3 | RESULTS

3.1 | Descriptive statistics

The participants' average IA within the study week was 40.86 mg/participant/wk (range = 13.32-74.78; SD = 11.87). For the sake of comparison, sedentariness relates to approximately 7 mg and walking to approximately 367 mg.[34] Sixty-eight participants (60%) exercised within the study week resulting in the total of 84 sports and 82 exercise sessions. The participants' mean mood was 5.59 (valence; SD = 0.54), 4.55 (energetic arousal; SD = 0.65), and 5.13 (calmness; SD = 0.63; see Table 1). Furthermore, the ICC was 0.32 for valence (adjudicating an amount of 68% within-person variance), and 0.36 (adjudicating an amount of 64% within-person variance) for both energetic arousal, and calmness, showing good within-person variance for multilevel analyses.[32] The participants' overall compliance was 82% (SD = 14.23) in completing the e-diaries. Accordingly, on average, every participant answered 45.12 (SD = 7.8) mood assessments/wk.

3.2 | Effects of incidental activity on mood dimensions

3.2.1 | Main effects—IA

In line with our hypotheses 1-3, our results showed significant within-subject influences for our main predictor of interest, that is, IA, on all three mood dimensions (valence, energetic arousal, and calmness). IA measured within the fifteen minutes prior to the e-diary prompt was significantly associated with increased valence (beta coefficient = 0.000710; *P* = .002; refer to Table 2) and increased energetic arousal (beta coefficient = 0.000377; *P* = .017; refer to Table 2), but decreased calmness (beta coefficient = −0.000325; *P* = .142; refer to Table 2). In particular, on average, when an adolescent walked instead of remained seated over the 15-minute interval prior to a mood assessment (eg 367 mg instead of 7 mg[34]), her or his valence and energetic arousal increased on average by 0.257 and 0.136 (on seven-point Likert scales)

Our within-subject predictors of no interest, that is, time of the day and time of the day squared revealed significant associations with valence and energetic arousal but not with calmness (see Table 2). In particular, the association of time of the day with valence and energetic arousal was reverse u-shaped, that is, participants' valence scores increased from the daily study's start time (at approximately 9:00) to the afternoon (approximately 16:00) and then decreased until the study's end time (at approximately 20:30).

Age, as a between-subject predictor of no interest, showed a significant negative effect on valence and energetic arousal but not on calmness (see Table 2). Sex, as a between-subject predictor of no interest, showed no significant effect on valence and calmness but approached significance in predicting energetic arousal (*P* = .056; see Table 2). BMI, as a between-subject predictor of no interest, showed a significant positive effect on valence and calmness but not on energetic arousal (see Table 2).

3.2.2 | Time course of effects—IA

To investigate how stable associations between IA and mood are distinct across time frames, we analyzed whether IA parameterized within the time frames 1-15, 16-30, 31-45, 46-60, and 61-75 minutes prior to the e-diary prompt affected the mood dimensions. In Figure 1, the x-axis depicts the time frames, and the standardized beta coefficients from the respective multilevel models are displayed on the y-axis. The associations between IA and both valence and energetic arousal are stable across all investigated time frames. The association between IA and calmness is only significant for the time frame of 16-30 minutes. These results largely support the findings from our main analyses (see 3.2.1 Main effects).

3.3 | Explorative analyses on the effects of exercise activities on mood dimensions

Exercise revealed a significant main effect on energetic arousal (*P* =< .001) and calmness (*P* = .037), whereas valence approached the defined significance level (*P* = .069).

TABLE 2 Effect of physical activity on mood: fixed and random effects of multilevel model analysis

		Fixed effects					Random effects			
	Predictor	Beta coefficient	Standardized beta coefficient	Standard error	*t*-value (*df*)	*P*-value	Variance estimate	SD	Wald-*Z*	*P*-value
Valence	Intercept	5.697*		0.497	11.469	<.001	0.228	0.038	5.951	<.001
	Time (h)	0.064*		0.014	4.701	<.001	0.001	0.0003	3.610	<.001
	Time-squared (h)	−0.005*		0.001	−4.412	<.001				
	Age (y)	−0.074*		0.031	−2.368	.023				
	BMI (kg/m^2)	0.044*		0.020	2.152	.036				
	Sex	−0.112		0.100	−1.118	.263				
	Incidental activity (mg)	0.0007*	0.075*	0.0002	3.278	.002	0.000002	6.9055E-7	3.203	.001
	Sports (2)	−0.120	−0.029	0.118	−1.015	.310				
	Exercise (1)	0.258*	0.064*	0.125	2.065	.039				
	Reference: no activity (0)									
Energetic arousal	Intercept	5.390*		0.621	8.677	<.001	0.350	0.059	5.888	<.001
	Time (h)	0.142*		0.016	9.017	<.001	0.003	0.0007	5.086	<.001
	Time-squared (h^2)	−0.012*		0.001	−10.080	<.001				
	Age (y)	−0.102*		0.039	−2.620	.010				
	BMI (kg/m^2)	0.027		0.026	1.041	.300				
	Sex	−0.243		0.126	−1.934	.056				
	Incidental activity (mg)	0.0004*	0.033*	0.0002	2.388	.017				
	Sports (2)	−0.574*	−0.119*	0.130	−4.418	<.001				
	Exercise (1)	−0.110	−0.023	0.140	−0.787	.431				
	Reference: no activity (0)									
Calmness	Intercept	5.061*		0.590	8.573	<.001	0.338	0.054	6.292	<.001
	Time (h)	0.004		0.015	0.294	.769	0.001	0.0004	3.287	.001
	Time-squared (h^2)	−0.002		0.001	−1.429	.153				
	Age (y)	−0.060		0.037	−1.629	.106				
	BMI (kg/m^2)	0.056*		0.024	2.308	.023				
	Sex	−0.169		0.119	−1.416	.160				
	Incidental activity (mg)	−0.0003	−0.031	0.0002	−1.486	.142	0.000002	7.9335E-7	2.516	.012
	Sports (2)	−0.190	−0.043	0.126	−1.511	.131				
	Exercise (1)	−0.280*	−0.063*	0.134	−2.095	.036				
	Reference: no activity (0)									

Note: Standardized beta coefficients are shown for incidental activity, exercise, and sports. Random effects are only depicted if significance was observed. Stars (*) indicate significant associations.

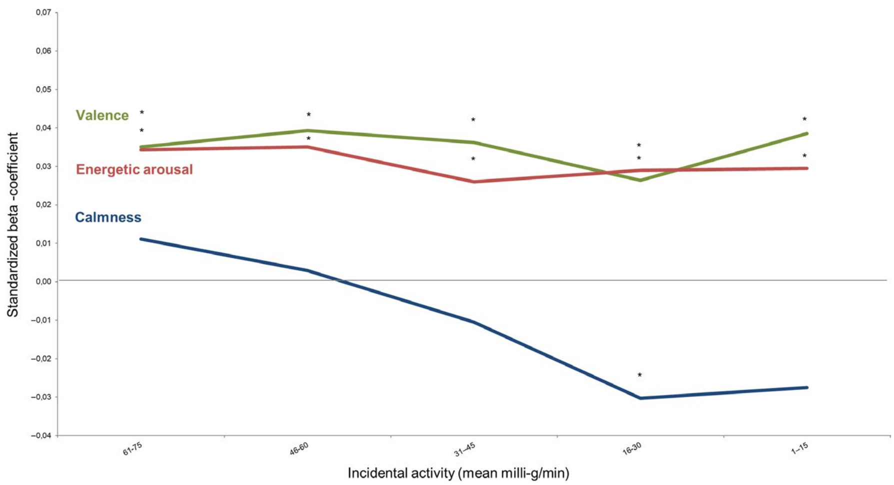
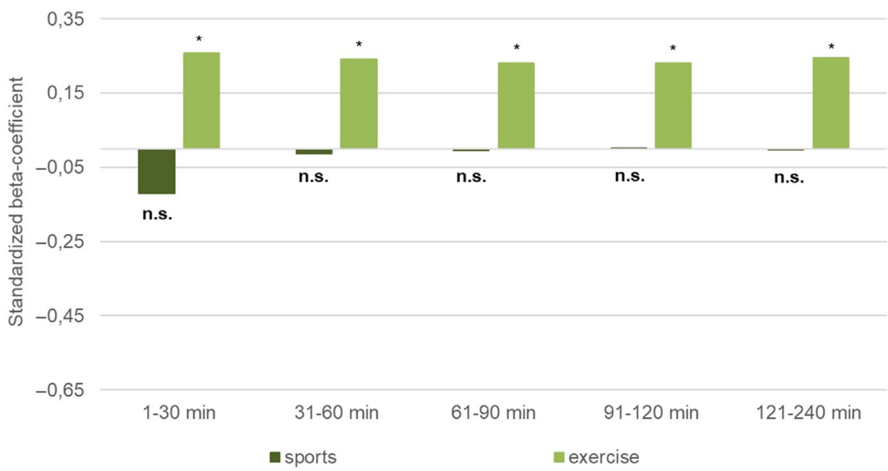


FIGURE 1 Incidental activity within distinct time frames predicts mood: Effects of incidental activity on mood across subsequent 15-min intervals prior to the e-diary prompts. The y-axis represents the standardized beta coefficients of valence, energetic arousal, and calmness predicted by incidental activity (x-axis). Significant effects of incidental activity on valence, energetic arousal, and calmness are highlighted (*$P \leq .05$)

FIGURE 2 The effect of exercise activities within distinct time frames on valence: Effects of exercise and sports on valence (standardized beta coefficients; y-axis) across five subsequent 30-min intervals (x-axis) prior to the e-diary prompts. Significant effects of exercise and sports on valence are highlighted (*$P \leq .05$)



3.3.1 | Sports

Sports were negatively associated with consecutive energetic arousal (beta coefficient = −0.574; $P < .001$; see Table 2) compared to no activity (ie not moving at all). Translated into practice, when an adolescent engaged in sports vs did not engage in any exercise activity, her or his energetic arousal decreased on average by −0.574 in one unit (on seven-point Likert scales). However, cosports were not associated with valence and calmness (see Table 2).

3.3.2 | Exercise

Exercises were positively associated with valence (beta coefficient = 0.258; $P = .039$, see Table 2) compared to no activity (ie not moving at all). Translated into practice, when an adolescent engaged in an exercise vs did not engage in any exercise, her or his valence increased on average by 0.258 in one unit (on seven-point Likert scales). However, exercises were negatively associated with calmness (beta coefficient = −0.280; $P = .036$, see Table 2) compared to no activity (ie not moving at all). In particular, when an adolescent engaged in an exercise vs did not engage in any exercise, her or his calmness decreased on average by −0.280 in one unit (on seven-point Likert scales). Additionally, exercises were not associated with energetic arousal (see Table 2).

3.3.3 | Time course of effects—sports and exercises

To investigate whether associations between exercise activity and mood dimensions are short-term or long-term in nature, we averaged sports and exercises across five time frames prior to the mood ratings (ie {1-30}, {31-60}, {61-90}, and {91-120}, and {121-240}). The x-axes of Figures 2-4 depict the five time frames after the exercise activities and prior to an e-diary prompt. The y-axes depict the beta coefficients of the multilevel models predicting the mood dimensions valence (Figure 2), energetic arousal (Figure 3), and calmness (Figure 4).

The findings indicate a significant positive effect of exercise on valence over time (Figure 2) and a negative effect of sports on energetic arousal (Figure 3). In contrast, sports showed no effect on valence and we found no effect of exercise on energetic arousal across all time frames. Exercise was significantly associated with calmness in the time frame {1-30}, but not in any other time frame.

3.4 | Comparison of the maximum likelihood estimates with the bootstrap estimates

Alongside the normal theory results based on maximum likelihood, we obtained bootstrap estimates with standard errors and 95% confidence intervals. This procedure yielded pretty close estimates both in fixed and random effects for all three outcome variables (refer to Appendix 4).

4 | DISCUSSION

In line with our main hypotheses, our study illustrated that after incidental activity (such as climbing stairs), adolescents felt better and more energized; explorative analyses revealed that after exercise (such as skating), adolescents felt better but less calm; and after sports (such as playing tennis), adolescents felt less energized. To the best of our knowledge, our study was the first Ambulatory Assessment study to investigate the effect of different types of physical activity on subsequent mood in a community-based sample of adolescents. We aimed to consider the differential effects of distinct types of physical activity on subsequent mood. Our findings that IA was positively related to subsequent valence and energetic arousal are in line with those of Hulley et al,[35] who demonstrated that walking longer distances was related to increases in valence and energetic arousal among 99 children aged 5-10 years over a period of 2 weeks. In addition, there is converging evidence for a positive within-subject relationship between physical activity and energetic arousal in adult populations[17,29] and some evidence for a positive within-subject association between physical activity and valence in adult populations.[17,29]

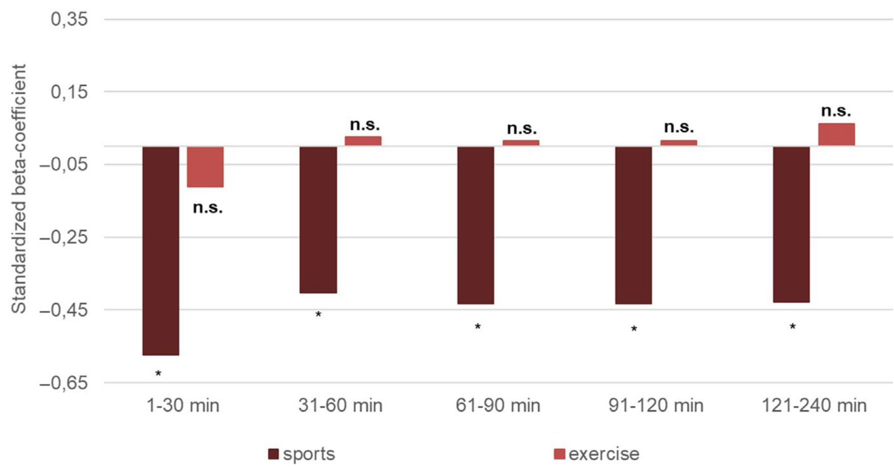


FIGURE 3 The effect of exercise activities within distinct time frames on energetic arousal: Effects of exercise and sports on energetic arousal (standardized beta coefficients; y-axis) across five subsequent 30-min intervals (x-axis) prior to the e-diary prompts. Significant effects of exercise and sports on energetic arousal are highlighted (*$P \leq .05$)

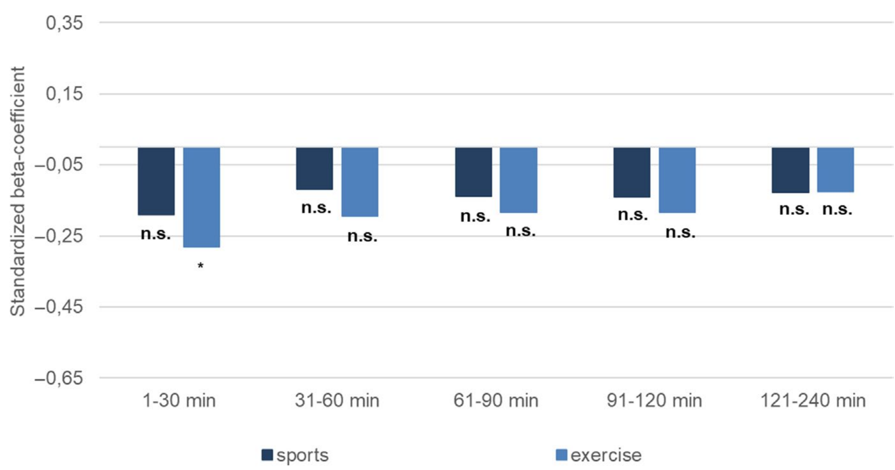


FIGURE 4 The effect of exercise activities within distinct time frames on calmness: Effects of exercise and sports on calmness (standardized beta coefficients; y-axis) across five subsequent 30-min intervals (x-axis) prior to the e-diary prompts. Significant effects of exercise and sports on calmness are highlighted (*$P \leq .05$)

Beyond these findings, we identified clear differences in associations between distinct types of exercise activities on subsequent mood; specifically, while adolescents felt better but less calm after exercise, they felt less energized after sports. Our study is the first to focus on the differential effects of distinct types of physical activity on subsequent mood in a real-life setting; consequentially, this makes comparisons with existing literature challenging. Although there have been four studies that showed distinct influences on mood and thus support our findings, these studies were very methodologically very different and focused on affect responses pre, during, and after exercises and sports. In particular, our finding demonstrated that sports were negatively related to subsequent energetic arousal is partly supported by Szabo et al,[21] who found the highest negative affect in competitive situations when comparing positive and negative affect between competitive and training situations among 26 girls performing dancing sports by measuring the affect prior and subsequent to the conditions. Interestingly, even among university students classified as exhibiting a Type A Behaviour Pattern (ie TABP), exercising under noncompetitive conditions led to mood increases, whereas competitive conditions did not change their acute mood response at all.[22] Also supporting our findings, Subramaniapillai et al[36] found a decrease in calmness in 31 healthy controls aged 13-20 years subsequent to a laboratory cycling ergometer test. In addition, Cushing et al[20] supports our suggestion that different dimensions of affect may have different associations with physical activity. However, due to a lack of studies investigating the post-bout effect of physical activity, exercise, and sports on mood, a comparison with the current literature is challenging and further studies should take the time point of measurement into account.[37]

Since adolescents attended school on weekdays, variance in physical activity patterns was limited; for example, pupils usually have to remain seated during lessons and because adolescents were not allowed to use smartphones in school, e-diaries queried for mood from 16:00 to 20:30 on weekdays and 09:00 to 20:00 on weekend days. To account for possible confounds introduced by different assessment ranges, we added weekday vs weekend as a dichotomous covariate into our main model. However, this did not change the results (for an overview see Appendix 5). We continued to explore possible weekday vs weekend effects by applying multilevel interaction analyses (weekday vs weekend × incidental activity and weekday vs weekend × exercise activity) for all of our main models. Here, we found three significant interaction effects, indicating that sports on weekend days were negatively associated with valence and calmness. Moreover, the negative association of sports with energetic arousal was stronger on weekend days compared to weekdays. These findings further support the conclusions of our study.

Our study provides evidence that a clear differentiation of distinct physical activity types is important for an in-depth understanding of dynamic real-life associations between physical activity and subsequent mood. This information may also help to clarify inconclusive findings in the literature, for example, studies that did not find any association between physical activity and mood in real life; the missing differentiation of distinct physical activity types might have diluted the effects.[38]

4.1 | Limitations

Some aspects of our study merits further discussion. First, we did not control for winning or losing a match or personal performance in sports. A competitive situation is affected by many parameters such as not playing well, social evaluation, parental pressure, not having fun but experiencing stress, trying to perform up to personal standards, and playing difficult technical and tactical shots.[39] However, we decided to take all these parameters as a whole, including winning or losing, as being part of competitive sports situations that may affect mood in adolescents. Of course, every one of these factors, for example, winning or losing a match, may influence participant's mood. Our data may be mixed, that is, including both “victories” and “failures”, which may explain our null findings for the mood dimensions valence and calmness. It should be a subject of investigation in further studies whether additional covariates, for example, “victories” vs “failures” or other factors, for example, exercise intensity, impact adolescents’ mood. Second, our sample (age range: 12-17 years) represents different developmental stages in puberty. It is possible that the effects of IA and exercise activity on the mood dimensions differ within these stages. Thus, we explored possible age effects by applying multilevel interaction analyses (age × incidental activity and age × exercise activity) for all of our main models but did not find any significant interaction effects with age. Third, although we parameterized mood as a consequence of exercise activity and IA (ie using mood ratings timely following the activities), this constitutes only one aspect of causality. For example, we cannot exclude that hidden third variables might account for our findings. In simple terms, every time adolescents went out to exercise, the weather may have been fine and thus the weather may have accounted for mood changes but not the exercise activity. Physical activity and mood may influence each other in a circular relationship, as suggested by Schwerdtfeger and researchers.[29] Further studies should substantiate this hypothesis, for example, using ecological momentary interventions.

4.2 | Perspectives

To the best of our knowledge, this is the first study investigating the effects of physical activity on mood dimensions in the everyday life of naturally behaving healthy adolescents. In sum, our results revealed the following: after incidental activity (such as climbing stairs), adolescents felt better and more energized; after exercising (such as skating), adolescents felt better but less calm; and after sports (such as playing soccer), adolescents felt less energized. While our explorative findings on exercise activity need to be substantiated in further investigations, we suggest future studies on the association of physical activity and mood to differentiate between distinct types of physical activity to receive unambiguous findings. Translated into practice, our results infer that incidental and exercise activities result in higher post-bout valence compared to sports in competitive settings..

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CONFLICT OF INTEREST

AM-L has received consultant fees from the following entities: the American Association for the Advancement of Science, Atheneum Partners, Blueprint Partnership, Boehringer Ingelheim, Daimler und Benz Stiftung, Elsevier, F. Hoffmann-La Roche, ICARE Schizophrenia, K. G. Jebsen Foundation, LE K Consulting, Lundbeck International Foundation (LINF), R. Adamczak, Roche Pharma, Science Foundation, Sumitomo Dainippon Pharma, Synapsis Foundation—Alzheimer Research Switzerland, and System Analytics. AM-L has received lectures fees, including travel fees, from Boehringer Ingelheim, Fama Public Relations, Institut d'investigacions Biomèdiques August Pi i Sunyer (IDIBAPS), Janssen-Cilag, Klinikum Christophsbad, Göppingen, Lilly Deutschland, Luzerner Psychiatrie, LVR Klinikum Düsseldorf, LWL PsychiatrieVerbund Westfalen-Lippe, Otsuka Pharmaceuticals, Reunions i Ciencia S. L., Spanish Society of Psychiatry, Südwestrundfunk Fernsehen, Stern TV, and Vitos Klinikum Kurhessen. The other authors declare that there is no conflict of interest regarding financial or commercial relationships and that the results of the present study do not constitute endorsement by ACSM. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

AUTHOR CONTRIBUTIONS

EK, HT, UB, GG, MG, IR, AZ, AM-L, UE-P, and MR made substantial contributions to the conception and design of the study. MR and MG acquired data. EK, HT, IR, AM-L, UE-P, and MR analyzed and interpreted the data. EK, HT, UB, GG, MG, IR, AZ, AM-L, UE-P, and MR were involved in drafting the manuscript and revising it critically for important intellectual content. EK, HT, UB, GG, MG, IR, AZ, AM-L, UE-P, and MR have given final approval for this version of the manuscript to be published. EK, HT, UB, GG, MG, IR, AZ, AM-L, UE-P, and MR agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of this work are appropriately investigated and resolved.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the ethics committee of the Medical Faculty Mannheim at Heidelberg University. This study fulfilled the ethical guidelines for medical research according to the declaration of Helsinki. Adolescents participating in the study and their parents were informed about any study procedure before written consent was obtained. The participants had the option to withdraw their participation from the study at any time and without consequences.

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APPENDIX 1

Group differences in demographic characteristics in datasets that were removed and those that were retained for analysis

Descriptive statistics on gender for included and excluded participants

Count		Gender: Female	Gender: Male	Total
Included and excluded participants	Included	54	59	113
	Excluded	12	9	21
Total		66	68	134

Group differences on gender for included and excluded participants

	Value	*df*	Asymptotic significance (2-sided)
Pearson Chi-Square	0.620	1	0.431

Descriptive statistics on age, BMI, socioeconomic status for included and excluded participants

Group statistics	Included and excluded participants	N	Mean	SD	SE
Age	Included	113	15.041	1.839	0.173
	Excluded	21	14.407	1.242	0.271
BMI	Included	113	20.143	2.657	0.250
	Excluded	21	19.708	2.883	0.629
SES-index (Lampert et al metric)	Included	110	16.646	2.740	0.261
	Excluded	20	16.380	1.877	0.420

Group differences on age, BMI, socioeconomic status for included and excluded participants

Independent samples test		Levene's test for equality of variances		t-test for equality of means						
									95% confidence interval of the difference	
		F	Sig.	*t*	*df*	Sig. (2-tailed)	Mean difference	Std. error difference	Lower	Upper
Age	Equal variances not assumed	7.593	0.007	1.973	38.491	0.056	0.634	0.32148	−0.016	1.285
BMI	Equal variances assumed	0.077	0.782	0.680	132	0.498	0.435	0.6397	−0.830	1.701
SES-Index (Lampert et al metric)	Equal variances not assumed	5.765	0.018	0.537	35.635	0.595	0.266	0.49439	−0.738	1.269

APPENDIX 2

Reliability of the mood scales

McDonald's Omega for valence, energetic arousal, and calmness

Parameters	Estimate	SE	Est./SE	*P*-value
Valence within (ω)	0.822	0.017	49.554	.000
Valence between (ω)	0.768	0.078	9.863	.000
Energetic arousal within (ω)	0.637	0.019	33.672	.000
Energetic arousal between (ω)	0.586	0.178	3.286	.001
Calmness within (ω)	0.418	0.031	13.359	.000
Calmness between (ω)	0.821	0.032	25.893	.000

APPENDIX 3

Model fit indices of valence, energetic arousal, and calmness

Model fit for valence

	Time	Time, Time^2	Time, Time^2, NEA	Time, Time^2, NEA, age	Time, Time^2, NEA, age, BMI	Time, Time^2, NEA, age, BMI, sex	Time, Time^2, NEA, age, BMI, sex, exercise
2 Log Likelihood	9652.205	9638.535	9646.344	9649.876	9652.521	9653.389	9651.236
AIC	9656.205	9642.535	9650.344	9653.876	9656.521	9657.389	9655.236
IC	9656.208	9642.538	9650.346	9653.879	9656.524	9657.392	9655.239
CAIC	9670.853	9657.183	9664.991	9668.523	9671.167	9672.035	9669.881
BIC	9668.853	9655.183	9662.991	9666.523	9669.167	9670.035	9667.881

Model fit for energetic arousal

	Time	Time, Time^2	Time, Time^2, NEA	Time, Time^2, NEA, age	Time, Time^2, NEA, age, BMI	Time, Time^2, NEA, age, BMI, sex	Time, Time^2, NEA, age, BMI, sex, exercise
2 Log Likelihood	10754.809	10651.416	10660.675	10664.545	10668.793	10665.960	10649.087
AIC	10758.809	10655.416	10664.675	10668.545	10672.793	10669.960	10653.087
IC	10758.812	10655.419	10664.678	10668.548	10672.796	10669.963	10653.090
CAIC	10773.457	10670.064	10679.323	10683.192	10687.440	10684.607	10667.732
BIC	10771.457	10668.064	10677.323	10681.192	10685.440	10682.607	10665.732

Model fit for calmness

	Time	Time, Time^2	Time, Time^2, NEA	Time, Time^2, NEA, age	Time, Time^2, NEA, age, BMI	Time, Time^2, NEA, age, BMI, sex	Time, Time^2, NEA, age, BMI, sex, exercise
2 Log Likelihood	10168.715	10177.869	10181.993	10186.633	10185.786	10186.453	10184.353
AIC	10172.715	10181.869	10185.993	10190.633	10189.786	10190.453	10188.353
IC	10172.718	10181.872	10185.996	10190.636	10189.789	10190.456	10188.356
CAIC	10187.363	10196.517	10200.641	10205.280	10204.433	10205.099	10202.998
BIC	10185.363	10194.517	10198.641	10203.280	10202.433	10203.099	10200.998

APPENDIX 4

Bootstrap estimates for valence, energetic arousal, and calmness

Fixed effects bootstrap estimates for outcome VALENCE dimensional predictors

Obs	Effect	mean	SE	CI 2.5	CI 97.5
1	Intercept	5.71934	0.19976	5.31882	6.10346
2	Age	−0.08069	0.01188	−0.10457	−0.05803
3	BMI	0.04751	0.00772	0.03252	0.06306
4	NEA	0.00083	0.00017	0.00051	0.00118
5	Time	0.06421	0.01315	0.03861	0.09050
6	$Time^2$	−0.00456	0.00104	−0.00663	−0.00255

Fixed effects bootstrap estimates for outcome VALENCE categorical predictors

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Sex	−0.10179	0.038343	−0.17464	−0.024931

Fixed effects bootstrap estimates for outcome VALENCE categorical predictors

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Exercise	−0.11730	0.15670	−0.44104	0.17356
2	Exercise	0.24485	0.10290	0.04417	0.44776

Random effects bootstrap estimates for outcome VALENCE

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Intercept	0.27125	0.027490	0.22363	0.33245
2	Residual	0.48764	0.019583	0.44941	0.52606
3	NEA	0.00001	0.000002	0.00000	0.00001
4	Time	0.00202	0.000466	0.00121	0.00305

Fixed effects bootstrap estimates for outcome ENERGETIC AROUSAL dimensional predictors

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Intercept	5.46012	0.28770	4.89715	6.02334
2	Age	−0.10676	0.01701	−0.14015	−0.07371
3	BMI	0.02622	0.01055	0.00581	0.04716
4	NEA	0.00036	0.00016	0.00005	0.00068
5	Time	0.14236	0.01575	0.11226	0.17410
6	$Time^2$	−0.01157	0.00120	−0.01399	−0.00926

Fixed effects bootstrap estimates for outcome ENERGETIC AROUSAL categorical predictors

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Sex	−0.23514	0.052522	−0.33749	−0.13281

Fixed effects bootstrap estimates for outcome ENERGETIC AROUSAL categorical predictors

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Exercise	−0.57525	0.12101	−0.81653	−0.33977
2	Exercise	−0.11162	0.15623	−0.41928	0.19794

Random effects bootstrap estimates for outcome ENERGETIC AROUSAL

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Intercept	0.43857	0.043287	0.35759	0.52708
2	Residual	0.62654	0.018108	0.59114	0.66201
3	Time	0.00475	0.000604	0.00362	0.00600

Fixed effects bootstrap estimates for outcome CALMNESS dimensional predictors

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Intercept	5.14916	0.21505	4.73557	5.57837
2	Age	−0.06606	0.01281	−0.09146	−0.04144
3	BMI	0.05607	0.00824	0.03998	0.07209
4	NEA	−0.00022	0.00018	−0.00058	0.00015
5	Time	0.00173	0.01396	−0.02486	0.02949
6	$Time^2$	−0.00141	0.00109	−0.00356	0.00071

Fixed effects bootstrap estimates for outcome CALMNESS categorical predictors

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Sex	−0.17051	0.040466	−0.25101	−0.091856

Fixed effects bootstrap estimates for outcome CALMNESS categorical predictors

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Exercise	−0.18364	0.13782	−0.45050	0.095582
2	Exercise	−0.28775	0.13659	−0.55354	−0.009774

Random effects bootstrap estimates for outcome CALMNESS

Obs	Effect	Mean	SE	CI 2.5	CI 97.5
1	Intercept	0.39577	0.031396	0.33989	0.46412
2	Residual	0.55641	0.015928	0.52529	0.58796
3	NEA	0.00001	0.000001	0.00000	0.00001
4	Time	0.00228	0.000440	0.00148	0.00322

APPENDIX 5

Main model results with weekday and weekend as additional covariate

Effect of Physical Activity on Mood: Fixed Effects of Multilevel Model Analysis with weekday and weekend as additional covariate

	Fixed effects			
Predictor	**Beta coefficient**	**Standard Error**	***t*-value (*df*)**	***P*-value**
Valence				
Intercept	5.675	0.497	11.422	<.001
Time (h)	0.073	0.014	5.256	<.001
$Time^2$ (h^2)	−0.005	0.001	−4.410	<.001
Age (y)	−0.074	0.031	−2.384	.019
BMI (kg/m^2)	0.044	0.020	2.183	.031

	Fixed effects			
Predictor	Beta coefficient	Standard Error	*t*-value (*df*)	*P*-value
Sex	−0.111	0.100	−1.105	.272
Incidental activity (mg)	0.001	0.000	3.326	.001
Sports (2)—reference: no activity (0)	−0.115	0.118	−0.981	.326
Exercise (1)—reference: no activity (0)	0.260	0.125	2.083	.037
Weekday—reference: Weekend	−0.096	0.028	−3.402	.001
Energetic arousal				
Intercept	5.367	0.622	8.629	<.001
Time (h)	0.153	0.016	9.518	<.001
Time ^{2} (h^2)	−0.012	0.001	−10.093	<.001
Age (y)	−0.103	0.039	−2.641	.010
BMI (kg/m^2)	0.028	0.026	1.075	.285
Sex	−0.241	0.126	−1.914	.058
Incidental activity (mg)	0.0004	0.0002	2.388	.017
Sports (2)—reference: no activity (0)	−0.570	0.130	−4.387	<.001
Exercise (1)—reference: no activity (0)	−0.107	0.140	−0.767	.443
Weekday—reference: weekend	−0.111	0.032	−3.533	<.001
Calmness				
Intercept	5.030	0.590	8.530	<.001
Time (h)	0.017	0.015	1.150	.250
$Time^2$ (h^2)	−0.002	0.001	−1.422	.155
Age (y)	−0.061	0.037	−1.644	.103
BMI (kg/m^2)	0.057	0.024	2.341	.021
Sex	−0.168	0.119	−1.406	.163
Incidental activity (mg)	−0.0003	0.000	−1.438	.155
Sports (2)—reference: no activity (0)	−0.184	0.125	−1.467	.142
Exercise (1)—reference: no activity (0)	−0.277	0.133	−2.076	.038
Weekday—reference: weekend	−0.139	0.030	−4.610	<.001