Affect improvements and measurement concordance between a subjective and an accelerometric estimate of physical activity

Björn Pannicke[1*], Julia Reichenberger[1], Dana Schultchen[2], Olga Pollatos[2], & Jens Blechert[1]

[1]Department of Psychology, Centre for Cognitive Neuroscience, Paris-Lodron-University of Salzburg, Austria

[2]Department of Clinical & Health Psychology, Ulm University, Germany

[*]Correspondence:

Björn Pannicke MSc

Department of Psychology

Paris-Lodron-University of Salzburg

Hellbrunner Straße 34

5020 Salzburg, Austria

E-mail: bjoern.pannicke@sbg.ac.at

Acknowledgements: This work was supported by the Peer-Mentoring Team-Program (Line A) of the German Psychological Society (DGPs, section Health Psychology). In addition, this work was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (ERC-StG-2014 639445 NewEat) and the Austrian Science Fund (FWF): [I 02130-B27].

Abstract

Objectives: Physical activity (PA) positively influences several aspects of mental well-being including affect improvements. Yet, the fact that subjective and objective measures of PA often diverge challenges research on the relationship of PA and affect. **Methods:** Subjective (ecological momentary assessment, EMA) and objective (combined heart rate and accelerometric activity tracker) measures of PA alongside repeated ratings of positive and negative affects were obtained from 37 participants over seven consecutive days. **Results:** Subjective and objective PA were significantly positively correlated. Affect improvements, i.e. negative affect decrease as well as positive affect increase, were predicted by both subjective (EMA) and objective (activity tracker) data. **Conclusions:** Measurement concordance supports the validity of both assessment strategies. Affect improvements result from both subjective representations of one's own activity as well as from physiological mechanisms of PA that one is not aware of, suggesting two independent routes to affect improvements.

Keywords: physical activity, affect improvements, ecological momentary assessment, accelerometry, everyday life

Introduction

Frequent physical activity (PA) is associated with broad physical health gains, e.g. reduced risk for cardiovascular disease in primary prevention and slowed progression of coronary artery disease in secondary prevention (Warburton, Nicol, & Bredin, 2006). In addition to physiological health effects, PA also makes the onset of various mental disorders less likely and helps in reducing related psychological symptoms as a treatment component (Peluso & Andrade, 2005). Lifestyle modification treatments promoting PA show beneficial effects on depression and various stress related disorders (e.g. Cooney et al., 2013; Richardson et al., 2005; Rosenbaum, Tiedemann, Sherrington, Curtis, & Ward, 2014) as well as on non-clinical forms of depressed moods (Rebar et al., 2015).

Importantly, besides planned and purposeful exercising, there are also various everyday activities of moderate intensity such as brisk walking or commuting by bicycle that can be beneficial for mental and physical health by contributing to the overall PA level (Audrey, Procter, & Cooper, 2014; Haskell et al., 2007; Martin, Kelly, Boyle, Corlett, & Reilly, 2016). The World Health Organization (2010) therefore recommends a minimum of 150 minutes of moderate PA or 75 minutes of vigorous PA per week, or respectively a combination of both, to achieve these benefits. Additionally, the benchmark of 10.000 steps per day was also suggested to ensure a certain degree of physical activity (Tudor-Locke & Bassett, 2004). Yet, research has repeatedly shown that large proportions of the population fail to reach these numbers due to multiple psychological and environmental barriers and constraints (e.g. Hallal, Andersen, Bull, Guthold, & Ekelund, 2012; Liu, Bennett, Harun, & Probst, 2008), although each episode of everyday PA might help reduce associated mental and physical health risks (Saris et al., 2003; World Health Organization, 2009; Zhai, Zhang, & Zhang, 2014). Thus, validly assessing and documenting everyday PA seems crucial as a starting point of effective prevention and intervention.

Yet, methodological issues limit research on everyday PA: individuals are not always aware of their general fitness level (e.g. cardiorespiratory fitness level) as well as their daily extent of PA, especially regarding unplanned activities or shorter periods of PA. For instance, subjective moderate PA was found to be over-reported when compared against objective indicators in a college student sample (Downs, Van Hoomissen, Lafrenz, & Julka, 2014). Thus, the predictive validity of (mental) health effects from such subjective reports of PA might be limited due to the discordance between subjective and objective reports. It could therefore be problematic that research on health-related behaviours mostly uses self-reported PA (Sallis & Saelens, 2000).

Such subjective reports are mainly operationalised through recall questionnaires or activity diaries, completed either on paper or electronically (Bert, Giacometti, Gualano, & Siliquini, 2013). However, there might be several limitations that bias such data such as effects of social desirability, memory limitations, or compliance with study instructions (Sallis & Saelens, 2000). Some of these disadvantages might be addressed through real-time assessment as afforded by smartphone apps (i.e. ecological momentary assessment, EMA): although subjective, they allow capturing activities right when they occur (Shiffman, Stone, & Hufford, 2008). Particularly memory bias might be reduced because of a relatively short time period between occurrence of behaviour and assessment. While EMA reports are still subjective, they can be backed up with objective measures of PA (e.g. accelerometers, fitness trackers). These devices bypass any memory or reporting biases through continuously recording objective measures, e.g. heart rate and accelerometry (Warren et al., 2010) to derive for instance metabolic equivalents of task (METs; Jetté, Sidney, & Blümchen, 1990). METs reflect the ratio of the energy expenditure rate relative to body weight for specific physical activities compared to resting (Jetté et al., 1990). In sum, subjective and objective markers of PA might have varying advantages and disadvantages and might differ from each other, especially regarding their reliability, but potentially also regarding their effects.

Thus, the question arises as to whether data from simultaneous assessment of subjective (e.g. via EMA) and objective PA (e.g. via heart rate weighted accelerometry) agree and show *measurement concordance*. A systematic review comparing self-reported data of PA with objectively measured data found not only positive associations (resulting in a low-to-moderate mean correlation coefficient) but also zero and even negative associations (Prince et al., 2008). Thus, the present study will analyse the degree of within-person *measurement concordance* between subjective, EMA-based estimates and objective, heart rate weighted accelerometric data of PA (Aim 1).

Subjectively experienced and objectively measured PA might not only be discordant, but might also have different impacts on health outcomes. A particularly relevant health outcome concerns affect. According to psychophysiological theories, PA improves affect due to a reduction in the cortisol response from the hypothalamic-pituitary-adrenal axis (HPA axis) (Zschucke, Renneberg, Dimeo, Wüstenberg, & Ströhle, 2015) as well as to changes in specific brain regions and neurotransmitters (Bothe et al., 2013). Another mechanism for explaining PA mediated affect improvements posits that *subjective awareness* (a prerequisite for subjective reports; e.g. Ronda, Assema, & Brug, 2001) of one's own successful engagement in PA might fuel positive experiences (e.g. of self-efficacy). To exemplify, research in youth has shown that only subjective (i.e. aware) reports in contrast to objective reports of PA were related to experienced self-efficacy (Kavanaugh, Moore, Hibbett, & Kaczynski, 2015). PA-related self-efficacy is in turn associated with affect (e.g. Bodin & Martinsen, 2004; Kwan & Bryan, 2010). Hence, the present study contrasted EMA-based and objective indices of PA in predicting subsequent affect changes (Aim 2). Particularly, we aimed to gain clarity on the nature of affect improvements: There is a plethora of evidence suggesting that PA increases subsequent positive affect. This effect has been found for subjectively reported PA (e.g. Kanning & Schlicht, 2010; Liao, Shonkoff, & Dunton, 2015; Schöndube, Kanning, & Fuchs, 2016) as well as objectively assessed PA (e.g. Bossmann, Kanning, Koudela, Hey, & Ebner-Priemer, 2013; Hogan, Mata,

& Carstensen, 2013). However, the role of negative affect (reductions) is less clear (e.g. Liao et al., 2015; Puterman, Weiss, Beauchamp, Mogle, & Almeida, 2017), which is important as it might facilitate negative reinforcement.

The present study and research aims

The present study used EMA measures to examine the two main study aims: smartphone supported subjective PA measurements were accompanied by objective PA measurements assessed by a heart rate / accelerometer monitoring device. Based on the literature, the main focus of the study was on moderate to vigorous activity (i.e. defined as subjectively being out of breath or sweating, respectively, objective METs > 3) to a) ensure some degree of awareness and b) include daily activities and not only planned exercise. Additionally, mental health effects are more frequently reported for these intensities (e.g. Asztalos, De Bourdeaudhuij, & Cardon, 2010). Therefore, we expected within-participant *concordance* between subjective and objective PA measures (Aim 1). Regarding affect improvements, we expected that both subjective PA (assessed via EMA) and objective PA (assessed via activity tracking measures) influence subsequent changes in positive and negative affect (Aim 2). Based on the literature reviewed above, we hypothesised that higher subjective and objective PA would result in higher positive and lower negative affect. However, due to a lack of previous research, we had no specific hypothesis as to whether subjective or objective PA would be more important for affect improvements. In addition, to acknowledge individual differences potentially influencing the associations described above we controlled for body-mass index (BMI) as well as gender based on differences found in previous literature (Slootmaker, Schuit, Chinapaw, Seidell, & Mechelen, 2009; Thome & Espelage, 2004). We decided to investigate the described research aims in a sample of university students, given that PA is related to health variables and mood improvements in (university) student populations (Annesi, Porter, Hill, & Goldfine, 2017;

Joseph, Royse, Benitez, & Pekmezi, 2014; Wunsch, Kasten, & Fuchs, 2017). Moreover, students are prone to regularly experience stress as well as negative affect and are even increasingly at risk for mental health problems (Storrie, Ahern, & Tuckett, 2010).

Method

Participants

Participants were recruited by means of a study announcement via e-mail, flyers and by word of mouth. Initially, data of 51 participants were collected. Since not all participants were able to wear the activity tracking device (e.g. because of a sticking plaster allergy; constraints with regard to the number of devices), objective PA data could not be attained for all recruited participants (N = 12). Additionally, participants were excluded in case of substantial missing data in both EMA (< 50% of completed EMA questionnaires) and activity tracker assessment methods (N = 2). Thus, in total 37 participants (28 female) were included in the statistical analyses. Participants, mostly university students, had a mean age of 23.5 years (*SD* = 2.60 years, age range: 19–28 years). All participants received written and oral information on the purpose of the study and signed an informed consent according to the relevant ethics committee that also granted the ethical approval for the present study.

Procedure

Given the inclusion criteria, we only recruited participants ranging from 18–35 years, who owned a smartphone to complete EMA data and were willing and able to carry the Actihearts device (i.e. without sticking plaster allergy). Initially, the participants' demographic variables and their body weight and height (for BMI) were measured in the laboratory. Afterwards, participants were asked to answer the 'Freiburger Fragebogen zur körperlichen Aktivität' (FFKA; Freiburg Questionnaire of Physical Activity; Frey & Berg, 2002; Frey, Berg, Grathwohl, & Keul, 1999). It refers to physical activities at work and during leisure-time and allows classification of the recent level of physical activity for each participant in terms of body weight related energy metabolism per week. The FFKA shows acceptable psychometric properties (Frey et al., 1999). Then, participants received the monitoring device for objective PA with instructions on how to wear it (e.g. participants were told to wear the device all day and all night for seven consecutive days unless they engaged in long-lasting water activities such as swimming) and how to install and use the smartphone app. The smartphone app enabled subjective data collection multiple times a day throughout the following eight days. However, only the respective days of smartphone assessment with concurrent objective monitoring data were used for analyses. The first day functioned as a practice day for participants to become familiar with the surveys via app and the wearing of the device (data not used in the present study). The majority of participants wore the device for six days, two individuals only for five days and four individuals for seven days (practice day not taken into account). At the end of the study period individuals answered final questionnaires which included compliance and reactivity items asking for altered behaviour based on study participation. Reactivity concerning PA was assessed by asking ‘How much did the assessment itself influence your physical activity during the duration of the study?’ (0 = not at all – 100 = very much). Reactivity concerning affects was assessed by asking ‘Did the assessment itself influence your mental well-being during the duration of the study?’ (0 – 100, with 0 = negatively, 50 = not at all, 100 = positively). Moreover, compliance items (i.e. estimates of answered questionnaires as well as acceptability and feasibility of data entries) asked to what extent participants followed the study instructions. Please note that other parts of the dataset have previously been analysed and published in Schultchen et al. (2019) as well as Reichenberger et al. (2018).

Measures

Smartphone app. Participants received six app notifications (*beeps*) per day every 2.5 hours starting at 9:00 a.m. and ending at 9:30 p.m.. With each of these beeps individuals were asked among other things (e.g. eating behaviour, food craving, stress; not of relevance for the present study) to estimate their extent of moderate to vigorous PA since the last answered beep with the question '*How many minutes have you been physically active since the last entry? Under physical activity we define activities that got you sweating or out of breath.*'. Answers were given on a continuous rating slider from 0 to 160 minutes. Participants were given 10 additional minutes for their subjective data entry because of a potential short delay in answering the questionnaire after the first initial beep. Moreover, each beep contained adjectives concerning current positive and negative affective states rated on a continuous rating slider from 0 (= not at all) to 100 (= very much). Some adjectives were chosen in the style of the *Positive and Negative Affect Schedule* (PANAS; Watson, Clark, & Tellegen, 1988), more specifically the German Version of the PANAS (Breyer & Bluemke, 2016). Additionally, we included items in the same style referring to emotions with a lower threshold (e.g. worried instead of afraid), items which might optimally cover a high and low arousal space (e.g. relaxed as a low-arousal positive emotion), or items that are relevant to the specific study content (e.g. bored). Positive affect adjectives used were "cheerful", "enthusiastic", "relaxed", "calm", "active" and "awake", whereas negative ones were "irritated", "worried", "troubled", "bored", "nervous/stressed" and "dissatisfied with self". The within-person reliability of affect items was calculated using the variance decomposition technique (Shrout & Lane, 2012) and was moderate for positive affect (R_c = .78) as well as for negative affect (R_c = .69) according to Shrout (1998). For safety reasons (e.g. while driving) and practicability, it was permitted to answer the app prompts with a maximum delay of one hour after the onset of each beep interval. Later entries were registered as missing.

Objective PA measures. To measure objective parameters of PA, a combined heart rate and movement sensor (Actiheart; Cambridge Neurotechnology Ltd, 2010) was used. The first of two electrodes is located on the lower end of the sternum while the second one is attached laterally on the left side of the chest. The device determines heart rate (Brage, Brage, Franks, Ekelund, & Wareham, 2005) and activity impulses (using accelerometry) every 15 seconds and establishes METs classified in sedentary behaviour (< 1.5 METs), light PA (1.5 – 3 METs), moderate PA (3 – 6 METs), and vigorous PA (> 6 METs). Based on these data and the Actiheart's branched model of analysis, minutes of specific MET-levels in the interval between two smartphone beeps were calculated for each participant. As described above, only intervals for which both subjective and objective data were available were included in the statistical analyses, i.e. a maximum of seven days due to the Actiheart's battery life. In general, the Actiheart device is a technically reliable and valid instrument (Brage et al., 2005) for the measurement of heart rate and PA under natural conditions (Barreira, Kang, Caputo, Farley, & Renfrow, 2009). It has previously been used for PA research (Georgiou et al., 2015) and therefore served as the source of objective data in the present study.

Data reduction and statistical analyses

Due to the study's focus on all everyday (incidental) moderate to vigorous PA instead of exclusively intentional and planned exercising, analyses targeted minutes of moderate and vigorous PA (MVPA; > 3 METs) during a given 2.5 h interval between smartphone beeps. Because of repeated measures for each participant, hierarchical multilevel modeling was used for analyses by means of the software HLM7 (Raudenbusch, Bryk, & Congdon, 2011). Repeated assessments of an individual on Level 1 were nested within participants on Level 2.

Regarding the first research aim of *subjective-objective measurement concordance*, the subjective estimation of PA within the last 2.5 h between t_0 and t_1 (reported at t_1) was predicted on Level 1 by objectively measured data of PA, which were aggregated in the respective time interval. Secondary analyses were conducted including gender and BMI in prediction of the intercept on Level 2 to control for their influences. Moreover, similar to the measurement concordance analysis, an exploratory control analysis used sedentary behaviour (< 1.5 METs) as the predictor of subjective PA. Continuous predictor variables were person-mean centred on Level 1 and grand-mean centred on Level 2, whereas the dichotomous variable, i.e. gender (0 = female, 1 = male), was entered uncentred into the models.

For the second research aim of *affect improvements* participants' momentary mean positive (based on the 6 positive affect items above) and respectively mean negative (based on the 6 negative affect items above) affective states were calculated for each beep at t_1. Both mean affects were then predicted separately by subjective and objective measures of PA (person-mean centred) during the preceding 2.5 h interval (between t_0 and t_1). To avoid obtaining general affect maintenance effects, the influence of the preceding affect (at t_0) was simultaneously controlled for by using lagged affect variables (person-mean centred and auto-correlated). Additionally, exploratory control analyses used sedentary behaviour as the predictor of changes in affect. The slopes and intercepts in all models were allowed to vary randomly.

Results

Descriptives

Table 1 reports participants' descriptive statistics based on 1155 records of both EMA- (subjective) and Actiheart- (objective) based data. The overall compliance (percentage of completed EMA questionnaires) was 86%. Based on the FFKA questionnaire overall activity score, 27 participants were classified as having high physical activity levels, 7 medium PA levels and 3 low PA levels during the weeks before the smartphone assessment. Participants reported that the influence of study participation on their PA was rather low, M = 10.8 (SD = 13.94, range = 0 – 46). Moreover, participants also reported that the study participation neither negatively nor positively changed their mental well-being, M = 49.2 (SD = 6.90, range = 38 – 73).

Table 1

Descriptive statistics of the assessed variables.

Variable	***M***	***SD***
Level 1		
EMA: Subjective PA (0 – 160 minutes)	7.62	18.02
Sedentary behaviour (< 1.5 METs; in minutes)	121.15	27.74
Light PA (1.5 - 3 METs; in minutes)	21.37	19.48
Moderate PA (3 – 6 METs; in minutes)	6.76	11.84
Vigorous PA (> 6 METs; in minutes)	0.63	3.93
Objective MVPA (> 3 METs; in minutes)	7.39	13.21
Daily MVPA (> 3 METs; in minutes)	45.05	42.29
Negative affect (0 – 100)	14.31	13.03
Positive affect (0 – 100)	41.06	17.81
Level 2		
BMI (kg/m^2)	22.28	2.72

Note. N = 37. Data based on 1,155 observations, except for 'Daily MVPA' (222 observations) and BMI (one-time measurement). PA = Physical activity; MVPA = Moderate to vigorous physical activity; MET = Metabolic equivalent; BMI = body mass index. Range of daily MVPA: 0 – 299.00 minutes. All PA values (including sedentary behaviour) refer to intervals of 2.5 hours, except the daily MVPA.

Subjective-objective concordance

A first set of analyses tested the relationship of objective moderate to vigorous PA (MVPA) and subjective PA. The models are expressed by the following equation.

Level 1 (occasions)

$$subjectivePA_{tj} = \beta_{0j} + \beta_{1j} * (objectiveMVPA_{tj}) + r_{tj}$$

Level 2 (participants)

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + u_{1j}$$

A significant positive association between subjective PA and objective data of MVPA was found (β_{10} = .497, *SE* = .097, *p* < .001) with an overall pseudo-R^2 of .219. The higher the objective MVPA, the higher participants' subjective PA was. Furthermore, there was no significant difference between the mean subjective PA and the mean objective MVPA (min/2.5 h, *objective: M* = 7.45 minutes, *SE* = 4.14; subjective: *M* = 7.53, *SE* = 4.73) as revealed by a paired sample *t*-test, *t*(36) = -.076, *p* = .936.

Moreover, exploratory analyses were run with objective sedentary behaviour as a form of (low) objective PA. Results revealed a significant negative association with subjective PA (β_{10} = -.205, *SE* = .045, *p* < .001) with an overall pseudo-R^2 of .231. The longer the time sedentary, the lower participants' subjective PA was. Additionally, to test whether participants improved in concordance between subjective PA and objective MVPA across study participation, the variable 'day' (i.e. days in the study) was taken into account. No significant interaction was found meaning that consecutive days (i.e. the longer participants were part of the study) did not influence the association of subjective and objective PA (β_{30} = .88, *SE* = 2.04, *p* = .669). Controlling for gender and BMI did not influence the pattern or significance of all reported results.

Affect improvements

In order to analyse potential associations between PA estimates and positive as well as negative affect within a day, the latter were predicted by subjective and objective PA separately. To account for autocorrelations or – stated differently – to focus on affect *changes* in a given interval, the respectively preceding positive or negative affect was included as lagged control predictor. The models are expressed by the following equation (exemplified for subjective PA as predictor of positive affect).

Level 1 (occasions)

$$Current\ positive\ affect_{ij} = \beta_{0j} + \beta_{1j}*(subjectivePA_{ij}) + \beta_{2j}*(preceding\ positive\ affect_{ij}) + r_{ij}$$

Level 2 (participants)

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + u_{1j}$$

$$\beta_{2j} = \gamma_{20} + u_{2j}$$

Positive affect

A significant positive association between subjective PA estimates and positive affect was found (β_{10} = .193, SE = .041, p < .001) with an overall pseudo-R^2 of .059. The higher participants estimated the amount of their own (preceding) PA, the higher their current positive affect was. A significant positive association was also found regarding objective MVPA and positive affect (β_{10} = .141, SE = .036, p < .001) with an overall pseudo-R^2 of .027. When both assessment types were combined in one simultaneous model, subjective PA (β_{10} = .159, SE = .044, p < .001) as well as objective MVPA (β_{10} = .088, SE = .036, p < .001) remained significant with an overall pseudo-R^2 of .070. In contrast, a significant negative association between objective sedentary behaviour and positive affect was found (β_{10} = -.077, SE = .021, p < .001) with an overall pseudo-R^2 of .032. The longer the duration of sedentary behaviour, the lower participants' subsequent positive affect was. Again, controlling for gender and BMI did not influence the pattern or significance of all reported results.

Negative affect

Participants showed lower negative affect subsequent to higher subjective PA estimates: analyses revealed a significant negative association between negative affect and subjective PA

(β_{10} = -.107, *SE* = .017, *p* < .001) with an overall pseudo-R^2 of .039. Again, this result was also found for objective MVPA as the predictor of negative affect (β_{10} = -.095, *SE* = .024, *p* < .001) with an overall pseudo-R^2 of .020. When both assessment types were combined in one simultaneous model, subjective PA (β_{10} = -.092, *SE* = .016, *p* < .001) as well as objective MVPA (β_{10} = -.054, *SE* = .020, *p* < .001) remained significant with an overall pseudo-R^2 of .043. On the other hand, higher negative affect was found after longer episodes of sedentary behaviour, as objective sedentary behaviour was significantly positively associated with subsequent negative affect (β_{10} = .051, *SE* = .011, *p* < .001) with an overall pseudo-R^2 of .012. Again, controlling for gender and BMI did not influence the pattern or significance of all reported results.

Discussion

In the context of assessing affect improvements as a result of PA, the present study used a naturalistic EMA design to examine two research aims. The first question examined the concordance of subjective EMA data and objective, heart rate weighted accelerometric measures of PA within a given individual across seven days. The second question investigated both data sources of PA as predictors of affect improvements (increase in positive affect and decrease in negative affect examined separately).

Research aim 1: Subjective-objective (measurement) concordance

Regarding the first research aim, we obtained measurement concordance as hypothesised: Results revealed a significant association between subjective and objective MVPA, as well as largely accurate MVPA estimations (non-significant *t*-test). This result contrasts with previous findings of overestimation of moderate (to vigorous) PA in a comparable student sample (Downs et al., 2014). In addition, the present results differ from results of over- or underestimation that used different methodological approaches and samples (e.g. in an adult sample: Dyrstad, Hansen, Holme, & Anderssen, 2014; Prince et al., 2008).

However, our reported results correspond to findings of accurate (or even under-estimated) estimates by physically fit study participants in terms of overall concordance (Shook et al., 2016) as well as to time-specific within-subject concordance (Bexelius, Sandin, Trolle Lagerros, Litton, & Löf, 2011). One explanation of the accurate estimations in the present study might be that moderate to vigorous PA likely 'breaks into awareness' by reaching an intensity that is subjectively noted and remembered, whereas 'lighter' episodes of PA might go unnoticed. This interpretation is underpinned by a review observing that self-reports are more sensitive to high intensity objective PA compared to low-to-moderate ones (Prince et al., 2008). Thus, the observed measurement concordance could be the result of PA-awareness that enabled participants' precise and systematic self-reports of PA episode durations (for a detailed view on PA-related awareness, see Ronda et al., 2001; van Sluijs, Griffin, & van Poppel, 2007). In the present study, neither BMI nor gender changed the pattern or significance of the results (in line with Dyrstad et al., 2014; Poole et al., 2011) suggesting a rather broad applicability within the present population.

Research aim 2: Affect improvements

Regarding the second research aim, subjective estimates of PA emerged as significant predictors of improvements in both positive and negative affect (even in consideration of the controlled influence of the preceding affect and the respective objective PA). The same results were found regarding objective MVPA. Thus, both objective and subjective PA indices appear to be unique, non-redundant and reliable predictors of both types of affect improvement (decrease in negative affect and increase in positive affect). Similarly, subjective and objective PA assessments have shown specific associations with health relevant outcomes such as different cardiovascular measures (Schmidt, Cleland, Thomson, Dwyer, & Venn, 2008). Complementing these findings, objective sedentary behaviour was significant as a positive predictor of affect deterioration in the present study. Our reported effects for objective MVPA agree with previous findings regarding positive affect increases (Cox, Thomas, & Davis, 2001; Hogan et al., 2013) as well as negative affect decreases (Aggio et al., 2017). However, also the subjective perception of PA was associated with (positive and negative) affect improvements: the predictive potential of subjective PA in the present study corresponds to previous findings regarding positive affect increases (e.g. Kanning & Schlicht, 2010; Mata et al., 2012; Wichers et al., 2012). In contrast to other studies (Mata et al., 2012; Schwerdtfeger, Eberhardt, & Chmitorz, 2008; Wichers et al., 2012), the present study was also able to find negative affect decreases after PA. The results suggest that introspection and self-monitoring/self-awareness regarding PA translate into affect improvements independently of objective PA. At the same time, the results support the affect changing potential of actual (objective) PA, as the effects of PA on physical and mental health are undisputed.

Together, these two associations suggest different mediating routes from PA to affect. Psychophysiological research on the one hand has shown that objective movement, for instance aerobic exercise, inhibits the feedback mechanism of the hypothalamic-pituitary-adrenal axis (HPA axis) and thereby reduces the cortisol response in stressful situations (i.e. *stress buffering*) while also increasing positive affect (Zschucke et al., 2015). Moreover, brain regions (e.g. ventral striatum) and neurotransmitters (e.g. dopamine), that are associated with reward systems, are influenced by PA (Bothe et al., 2013). Thus, psychophysiological or ‘bottom-up’ mechanisms might likely be at play. In addition to physiological mechanisms, the subjective perception of one’s own PA seems to positively influence affect and thereby might contribute to the maintenance of health relevant behaviour. As already described above, psychological aspects such as awareness and self-efficacy (or related experiences such as pride and goal attainment) might play important roles in this context (Bodin & Martinsen, 2004; Kavanaugh et al., 2015; McAuley et al., 2007; Pickett, Yardley, & Kendrick, 2012; van Sluijs et al., 2007). The fact that affect improvements can be attained through both positive affect increases and negative affect decreases suggests that (positive and negative) reinforcement should work for both negative and ‘neutral’ baseline affects. Regarding both types of reinforcement, previous research has found that PA can lead to an increase in positive affect as well as to a decrease in negative affect in individuals with rather ‘neutral’ baseline affects (i.e. healthy individuals; Annesi et al., 2017; Joseph et al., 2014; Wunsch et al., 2017) as well as individuals with rather negative baseline affects, i.e. (subclinically) depressed individuals (Mata, Hogan, Joormann, Waugh, & Gotlib, 2013; Pickett et al., 2012).

Limitations, future directions and conclusions

The following limitations must be acknowledged: Firstly, our sample consisted mostly of female university students. Therefore, results cannot be generalised, which appears plausible given that different results were found in different samples (e.g. Dyrstad et al., 2014). Hence, future studies may examine participants with broader sample characteristics, especially from vulnerable populations such as older adults (e.g. Shiroma et al., 2015) or individuals with chronic diseases (e.g. O’Neill et al., 2017; Thyregod & Bodtger, 2016). Additionally, the sample size of the present study was also relatively small and might be increased in future studies to improve statistical power on Level 2. In order to increase power on Level 1, future studies might also extend the assessment period (more days) and / or increase the frequency of assessment (more beeps per day). Secondly, our methodological approach was to assess subjective MVPA across the last 2.5 h in order to balance study interest and participant burden. However, future research might profit from a more fine-grained assessment of PA (e.g. with regard to kind of activity, individual intensity according to fitness level, etc.) and variability in recall period (e.g. reporting PA directly when it occurs). This approach might also aid in mapping subjective PA more closely to the objective PA assessment. Moreover, future studies could additionally make use of objective physiological markers to examine PA and affect related biological mechanisms, for instance by means of an ambulatory sampling of cortisol. Thirdly, because of the monitoring device (and related battery life) the assessment period was shorter than the possible smartphone assessment period. Future research might utilise other kinds of PA tracking like an inbuilt accelerometer in modern smartphones, a wrist-worn fitness tracker or combinations of smartphone apps and fitness trackers to gather objective PA.

To conclude, the present study shed light on the association between subjective EMA estimates and objective, heart rate weighted accelerometric PA measures. In this context, smartphone-based subjective assessment seems a promising and valid method (e.g. Knell et al., 2017) because of its high practicability and ubiquity. Importantly, a psychological advantage might be that the above-mentioned awareness of one's individual extent of PA may be increased in the course of self-reporting (van Sluijs, van Poppel, Twisk, & Mechelen, 2006) and could thereby initiate a self-reflective process. Such competence appears to be of great importance for health-related awareness and increased engagement in PA (Lechner, Bolman, & van Dijke, 2006; Ronda et al., 2001; van Sluijs et al., 2007). Future studies could make use of individual (bio-) feedback regarding both subjective and objective assessment methods in order to examine an enhancement of participants' PA-awareness as a potential form of health beneficial intervention. As the present study underlines the relevance of subjective perception and objective measures regarding health behaviour, both sources of data are relevant parts of any comprehensive monitoring or intervention approach targeting PA and its affect improving benefits.

Conflict of interest

The authors declare that there is no conflict of interest.

References

Aggio, D., Wallace, K., Boreham, N., Shankar, A., Steptoe, A., & Hamer, M. (2017). Objectively measured daily physical activity and postural changes as related to positive and negative affect using ambulatory monitoring assessments. *Psychosomatic Medicine, 79*(7), 792–797. doi:10.1097/PSY.0000000000000485

Annesi, J. J., Porter, K. J., Hill, G. M., & Goldfine, B. D. (2017). Effects of instructional physical activity courses on overall physical activity and mood in university students. *Research Quarterly for Exercise and Sport, 88*(3), 358–364. doi:10.1080/02701367.2017.1336280

Asztalos, M., De Bourdeaudhuij, I., & Cardon, G. (2010). The relationship between physical activity and mental health varies across activity intensity levels and dimensions of mental health among women and men. *Public Health Nutrition, 13*(8), 1207–1214. doi:10.1017/S1368980009992825

Audrey, S., Procter, S., & Cooper, A. R. (2014). The contribution of walking to work to adult physical activity levels: A cross sectional study. *International Journal of Behavioral Nutrition and Physical Activity, 11*(37). doi:10.1186/1479-5868-11-37

Barreira, T., Kang, M., Caputo, J., Farley, R., & Renfrow, M. (2009). Validation of the Actiheart monitor for the measurement of physical activity. *International Journal of Exercise Science, 2*(1), 60–71.

Bert, F., Giacometti, M., Gualano, M. R., & Siliquini, R. (2013). Smartphones and health promotion: A review of the evidence. *Journal of Medical Systems, 38*(1), 9995. doi:10.1007/s10916-013-9995-7

Bexelius, C., Sandin, S., Trolle Lagerros, Y., Litton, J.-E., & Löf, M. (2011). Estimation of physical activity levels using cell phone questionnaires: A comparison with accelerometry for evaluation of between-subject and within-subject variations. *Journal of Medical Internet Research, 13*(3), e70. doi:10.2196/jmir.1686

Bodin, T., & Martinsen, E. W. (2004). Mood and self-efficacy during acute exercise in clinical depression. A randomized, controlled study. *Journal of Sport and Exercise Psychology, 26*(4), 623–633. doi:10.1123/jsep.26.4.623

Bossmann, T., Kanning, M., Koudela, S., Hey, S., & Ebner-Priemer, U. (2013). The association between short periods of everyday life activities and affective states: A replication study using ambulatory assessment. *Frontiers in Psychology, 4*(102). doi:10.3389/fpsyg.2013.00102

Bothe, N., Zschucke, E., Dimeo, F., Heinz, A., Wustenberg, T., & Strohle, A. (2013). Acute exercise influences reward processing in highly trained and untrained men. *Medicine & Science in Sports & Exercise, 45*(3), 583–591. doi:10.1249/MSS.0b013e318275306f

Brage, S., Brage, N., Franks, P. W., Ekelund, U., & Wareham, N. J. (2005). Reliability and validity of the combined heart rate and movement sensor Actiheart. *European Journal of Clinical Nutrition, 59*(4), 561–570. doi:10.1038/sj.ejcn.1602118

Breyer, B., & Bluemke, M. (2016). *Deutsche Version der Positive and Negative Affect Schedule PANAS (GESIS Panel) [German version of the Positive and Negative Affect Schedule PANAS (GESIS Panel)].* Mannheim, Germany: GESIS - Leibniz-Institut für Sozialwissenschaften.

Cambridge Neurotechnology Ltd. (2010). *The Actiheart User Manual (v. 4.0.35)*. Cambridgeshire, United Kingdom: Cambridge Neurotechnology Ltd.

Cooney, G., Dwan, K., Greig, C., Lawlor, D., Rimer, J., Waugh, F., . . . Mead, G. (2013). Exercise for depression. *The Cochrane Database of Systematic Reviews, 9*(CD004366). doi:10.1002/14651858.CD004366.pub6

Cox, R. H., Thomas, T. R., & Davis, J. E. (2001). Postive and negative affect associated with an acute bout of aerobic exercise. *Journal of Exercise Physiology online, 4*(4), 13–20.

Downs, A., Van Hoomissen, J., Lafrenz, A., & Julka, D. L. (2014). Accelerometer-measured versus self-reported physical activity in college students: Implications for research and practice. *Journal of American College Health, 62*(3), 204–212. doi:10.1080/07448481.2013.877018

Dyrstad, S., Hansen, B., Holme, I., & Anderssen, S. (2014). Comparison of self-reported versus accelerometer-measured physical activity. *Medicine & Science in Sports & Exercise, 46*(1), 99–106. doi:10.1249/MSS.0b013e3182a0595f

Frey, I., & Berg, A. (2002). Physical activity counseling: Assessment of physical activity by questionnaire. *European Journal of Sport Science, 2*(4), 1–6. doi:10.1080/17461390200072406

Frey, I., Berg, A., Grathwohl, D., & Keul, J. (1999). Freiburger Fragebogen zur körperlichen Aktivität - Entwicklung, Prüfung und Anwendung [Freiburg questionnaire of physical activity - development, evaluation and application]. *Sozial-und Präventivmedizin, 44*(2), 55–64. doi:10.1007/bf01667127

Georgiou, E., Matthias, E., Kobel, S., Kettner, S., Dreyhaupt, J., Steinacker, J., & Pollatos, O. (2015). Interaction of physical activity and interoception in children. *Frontiers in Psychology, 6*. doi:10.3389/fpsyg.2015.00502

Hallal, P., Andersen, L., Bull, F., Guthold, R., & Ekelund, U. (2012). Global physical activity levels: Surveillance progress, pitfalls, and prospects. *The Lancet, 380*(9838), 247–257. doi:10.1016/S0140-6736(12)60646-1

Haskell, W. L., Lee, I.-M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., . . . Bauman, A. (2007). Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Medicine & Science in Sports & Exercise, 39*(8), 1423–1434. doi:10.1249/mss.0b013e3180616b27

Hogan, C., Mata, J., & Carstensen, L. (2013). Exercise holds immediate benefits for affect and cognition in younger and older adults. *Psychology and Aging, 28*(2), 587-594. doi:10.1037/a0032634

Jetté, M., Sidney, K., & Blümchen, G. (1990). Metabolic Equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity. *Clinical Cardiology, 13*(8), 555–565. doi:10.1002/clc.4960130809

Joseph, R. P., Royse, K. E., Benitez, T. J., & Pekmezi, D. W. (2014). Physical activity and quality of life among university students: Exploring self-efficacy, self-esteem, and affect as potential mediators. *Quality of Life Research, 23*(2), 659–667. doi:10.1007/s11136-013-0492-8

Kanning, M., & Schlicht, W. (2010). Be active and become happy: An ecological momentary assessment of physical activity and mood. *Journal of Sport and Exercise Psychology, 32*(2), 253–261. doi:10.1123/jsep.32.2.253

Kavanaugh, K., Moore, J. B., Hibbett, L. J., & Kaczynski, A. T. (2015). Correlates of subjectively and objectively measured physical activity in young adolescents. *Journal of Sport and Health Science, 4*(3), 222–227. doi:10.1016/j.jshs.2014.03.015

Knell, G., Gabriel, K., Businelle, M., Shuval, K., Wetter, D., & Kendzor, D. (2017). Ecological momentary assessment of physical activity: Validation study. *Journal of Medical Internet Research, 19*(7), e253. doi:10.2196/jmir.7602

Kwan, B., & Bryan, A. (2010). Affective response to exercise as a component of exercise motivation: Attitudes, norms, self-efficacy, and temporal stability of intentions. *Psychology of Sport and Exercise, 11*(1), 71–79. doi:10.1016/j.psychsport.2009.05.010

Lechner, L., Bolman, C., & van Dijke, M. (2006). Factors related to misperception of physical activity in the Netherlands and implications for health promotion programmes. *Health Promotion International, 21*(2), 104–112. doi:10.1093/heapro/dal011

Liao, Y., Shonkoff, E., & Dunton, G. (2015). The acute relationships between affect, physical feeling states, and physical activity in daily life: A review of current evidence. *Frontiers in Psychology, 6*(1975). doi:10.3389/fpsyg.2015.01975

Liu, J., Bennett, K., Harun, N., & Probst, J. (2008). Urban-rural differences in overweight status and physical inactivity among US children aged 10-17 years. *The Journal of Rural Health, 24*(4), 407–415. doi:10.1111/j.1748-0361.2008.00188.x

Martin, A., Kelly, P., Boyle, J., Corlett, F., & Reilly, J. J. (2016). Contribution of walking to school to individual and population moderate-vigorous intensity physical activity: Systematic review and meta-analysis. *Pediatric Exercise Science, 28*(3), 353–363. doi:10.1123/pes.2015-0207

Mata, J., Hogan, C. L., Joormann, J., Waugh, C. E., & Gotlib, I. H. (2013). Acute exercise attenuates negative affect following repeated sad mood inductions in persons who have recovered from depression. *Journal of Abnormal Psychology, 122*(1), 45–50.

Mata, J., Thompson, R. J., Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Gotlib, I. H. (2012). Walk on the bright side: Physical activity and affect in major depressive disorder. *Journal of Abnormal Psychology, 121*(2), 297–308. doi:10.1037/a0023533

McAuley, E., Morris, K., Motl, R., Hu, L., Konopack, J., & Elavsky, S. (2007). Long-term follow-up of physical activity behavior in older adults. *Health Psychology, 26*(3), 375–380. doi:10.1037/0278-6133.26.3.375

O'Neill, B., McDonough, S., Wilson, J., Bradbury, I., Hayes, K., Kirk, A., . . . Tully, M. (2017). Comparing accelerometer, pedometer and a questionnaire for measuring physical activity in bronchiectasis: A validity and feasibility study. *Respiratory Research, 18*(16). doi:10.1186/s12931-016-0497-2

Peluso, M., & Andrade, L. H. (2005). Physical activity and mental health: The association between exercise and mood. *Clinics, 60*(1), 61–70. doi:10.1590/S1807-59322005000100012

Pickett, K., Yardley, L., & Kendrick, T. (2012). Physical activity and depression: A multiple mediation analysis. *Mental Health and Physical Activity, 5*(2), 125–134. doi:10.1016/j.mhpa.2012.10.001

Poole, L., Steptoe, A., Wawrzyniak, A. J., Bostock, S., Mitchell, E. S., & Hamer, M. (2011). Associations of objectively measured physical activity with daily mood ratings and psychophysiological stress responses in women. *Psychophysiology, 48*(8), 1165–1172. doi:10.1111/j.1469-8986.2011.01184.x

Prince, S., Adamo, K., Hamel, M., Hardt, J., Gorber, S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: A systematic review. *The International Journal of Behavioral Nutrition and Physical Activity, 5*(56). doi:10.1186/1479-5868-5-56

Puterman, E., Weiss, J., Beauchamp, M., Mogle, J., & Almeida, D. (2017). Physical activity and negative affective reactivity in daily life. *Health Psychology, 36*(12), 1186–1194. doi:10.1037/hea0000532

Raudenbusch, S. W., Bryk, A. S., & Congdon, R. (2011). HLM7 for Windows [Computer software]: Skokie, IL: Scientific Software International, Inc.

Rebar, A., Stanton, R., Geard, D., Short, C., Duncan, M., & Vandelanotte, C. (2015). A meta-meta-analysis of the effect of physical activity on depression and anxiety in non-clinical adult populations. *Health Psychology Review, 9*(3), 366–378. doi:10.1080/17437199.2015.1022901

Reichenberger, J., Richard, A., Smyth, J. M., Fischer, D., Pollatos, O., & Blechert, J. (2018). It's craving time: Time of day effects on momentary hunger and food craving in daily life. *Nutrition, 55-56*, 15–20. doi:10.1016/j.nut.2018.03.048

Richardson, C., Faulkner, G., McDevitt, J., Skrinar, G., Hutchinson, D., & Piette, J. (2005). Integrating physical activity into mental health services for persons with serious mental illness. *Psychiatric Services*, *56*(3), 324–331. doi:10.1176/appi.ps.56.3.324

Ronda, G., Assema, P., & Brug, J. (2001). Stages of change, psychological factors and awareness of physical activity levels in the Netherlands. *Health Promotion International, 16*(4), 305–314. doi:10.1093/heapro/16.4.305

Rosenbaum, S., Tiedemann, A., Sherrington, C., Curtis, J., & Ward, P. (2014). Physical activity interventions for people with mental illness: A systematic review and meta-analysis. *Journal of Clinical Psychiatry, 75*(9), 964–974. doi:10.4088/JCP.13r08765

Sallis, J., & Saelens, B. (2000). Assessment of physical activity by self-report: Status, limitations, and future directions. *Research Quarterly for Exercise and Sport, 71*(2), 1–14. doi:10.1080/02701367.2000.11082780

Saris, W., Blair, S. N., van Baak, M., Eaton, S., Davies, P., Pietro, L., . . . Wyatt, H. (2003). How much physical activity is enough to prevent unhealthy weight gain? Outcome of the IASO 1st Stock Conference and consensus statement. *Obesity Reviews, 4*(2), 101–114. doi:10.1046/j.1467-789X.2003.00101.x

Schmidt, M., Cleland, V., Thomson, R., Dwyer, T., & Venn, A. (2008). A comparison of subjective and objective measures of physical activity and fitness in identifying associations with cardiometabolic risk factors. *Annals of Epidemiology, 18*(5), 378–386. doi:10.1016/j.annepidem.2008.01.005

Schöndube, A., Kanning, M., & Fuchs, R. (2016). The bidirectional effect between momentary affective states and exercise duration on a day level. *Frontiers in Psychology, 7*(1414). doi:10.3389/fpsyg.2016.01414

Schultchen, D., Reichenberger, J., Mittl, T., Weh, T. R. M., Smyth, J. M., Blechert, J., & Pollatos, O. (2019). Bidirectional relationship of stress and affect with physical activity and healthy eating. *British Journal of Health Psychology, 24*(2), 315–333. doi:10.1111/bjhp.12355

Schwerdtfeger, A., Eberhardt, R., & Chmitorz, A. (2008). Gibt es einen Zusammenhang zwischen Bewegungsaktivität und psychischem Befinden im Alltag? [Is there an association between physical activity and mental well-being in everyday life?] *Zeitschrift für Gesundheitspsychologie*, *16*, 2–11. doi:10.1026/0943-8149.16.1.2

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological momentary assessment. *Annual Review of Clinical Psychology, 4,* 1–32.

Shiroma, E. J., Cook, N. R., Manson, J. E., Buring, J. E., Rimm, E. B., & Lee, I.-M. (2015). Comparison of self-reported and accelerometer-assessed physical activity in older women. *Plos One, 10*(12), e0145950. doi:10.1371/journal.pone.0145950

Shook, R., Gribben, N., Hand, G., Paluch, A., Welk, G., Jakicic, J., . . . Blair, S. (2016). Subjective estimation of physical activity using the IPAQ varies by fitness level. *Journal of Physical Activity & Health, 13*, 79–86. doi:10.1123/jpah.2014-0543

Shrout, P. (1998). Measurement reliability and agreement in psychiatry. *Statistical Methods in Medical Research*, *7*(3), 301–317. doi:10.1191/096228098672090967

Shrout, P., & Lane, S. P. (2012). Psychometrics. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of Research Methods for Studying Daily Life* (pp. 302–320). New York, NY: The Guilford Press.

Slootmaker, S., Schuit, A., Chinapaw, M., Seidell, J., & Mechelen, W. (2009). Disagreement in physical activity assessed by accelerometer and self-report in subgroups of age, gender, education and weight status. *The International Journal of Behavioral Nutrition and Physical Activity*, *6*(17). doi:10.1186/1479-5868-6-17

Storrie, K., Ahern, K., & Tuckett, A. (2010). A systematic review: Students with mental health problems—A growing problem. *International Journal of Nursing Practice, 16*(1), 1–6. doi:10.1111/j.1440-172X.2009.01813.x

Thome, J., & Espelage, D. L. (2004). Relations among exercise, coping, disordered eating, and psychological health among college students. *Eating Behaviors, 5*(4), 337–351. doi:10.1016/j.eatbeh.2004.04.002

Thyregod, M., & Bodtger, U. (2016). Coherence between self-reported and objectively measured physical activity in patients with chronic obstructive lung disease: A systematic review. *International Journal of Chronic Obstructive Pulmonary Disease, 11,* 2931–2938. doi:10.2147/COPD.S116422

Tudor-Locke, C., & Bassett, D. (2004). How many steps/day are enough? *Sports Medicine, 34,* 1–8. doi:10.2165/00007256-200434010-00001

van Sluijs, E., Griffin, S., & van Poppel, M. (2007). A cross-sectional study of awareness of physical activity: Associations with personal, behavioral and psychosocial factors. *The International Journal of Behavioral Nutrition and Physical Activity, 4*(53). doi:10.1186/1479-5868-4-53

van Sluijs, E., van Poppel, M., Twisk, J., & Mechelen, W. (2006). Physical activity measurements affected participants' behavior in a randomized controlled trial. *Journal of Clinical Epidemiology, 59*(4), 404–411. doi:10.1016/j.jclinepi.2005.08.016

Warburton, D. E., Nicol, C. W., & Bredin, S. S. (2006). Health benefits of physical activity: The evidence. *Canadian Medical Association Journal, 174*(6), 801–809.

Warren, J., Ekelund, U., Besson, H., Mezzani, A., Geladas, N., & Vanhees, L. (2010). Assessment of physical activity - A review of methodologies with reference to epidemiological research: A report of the exercise physiology section of the European Association of Cardiovascular Prevention and Rehabilitation. *European Journal of Cardiovascular Prevention and Rehabilitation, 17*(2), 127–139. doi:10.1097/HJR.0b013e32832ed875

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54*(6), 1063–1070.

Wichers, M., Peeters, F., Rutten, B., Jacobs, N., Derom, C., Thiery, E., . . . van Os, J. (2012). A time-lagged momentary assessment study on daily life physical activity and affect. *Health Psychology, 31*(2), 135–144. doi:10.1037/a0025688

World Health Organization. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. Geneva, Switzerland: World Health Organization.

World Health Organization. (2010). *Global recommendations on physical activity for health*. Geneva, Switzerland: World Health Organization.

Wunsch, K., Kasten, N., & Fuchs, R. (2017). The effect of physical activity on sleep quality, well-being, and affect in academic stress periods. *Nature and Science of Sleep, 9*, 117–126. doi:10.2147/NSS.S132078

Zhai, L., Zhang, Y., & Zhang, D. (2014). Sedentary behaviour and the risk of depression: A meta-analysis. *British Journal of Sports Medicine*, *49*(11), 705–709. doi:10.1136/bjsports-2014-093613

Zschucke, E., Renneberg, B., Dimeo, F., Wüstenberg, T., & Ströhle, A. (2015). The stress-buffering effect of acute exercise: Evidence for HPA axis negative feedback. *Psychoneuroendocrinology, 51*, 414–425. doi:10.1016/j.psyneuen.2014.10.019