Received: 27 March 2019 | Revised: 14 August 2019 | Accepted: 29 September 2019
DOI: 10.1002/erv.2706

RESEARCH ARTICLE

WILEY

Testing an emotion regulation model of physical activity in adolescents with anorexia nervosa: A pilot ecological momentary assessment

David R. Kolar[1] | Christina Neumayr[2] | Melina Roth[1] | Ulrich Voderholzer[2,3,4] | Karin Perthes[1] | Sandra Schlegl[4]

[1]Department of Child and Adolescent Psychiatry, University Medicine of the Johannes Gutenberg-University, Mainz, Germany

[2]Schoen Clinic Roseneck, Prien am Chiemsee, Germany

[3]Department of Psychiatry and Psychotherapy, Medical Center - University of Freiburg, Freiburg, Germany

[4]Department of Psychiatry and Psychotherapy, University Hospital of the Ludwig-Maximilians-University, Munich, Germany

Correspondence
David R. Kolar, Department of Child and Adolescent Psychiatry, University Medicine of the Johannes Gutenberg-University, Langenbeckstr. 1, 55131 Mainz, Germany.
Email: david.kolar@unimedizin-mainz.de

Funding information
Johannes Gutenberg-University Mainz, Germany

Abstract

Objective: Adolescents with anorexia nervosa (AN) often show increased levels of exercise and physical activity. Psychological models suggest that physical activity in AN might attenuate momentary negative affect. However, this has not been directly tested in adolescents with AN, and it remains unclear whether this is a distinct mechanism of physical activity in AN compared with healthy controls (HCs).

Method: In a 1-day ecological momentary assessment, 32 adolescent inpatients with AN and 30 HCs responded to hourly questions on momentary affect while wearing an actigraph to objectively assess physical activity.

Results: Linear mixed models identified that adolescents with AN experienced more aversive tension, more negative affect, and less positive affect throughout the day than HCs. Preliminary evidence for a momentary association of higher levels of physical activity with positive affect were found for both groups, whereas higher levels of physical activity were associated with less negative affect in adolescents with AN only. When correcting for multiple testing, interactions did not hold statistical significance.

Discussion: Our results indicate a down-regulation effect of physical activity on negative affect for AN and a more general up-regulation effect of positive affect. However, our sample size was small, and replication of our findings is needed.

KEYWORDS

anorexia nervosa, aversive tension, eating disorder, ecological momentary assessment, emotion regulation, physical activity

1 | INTRODUCTION

Anorexia nervosa (AN) is a severe mental disorder characterized particularly by continued weight-loss, restrictive eating and severe body image disturbances (American Psychiatric Association, 2013). In addition, a remarkable drive for physical activity is recognized as inherent to the disorder in many cases (Gummer et al., 2015; Meyer, Taranis, Goodwin, & Haycraft, 2011), with an average of 65.5% of the individuals showing features of compulsive exercise in samples of adolescents with AN (Fietz, Touyz, & Hay, 2014). AN is furthermore often associated with an onset in adolescence, risk of a chronic course (Hoek, 2006; Zipfel, Löwe, Reas, Deter, & Herzog, 2000), and high mortality (Franko et al., 2013; Smink, van Hoeken, & Hoek, 2012).

Modern etiological models of AN emphasize difficulties in emotion regulation as causal to the disorder (Haynos & Fruzzetti, 2011; Munro, Randell, & Lawrie, 2017). These models primarily assume that disordered eating behaviours serve to regulate current or persistent aversive emotional states. For example, Haynos and Fruzzetti (2011) proposed a transactional emotion dysregulation model of AN which describes disordered eating behaviours such as binge eating, purging, restrictive eating or excessive/compulsive exercise as dysfunctional behaviours to briefly reduce heightened emotional arousal, caused by both individual emotional vulnerability and momentary events. A growing body of literature supports the important role of emotion regulation in AN, as for example higher levels of difficulties in emotion regulation have been found in individuals with eating disorders compared with healthy control (HC) participants (Brockmeyer et al., 2014; Svaldi, Griepenstroh, Tuschen-Caffier, & Ehring, 2012), adolescents with AN show more difficulties identifying emotions as HCs (Kolar et al., 2017), starvation state (and therefore severe restrictive eating) in AN is associated with fewer emotion regulation difficulties only in individuals with acute AN (Brockmeyer et al., 2012), and these difficulties do not improve with weight restoration (Haynos, Roberto, Martinez, Attia, & Fruzzetti, 2014). Besides state differences in emotion regulation difficulties between healthy individuals and individuals with AN, several studies have investigated momentary within-subject associations of emotional states with other disordered eating behaviours, using ecological momentary assessment (EMA). With EMA, emotional states, disordered eating behaviours and their associations can be investigated in real time and outside of laboratory settings to increase ecological validity (Smyth et al., 2001). A recent study using EMA to investigate emotion regulation in AN in a two weeks period has found a rise of negative affect until the occurrence of loss of control eating and/or purging behaviours, with a significant decrease of negative affect directly after their occurrence (Engel et al., 2013). In particular, momentary levels and changes of anxiety/tension were associated with disordered eating behaviours (Lavender et al., 2013), rumination about food and weight (Seidel et al., 2016) and meal times (Kolar, Hammerle, Jenetzky, Huss, & Burger, 2016). Aversive tension, which is defined as a highly unpleasant feeling of distress without the qualitative specification as in fear, anger, guilt or shame (Stiglmayr et al., 2005), showed furthermore rapid fluctuations throughout a day when measured every other hour (Kolar, Hammerle, Jenetzky, Huss, & Burger, 2016). These findings are mostly in favour of an emotional escape or down-regulation functionality of disordered eating behaviours in AN, whereas an emotional avoidance model of restrictive eating has not been supported (Haynos et al., 2015).

Highlights

- Higher levels of physical activity predict less negative affect in anorexia nervosa.
- Higher levels of physical activity predict more positive affect in both groups.
- No effect of physical activity on momentary aversive tension was found.

Given the emotion regulation functionality of restriction, bingeing or purging, a similar functionality is assumed for physical activity in AN (Meyer, Taranis, Goodwin, & Haycraft, 2011). In fact, there is evidence in support of this hypothesis, as (a) individuals with AN report regulation of negative affect as a main reason for exercise (Bratland-Sanda et al., 2010), (b) higher levels of anxiety are associated with excessive exercise (Holtkamp, Hebebrand, & Herpertz-Dahlmann, 2004; Klein et al., 2004; Noetel et al., 2016; Penas-Lledo, Vaz Leal, & Waller, 2002), and (c) dysfunctional emotion regulation predicts compulsive exercise in adolescents even when controlling for baseline levels of compulsive exercise in a longitudinal community-based study (Goodwin, Haycraft, & Meyer, 2014). In addition, non-exercise levels of physical activity such as fidgeting or restless behaviour are increased in individuals with AN (Belak et al., 2017). However, in the literature large discrepancies were reported when retrospective self-reports of exercise were compared with more objectively assessed levels of physical activity based on accelerometers (Alberti et al., 2013; Keyes et al., 2015), which is why the latter is recommended (Gummer et al., 2015).

Although there are several studies investigating cross-sectional associations of excessive exercise with emotion regulation in AN, fewer studies focus on momentary within-person associations of emotional states and physical activity compared with associations of these states with other disordered eating behaviours. In the study by Engel et al. (2013), exercise is associated with an antecedent increase of negative affect immediately before and a subsequent decrease of negative affect immediately afterwards. This indicates that exercise might serve as an emotion regulation strategy to evade negative emotional states. However, the results are based on self-reported exercise and no linear change was found when trajectory analyses were conducted. Another study finds that the momentary urge to move and physical activity itself are associated with chronically negative affect, and momentary emotional states, particularly positive emotional states, are associated with physical activity (Vansteelandt, Rijmen, Pieters, Probst, & Vanderlinden, 2007). Lastly, a small pilot study based on nine patients with AN revealed reciprocal interactions of positive affect with physical activity, indicating that increased physical activity might increase positive affect, which in turn facilitates further activity (Karr et al., 2017). These few findings are in line with community-based EMA studies, indicating that higher daily physical activity in young adults is associated with less negative affect at the end of day (Haas, Schmid, Stadler, Reuter, & Gawrilow, 2017) and momentary physical activity is associated with subsequent increases in positive affect within 15 min (Schwerdtfeger, Eberhardt, & Chmitorz, 2008). Evidence for a decrease in momentary negative affect after physical activity is considered inconclusive for community-based samples (Liao, Shonkoff, & Dunton, 2015; Schwerdtfeger et al., 2008), and stress is only associated with exercise in individuals with lower levels of eating disorder symptoms (Sala, Brosof, Rosenfield, Fernandez, & Levinson, 2017). Furthermore, states of momentary positive and in some studies also negative affect are associated with subsequent increases in physical activity (Liao, Shonkoff, & Dunton, 2015; Schwerdtfeger, Eberhardt, Chmitorz, & Schaller, 2010). Hence, it remains inconclusive if physical activity truly serves as an effective strategy to regulate negative affect rather than increasing positive affect in healthy individuals.

2 | CURRENT STUDY

Overall, mixed results are found regarding the emotion regulation functionality of physical activity in AN. Although cross-sectional studies suggest that higher levels of physical activity are associated with more difficulties in emotion regulation and higher levels of negative affect, especially anxiety, it is unclear if momentary physical activity is associated with subsequent decreased negative affect or even an increased positive affect in individuals with AN, particularly as mixed findings exist in community-based studies. As some affect regulation functionality of physical activity most likely exists also in HC and previous studies in clinical populations did not account for differential effects, a study comparing HC to individuals with AN might provide further understanding. In addition, previous studies on this momentary association have relied mostly on self-reported physical activity, which is prone to recall bias and social desirability, resulting in low reliability in samples of patients with AN. In the current study, we tested the momentary association of objectively measured physical activity with aversive tension, positive affect, and negative affect of adolescents with AN in comparison with HCs. We decided to investigate aversive tension in addition to negative affect as aversive tension might account for high emotional arousal in the absence of specified emotions compared with negative affect. In line with the proposed models of emotion dysregulation (Haynos & Fruzzetti, 2011) and of affect regulation of exercise in AN (Meyer et al., 2011) indicating an emotion regulation function of physical activity, we expect that only adolescents with AN experience higher levels of physical activity before states of (a) low aversive tension and (b) low negative affect compared with HC, whereas HCs were expected to report higher levels of physical activity before (c) high levels of positive affect compared with adolescents with AN.

3 | METHODS

3.1 | Participants

Initially, 51 adolescents with AN and 37 healthy adolescents participated in the study. All participants were female and aged 12 to 20 years. Participants with AN were recruited at the beginning of inpatient treatment at a specialized treatment centre for eating disorders in Prien, Germany. HC participants were recruited by word-of-mouth invitation and at local youth groups near Mainz, Germany. For inclusion, all participants were required to use their own Android smartphone or a research smartphone during participation. Participants with AN were assessed by an experienced clinician at admission to the specialized eating disorders treatment department and self-report measures were used to further justify clinical diagnoses. Participants with AN were excluded if diagnosed or suspected to be diagnosed with moderate to severe major depressive disorder, attention-deficit hyperactivity disorder or borderline personality disorder, as these disorders are associated with alterations in affective states and/or physical activity throughout the day. HC participants were excluded at baseline if they reported a history of psychiatric treatment within the last five years or the current experience of heightened psychological distress comparable with individuals with AN (as assessed with the Brief Symptom Inventory [BSI], see below). Five HC participants reported BSI scores above the exclusion criterion and were therefore excluded. Due to technical errors, deliberate removal of the actigraph device and/or non-compliance resulting in no EMA measurements with corresponding physical activity data, nine participants (eight with AN, one HC) were excluded. Further twelve participants (11 with AN, one HC) were excluded as they provided data on less than one third of the measurement occasions (see data preparation section for details). Hence, a final sample size of 32 participants with AN and 30 HC participants was obtained.

3.2 | Diagnoses and clinical characteristics

Participants fulfilled DSM-5 (American Psychiatric Association, 2013) diagnostic criteria for AN restrictive subtype ($N = 26$, 81%), AN binge/purge subtype ($N = 2$, 6%) and subclinical AN ($N = 4$, 13%). Clinical diagnoses were supported with self-report measures (Eating Disorder Examination Questionnaire [EDE-Q], Hilbert, Tuschen-Caffier, Karwautz, Niederhofer, & Munsch, 2007; and Eating Disorder Inventory-2 [EDI-2], Thiel et al., 1997). Two participants were diagnosed with an additional mild mood disorder, seven with anxiety or stress-related disorders and one participant with obsessive compulsive disorder. The mean and standard deviation scores of the EDE-Q global mean ($M = 3.58$, $SD = 1.43$, $N = 28$) and EDI-2 sum score ($M = 303.31$, $SD = 62.61$, $N = 27$) of the AN sample were comparable with other studies with adolescent AN samples.

3.3 | Measures

3.3.1 | Trait-level measures

Eating Disorder Examination Questionnaire

The EDE-Q is an instrument assessing disordered eating behaviours within the last 4 weeks (Fairburn & Beglin, 1994). The EDE-Q consists of 22 items grouped into four eating disorder-specific scales: restraint eating, eating, weight, and shape concern. Additionally, a global scale can be calculated. The EDE-Q is widely used both in clinical practice and research. It is well validated in a German clinical sample (Hilbert, Tuschen-Caffier, Karwautz, Niederhofer, & Munsch, 2007). Internal consistency in this study was excellent (Cronbach's $\alpha = .94$).

Eating Disorder Inventory-2

The EDI-2 is a multidimensional self-report questionnaire assessing disordered eating and related constructs. Both the original version (Garner, Olmstead, & Polivy, 1983) and the German translation (Thiel et al., 1997) showed good validity and reliability, and the use in adolescents is also adequate (Kappel et al., 2012). Internal consistency was excellent for this study (Cronbach's $\alpha = .96$). In this study, the EDI-2 and the EDE-Q are used to describe the severity of the eating disorder in the AN sample.

Brief Symptom Inventory-18

The BSI is a short scale derived from the Symptom Checklist by Derogatis (1979), assessing psychopathological symptoms with 18 items. The scale provides a global severity index as an indicator of current psychological distress. The German version (Franke et al., 2011) showed good validity and reliability measures in both healthy and clinical populations. In this study, HC participants were excluded when they reported a global severity index equal or above the mean of the AN participants in the validation study (Franke et al., 2011). Internal consistency in this study was good (Cronbach's $\alpha = .88$).

Exercise Addiction Inventory

The Exercise Addiction Inventory (EAI) is a short instrument assessing addiction to exercising (Terry, Szabo, & Griffiths, 2004). On six 5-point scale items, participants self-rate their exercising behaviour regarding saliency, withdrawal and interpersonal conflicts. The split-half reliability and internal consistency measurements were good in the original study, but very low (Cronbach's $\alpha = .59$) in the initial German translation (Ziemainz et al., 2013). However, the internal consistency in our sample is similar to the original study (Cronbach's $\alpha = .90$).

Additional measures

Self-reported weight and height were obtained to calculate BMI (kg/m^2) in the control sample, whereas patients with AN were weighed and measured at admission. The ambient temperature at the residency or clinical site at the day of the EMA was obtained from the official German weather service (DWD, Deutscher Wetterdienst), as physical activity levels are dependent to climate variables (Hechler et al., 2008).

3.3.2 | Ecological momentary assessment measures

Objective assessment of physical activity

Physical activity was measured with the triaxial SOMNOwatch™ accelerometer device (SOMNOmedics, Randersacker, Germany) on the non-dominant wrist. Acceleration in mG was recorded with 60-Hz sampling rate. The device showed good accuracy (Dick et al., 2010), and had previously been used in the objective assessment of physical activity in eating disorders

(Alexandridis, Alexandridis, & Herzog, 2011). Generally, triaxial accelerometer devices are considered reliable for the assessment of physical activity, but the validity of the data is sometimes questioned as researchers choose arbitrary cut-offs for the classification of intensity into low or high-level physical activity (Pedisic & Bauman, 2015). Hence, we used the continuous data in this study.

Positive and Negative Affect Schedule—abbreviated for eating disorders

We used an abbreviated version (PANAS) of the 60-item PANAS-X (expanded version) by Watson and Clark (1994) to assess momentary positive and negative affect on a 5-point Likert scale from *not at all* to *extremely.* Engel et al. (2013) selected eight items assessing positive and eight items assessing negative affective states according to their clinical relevance to patients with eating disorders, showing high reliability in a large EMA study with individuals with AN. Accordingly, we chose these items from the German version of the PANAS-X (Grühn, Kotter-Grühn, & Röcke, 2010) for this study: strong, enthusiastic, proud, attentive, happy, energized, confident and cheerful as positive, and nervous, disgusted, distressed, ashamed, angry at self, afraid, sad, and dissatisfied with self as negative affective states. In line with Engel et al. (2013), positive and negative affect sum scores were computed. Using a generalizability theory framework (Cranford et al., 2006; Cronbach, Gleser, Nanda, & Rajaratnam, 1972), multilevel reliability estimates for between and within person reliability were calculated for the positive and negative subscale of the PANAS, indicating moderate between-person (R_{1R}) and good within-person (R_C) reliability estimates (see Table S1 for the estimates).

Aversive tension measurement

Aversive tension was assessed on a scale from zero to hundred ("At this time, how intense is your emotional tension?"), in line with a previous study (Kolar et al., 2016). A thorough definition of aversive tension was given in addition to two exemplary situations corresponding to aversive tension levels of 30–50 and 50–70 (see Kolar et al., 2017). Furthermore, participants reported the time point of each food intake, were asked to indicate how well they could name their affect and what they were doing immediately before responding to the questionnaire, which was not analysed in this study.

3.4 | Procedure

Prior to the EMA, all participants and their legal guardians consented to the study and all participants completed the BSI and a brief socio-demographic questionnaire. Study data were collected and managed using REDCap (Harris et al., 2009), a secure, web-based electronic data capture platform hosted at the University Medicine Mainz, Germany. All participants were briefed regarding the procedure and the measurements of the EMA, especially regarding how to wear the accelerometer device. The EMA was conducted using the Android application MovisensXS (movisens GmbH, Karlsruhe, Germany) and participants installed the application on their own devices or received a research device. On the following day, physical activity was measured continuously beginning immediately after waking up, whereas affective states were assessed hourly. An interval-contingent approach was used for the EMA with hourly signals to complete the questionnaire between 7 am and 11 pm. Furthermore, the participants were able to complete additional questionnaires at every given time, although they were not explicitly advised of this option. Participants were advised to delay responding if smartphone use was restricted during school or therapy activities and to respond as soon as convenient. In the control group, assessment days were chosen on weekdays with no regular sports training (e.g., soccer training and ballet) scheduled for that day. However, spontaneous sportive activity was neither prohibited nor encouraged. The day after the EMA assessment, participants completed a short survey containing the EAI and a questionnaire regarding usability of and adherence to the EMA app. HC participants received a small gift (card game) after returning the accelerometer. AN participants were not compensated. All procedures were approved by the ethics committee of the local medical association in Mainz, Germany, and the ethics board of the Ludwigs-Maximilians-University Munich, Germany.

3.5 | Statistical methods

Data was prepared and analysed with R 3.5.0 (R Core Team, 2013) and RStudio 1.1.447 (R Studio Team, 2016). Graphics were prepared using the ggplot2 package version 3.0.0 (Wickham, 2016).

3.5.1 | Data preparation

The raw accelerometer data were preprocessed with DOMINOlight (SOMNOmedics, Randersacker, Germany) and aggregated on a minute level for further data analysis. Data prior to 0:00 am and posterior to 11:59 pm at the day of the EMA were discarded. Several participants showed longer time frames with implausibly low levels of activity (defined as a mean activity level lower than 2 mG/min) most likely due to taking the accelerometer device off (e.g., due to showering, clothes changing). Hence, all measurement occasions with a mean physical activity of less than 2 mG/min were discarded. Physical activity was aggregated as a 30 min backward moving average as a predictor with the zoo package version 1.8-3 (Zeileis & Grothendieck, 2005), excluding observations with missing physical activity data. Unpublished feasibility data suggested that a 30-min interval is sufficient to capture significant changes in activity prior to the EMA observations and prevents an overlap between successive observations (which were scheduled hourly). Prior to the analysis, physical activity as a predictor was centred at the person-mean to allow analysis of within-person processes, whereas ambient temperature as a covariate predictor was centred at the group-mean by using the EMAtools package version 0.1.3 (Kleinman, 2017). Sum scores for positive and negative affect were calculated from the PANAS items for each observation.

As adherence to the EMA protocol was rather low in our study, we excluded participants who reported both physical activity and affect measurements on less than one third of the scheduled occasions on a per analysis basis. This a priori decision was agreed upon as a trade-off between as many measurements as possible and as few as possible participants with non-random missings to prevent a strongly skewed data distribution towards measurements with low activity. Linear mixed models are rather robust to missing data, but participants reporting on very few measurement occasions with very large intervals between the measurements might affect autocorrelation and parameter estimations, especially as error randomness cannot be assumed in these cases. The data that support the findings of this study are openly available in “Open Science Framework” at http://doi.org/10.17605/OSF.IO/BK4X8.

3.5.2 | Data analysis

Group comparisons of means were calculated for the baseline parameters. To assess the influence of physical activity in the interval 30 min prior to momentary affective states, mixed models were calculated for each affect measurement (aversive tension, positive affect, and negative affect). Single and interaction predictors of group and person-centred physical activity were included as predictors, as well as group-centred ambient temperature. Intercept and time in hours since midnight of the assessment day were included as fixed and random factors. Autocorrelation was modelled using a first-order continuous autoregressive model (a generalization of the AR1 model for discrete time data) based on time since midnight. The following equation shows the simplified general equation for the mixed models (Bolger & Laurenceau, 2013):

$$y_{ti} = \beta_0 + \beta_1 \mathrm{Time}_{ti} + \beta_2 \mathrm{Temp}_i + \beta_3 \mathrm{Group}_i + \beta_4 \mathrm{Activity}_{ti} + \beta_5 \mathrm{Activity}_{ti} \times \mathrm{Group}_i + r_{0i} + r_{2i} \mathrm{Time}_{ti} + r_{3i} \mathrm{Autocor} + e_{ti}.$$

We modelled fixed effects of intercept, time, ambient temperature, group, activity, and a Group × Activity interaction, and random effects of intercept and time.

Linear mixed models were analysed using the nlme package version 3.1-137 (Pinheiro, Bates, DebRoy, Sarkar, & Team, 2018) and effects package version 4.0-3 (Fox, 2003). R^2 model coefficients were calculated with the piecewiseSEM package version 2.0.2 (Lefcheck, 2016). As we only postulated a priori hypotheses regarding the main effects of group, activity, and group × activity interaction, Bonferroni–Holm corrections of alpha levels were specified model-wise (Holm, 1979).

4 | RESULTS

Thirty-two participants with AN and 30 HC participants provided a total of 668 observations with momentary affective states and corresponding levels of physical activity of the prior 30 min. Figure 1 displays the averaged time series of physical activity, aversive tension and positive/negative affect in adolescents with AN compared with HC. Table 1 shows the overall sample characteristics and group differences. At baseline, participants with and without AN differed regarding BMI, BMI Standard Deviation Scores (BMI-SDS), exercise addiction (EAI score) and general psychopathological distress (BSI scores) as expected, but also regarding ambient temperature at the day of assessment. During the EMA assessment, participants with AN reported on average higher negative affect, lower positive affect and higher tension scores compared with healthy adolescents. Daily levels of affect were correlated: Positive affect correlated negatively with negative affect ($r = -.58$; 95% CI [−.72, −.38]) and aversive tension ($r = -.46$; 95% CI [−.64, −.24]), whereas negative affect correlated positively with aversive tension ($r = .81$; 95% CI [.70, .88]). Adherence to the EMA protocol was rather low in this study, with patients reporting on fewer occasions than HCs (see Table 1), and lower than in other EMA studies with adolescents (e.g., in Kolar et al., 2016; Seidel et al., 2016; Wen, Schneider, Stone, & Spruijt-Metz, 2017). Participants, which used their own phone ($N = 20$, 32%),

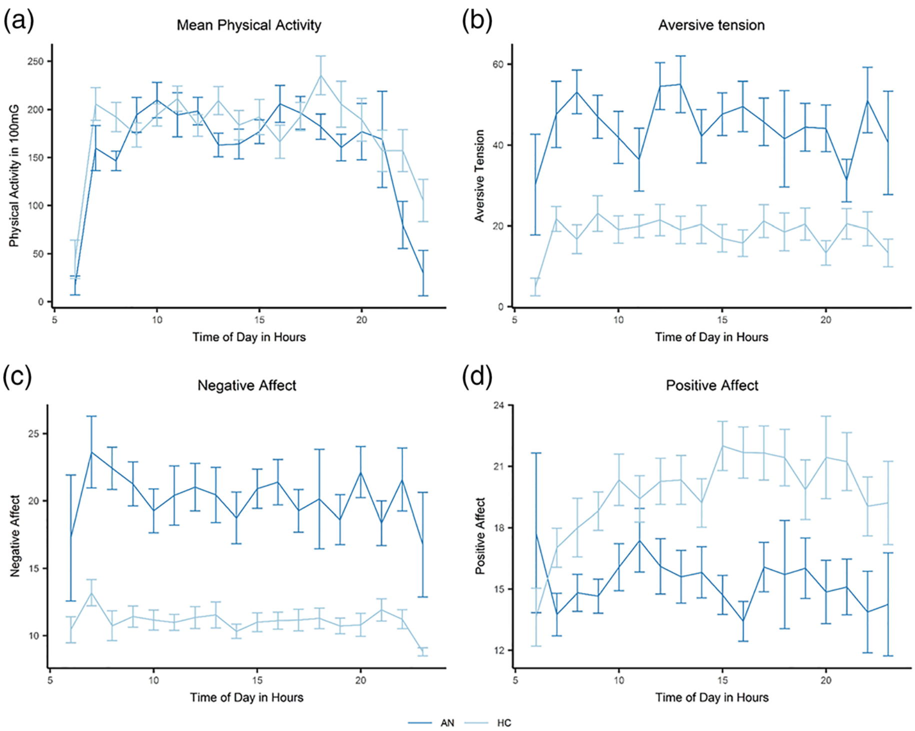

FIGURE 1 Time series of mean physical activity, aversive tension, negative affect, and positive affect per hour. All variables were calculated as means in the interval of ±30 min around each full hour for each participant individually. *N* varied for each time point due to missing observations. Error bars represent standard errors [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Sample characteristics of participants with anorexia nervosa and healthy control participants

	Participants with anorexia nervosa (*N* = 32)				Healthy control participants (*N* = 30)						
	M	*SD*	Min	Max	*M*	*SD*	Min	Max	*t*	*df*	*p*
Age	16.01	1.16	13.7	18.05	16.36	2.00	12.5	19.71	−0.833	45.89	.409
Mean activity in mG per day[a]	141.89	44.04	66.43	233.0	140.66	37.43	81.82	221.6	0.119	59.45	.906
Ambient temperature in °C[b]	5.66	5.98	−9	19	10.23	7.31	0	22	−2.685	56.11	.010
BMI	16.06	2.08	12.34	20.83	22.22	2.54	17.30	28.01	−10.403	56.12	<.001
BMI-SDS	−2.35	1.26	−4.93	−0.09	0.48	0.75	−1.48	1.83	−10.778	50.82	<.001
BSI score	21.28	10.73	1	44	8.37	4.23	1	18	6.308	40.94	<.001
EAI score	17.72	6.32	7	30	13.30	5.91	6	28	2.844	60.00	.006
N data entries	9.41	2.43	6	14	12.23	3.27	6	19	−3.844	53.50	<.001
Negative affect score	20.30	7.23	8.46	32.89	11.21	2.88	8.00	19.54	6.597	40.72	<.001
Positive affect score	15.60	4.70	9.94	26.46	20.31	4.81	11.75	33.00	−3.892	59.54	<.001
Tension score	46.16	22.82	4.00	92.11	18.81	12.23	0.06	41.20	5.932	48.07	<.001

Note. Minimum and maximum levels of momentary variables are based on mean daily levels of participants, rather than single momentary levels. BSI: Brief Symptom Inventory-18. EAI: Exercise Addiction Inventory.
[a]Mean of the average daily physical activity of each person after exclusion of implausibly low levels of activity.
[b]Ambient temperature in degrees Celsius at the day of participation (either at the residency or at the inpatient centre).

did not differ from those who used a research device, $N = 42$, 68%; $t(44) = -0.59$, $p = .60$, regarding adherence to the measurement protocol.

4.1 | Momentary relationships of preceding physical activity and affect

To assess the influence of physical activity on aversive tension, positive affect, and negative affect, three linear mixed models were conducted separately. The data were sufficiently appropriate to be analysed within linear mixed models. However, QQ-plots revealed slight deviations of normal error distributions for some of the models, especially for the control group. As there is evidence that linear mixed models are sufficiently robust to violations of this assumption (see Jacqmin-Gadda, Sibillot, Proust, Molina, & Thiébaut, 2007; McCulloch & Neuhaus, 2011), we continued to use non-transformed data for better interpretability of the results.

4.1.1 | The relationship of physical activity and aversive tension

In a first linear mixed model analysis, we assessed whether higher physical activity in the 30 min prior to the measurement predicted lower levels of aversive tension of participants with AN. Table 2a provides the parameter estimates for the model. Likelihood-ratio-tests indicated that a fixed effects model with additional random effects of intercept, time slope and autocorrelation showed the best model fit (see Table S2). A main effect of group on aversive tension was found, indicating that participants with AN experience higher levels of aversive tension in daily life. Contrary to our hypothesis, no effects of physical activity, neither generally nor group-specific, were found, indicating that the experience of aversive tension is not associated with physical activity in the preceding 30 min (Figure 2a).

4.1.2 | The relationship of physical activity and negative affect

Furthermore, we were interested in whether higher levels of physical activity in the preceding 30 min were associated with lower negative affect in participants with AN. Similar to the previous linear mixed model, likelihood-ratio-tests indicated that maintaining a random intercept, random slope of time and autocorrelation resulted in the best model fit (see Table S2). The parameter estimates of the fixed effects revealed a significant and clinically relevant group effect with higher levels of negative affect for participants with AN (Table 2b), and a general decrease over time from morning to evening was observed (significant fixed effect of time, see Table S2). No main effect of physical activity on negative affect was obtained, but a small negative interaction effect was found, indicating a decrease in negative affect after higher physical activity in the preceding 30 min for

TABLE 2 Linear mixed model parameter estimates of group, activity, and group activity interaction on aversive tension, negative affect, and positive affect

	(a) Aversive tension			(b) Negative affect			(c) Positive affect		
	Estimate	*SE*	*p*	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Group[a]	28.639	4.869	<.001	9.689	1.478	<.001	−4.624	1.180	<.001
Physical activity[b]	0.005	0.010	.592	0.002	0.002	.368	0.005	0.002	.049
Physical activity × Group interaction[a,b]	−0.007	0.014	.595	−0.006	0.003	.030	0.006	0.003	.055
Pseudo-R^2-marginal (conditional)	.045 (.953)			.050 (.983)			.029 (.938)		

Note. (a) N = 668 observations, 32 participants with anorexia nervosa (AN), 30 healthy control participants. (b, c) N = 660 observations, 31 participants with AN, 30 healthy control participants. For fixed effects of intercept, ambient temperature and time, as well as random effects and model parameters, see Table S2.
[a]Group effects are estimated for participants with AN.
[b]Physical activity refers to person-centred mean levels of physical activity in the preceding 30 min.

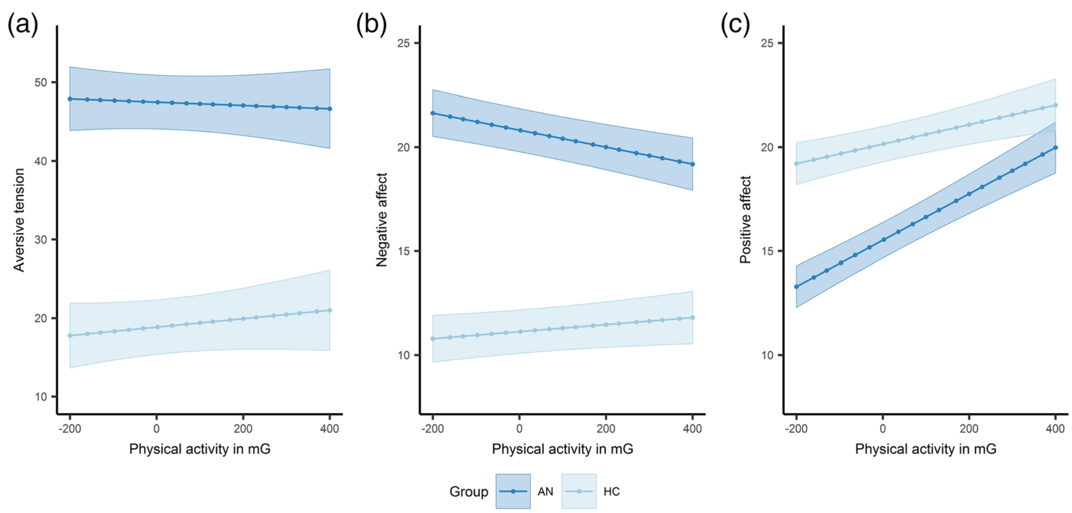

FIGURE 2 Interaction plots of the Physical activity × Group effects on aversive tension, negative affect, and positive affect. AN: patients with anorexia nervosa. HC: healthy control participants. Upper and lower limits represent 95% point-wise confidence interval bands based on standard error of the mean [Colour figure can be viewed at wileyonlinelibrary.com]

participants with AN compared with healthy adolescents (for an increase of 200 mG in physical activity, negative affect was reduced by 1.2 points in the AN group, see Figure 2b). However, this effect shortly failed to reach significance if strict Bonferroni–Holm correction ($\alpha_{crit} = .025$) for multiple testing was applied.

4.1.3 | The relationship of physical activity and positive affect

We conducted a third linear mixed model to investigate whether higher physical activity in the preceding 30 min was associated with an increase of positive affect. As in the previous models, the model with all random effects showed the best model fit, this time with a larger autocorrelation estimate (see Table S2). As expected, a significant group effect was found that showed lower levels of positive affect for participants with AN (see Table 2c). Furthermore, a significant main effect of physical activity on positive affect was found, and the Group × Physical activity interaction effect was close to significance (p = .055), but after correcting for multiple testing only the main group effect remained significant. However, the size of the parameter estimates indicate that both groups experienced more positive affect after higher preceding levels of physical activity, with a stronger effect for participants with AN than HC participants. Figure 2c displays the interaction effect, showing that 200 mG more physical activity in the preceding 30 min result in an increase of 2.2 points (5.5%) on the positive affect scale.

5 | DISCUSSION

We used an accelerometer device and a smartphone-based EMA application to assess whether physical activity is related to subsequent affective measures in adolescents with AN compared with HC. We were particularly interested in between-subject differences regarding the relationships of preceding physical activity within 30 min prior to repeated self-reports on aversive tension, negative and positive affect.

Overall, we replicated earlier findings that adolescents with AN showed higher levels of aversive tension and negative affect throughout the day compared with HC, whereas HC showed higher levels of positive affect (Kolar et al., 2016; Seidel et al., 2016). We also found that increases in physical activity in the 30 min preceding the affect measurement predicted lower levels of negative affect in adolescents with AN but not in HC, and that higher levels of preceding physical activity were associated with higher levels of positive affect in both groups. Contrary to our hypotheses, aversive tension was not predicted by physical activity, and AN remained the only significant predictor of any momentary affect outcome when strict corrections for multiple testing were applied.

The study broadens the existing literature using EMA in individuals with AN (Engel et al., 2013; Kolar et al., 2016; Seidel et al., 2016) as it is one of the first studies which linked objectively assessed physical activity to momentary affective states in this eating disorder population (Karr et al., 2017). Previous studies on momentary association of affect with physical activity in AN were mostly using a different approach and investigated whether affect changed before and after a self-described episode of exercise (Engel et al., 2013). Using devices to assess physical activity rather than relying on self-reports benefits the researcher with a more reliable and timelier assessment of physical activity, and additionally allows comparing the intensity of distinct forms of exercise. Thus, we were able to investigate the quantitative effect of even low to moderate intensity levels of physical activity on affect, instead of only self-reported high-intensity exercise as in previous studies.

Furthermore, our study is the first to compare the effect of physical activity on momentary affective states of adolescents with AN compared with HC. This is of particular relevance as physical activity is an effective moderator of positive affect in the general population (Kanning & Schoebi, 2016; Liao et al., 2015; Schwerdtfeger et al., 2008), and such associations in individuals with AN should differ from HC either in their magnitude or quality to be considered a maladaptive emotion regulation strategy. So far, the current study could be considered as a starting point indicating that down-regulation of negative affect might be an AN-specific effect of physical activity, whereas the up-regulation of positive affect might be a more general effect also present in healthy adolescents. The results, however, should be assessed with caution as strict correction for multiple testing removed statistical significance of the findings and a thorough replication of the findings in a larger sample is needed.

5.1 | Implications for future research on physical activity and emotion regulation in AN

Our study is one of the first that uses an objective assessment to investigate the effect of physical activity on momentary affect, indicating that physical activity might show some emotion regulation capacity in adolescents with AN. Although EMA assessments could be considered as "semi-causal", such results cannot be considered as direct evidence for a causal mechanism. Hence, future studies that would investigate whether physical activity facilitates the regulation of momentary affective states in an experimental setting, for example by assessing current mood after a mood induction followed by either a sedentary or exercise activity, could further enlighten the association of physical activity with emotion regulation in AN. In our study, we were primarily interested in short-term effects of physical activity on momentary affect within the hour. Therefore, we scheduled only one assessment day and did neither investigate daily differences in mood nor within-day instability of mood and its association with physical activity. Future studies might look into whether higher levels of physical activity on day one are associated with mood on day two, whether time-lagged effects of activity on for example affect two or three hours later exist, if high exercise days differ on daily levels of affect compared with low exercise days, or if days with higher physical activity are associated with lower mood instability on the same day, given that mood instability was associated with more disordered eating behaviours in a sample of adults with AN (Selby et al., 2015). Furthermore, our study did not differentiate between distinct categories of emotions, rather than positive or negative affect, and neither motives associated with physical activity were investigated. In particular, investigating whether such cognitions (e.g., "I work out to burn calories" and "When I exercise I can eat more") are related to physical activity and moderate the effect of physical activity on affect in individuals with AN compared with HC could be worthwhile. Lastly, previous research did only investigate whether physical activity is associated with changes in momentary affect as a means to assess the direct emotion-regulating effect of physical activity. However, it would also be interesting to assess whether physical activity facilitates the use of other functional emotion regulation strategies in both individuals with AN and HC. Recently, a state version of the widely used difficulties in emotion regulation scale was published (Lavender, Tull, DiLillo, Messman-Moore, & Gratz, 2017).

5.2 | Clinical implications

With regard to the sample size and the pilot character of our study, the clinical implications of our study should be considered preliminary. If physical activity in individuals with AN is associated with increased positive affect similar to HC, this effect might be useful in the treatment and underlines modern approaches which include sport and exercise into existing treatment programs (Dittmer et al., 2018; Schlegel, Hartmann, Fuchs, & Zeeck, 2015). For example, short and supervised exercise units in combination with cognitive behaviour therapy might enhance or stabilize the mood of the patients during inpatient treatment (Dittmer et al., 2018). Furthermore, if excessive physical activity in patients with AN can be considered a maladaptive emotion regulation strategy, treatment should also focus on providing the patients with other, more adaptive, skills to regulate negative affective states. In line with our findings, preliminary research indicates that dialectical behaviour therapy skills trainings could enhance evidence-based treatments for adolescents with AN by teaching such adaptive skills (Peterson, Van Diest, Mara, & Matthews, 2019). Such skills might be a substitute to regulate negative affect where adolescents with AN would otherwise engage in excessive physical activity.

5.3 | Limitations

Probably the most significant limitation of our study is the low adherence to the EMA protocol by the adolescents with AN, which led to a substantial loss of affect measurements and the exclusion of several participants. This was unexpected as previous studies with samples of adolescents with AN did not report differences in adherence compared with HC (Kolar et al., 2016; Seidel et al., 2016) and as the participants could choose their own smartphone for the study, indicating that measuring physical activity with visibly-attached accelerometer devices might be considered aversive by the patients with AN and thus the devices were removed. Furthermore, the exclusion criterion of less than 33% responses is debatable, and future studies should aim at increasing overall compliance rather than excluding participants with low compliance. The small sample size, which was reinforced by the low adherence, is another clear limitation of our study, and the generalizability of the results based on adolescent inpatients to all individuals with AN is unclear and requires replication by another study with a larger sample and more measurement days. Future studies might rely on Bayesian methods which might be better equipped for small sample sizes (McNeish, 2016). Although many fitness trackers and accelerometer devices are expected to be attached at the non-dominant wrist, other studies used devices that were attached to either the hip or the ankle, which might reduce artefacts by movements of the hands only (e.g., writing or gesturing). However, attaching the device to the hip might result in less observed activity as for example fidgeting will not be assessed, whereas attachment to the ankle might lead to an overestimation of overall physical activity for the same reason. Lastly, relying on inpatients might confound the results as in general most inpatient service centres restrict physical activity for their patients with AN.

6 | CONCLUSIONS

Overall, our study found some preliminary evidence that momentary affect is associated with preceding physical activity, more specifically with a decrease of negative and an increase of positive affect in adolescents with AN, and merely an increase of positive affect in HC. We also replicated the robust effect that more negative and less positive affective states as well as more aversive tension are associated with adolescents with AN compared with HC on a momentary level. Given that our sample size was small and the effects not particularly robust, these results should be considered as preliminary. Furthermore, we provided an example study of how researchers could utilize actigraph devices to obtain more objective measurements of physical activity in adolescents with AN. We hope that future research will replicate and expand our study to further investigate the association of physical activity with other factors such as emotion regulation strategies, distinct emotions, daily levels of mood and affective instability.

ACKNOWLEDGEMENTS

We are grateful to Tim Schäfer for his significant contribution in data collection and to Hanna Preuss, Florian Hammerle, Michael Huss, and Ekkehart Jenetzky for their helpful comments during the drafting of the manuscript. We are very thankful to the authors of the R packages RColorBrewer, Cairo, dplyr, and tidyverse, which were helpful in the preparation of the data and the manuscript. Furthermore, we are thankful to all participants. This work is part of the doctoral thesis of Christina Neumayr.

FUNDING INFORMATION

This study was partially supported by a research grant of the intramural research funding of the Johannes Gutenberg-University Mainz, Germany.

CONFLICT OF INTERESTS

The authors declare no conflict of interests.

ORCID

David R. Kolar https://orcid.org/0000-0002-8649-5467
Sandra Schlegl https://orcid.org/0000-0003-1791-7379

REFERENCES

Alberti, M., Galvani, C., El Ghoch, M., Capelli, C., Lanza, M., Calugi, S., & Dalle Grave, R. (2013). Assessment of physical activity in anorexia nervosa and treatment outcome. *Med Sci Sports Exerc*, *45*(9), 1643–1648. https://doi.org/10.1249/MSS.0b013e31828e8f07

Alexandridis, J., Alexandridis, K., & Herzog, S. (2011). 4-Tage-Profil zur Erfassung der körperlichen Aktivität bei Männern und Frauen mit Adipositas Grad II im Vergleich zu normalgewichtigen Probanden. Abstracts zum Symposium von DGRW, DVS und DVGS am 6. Oktober in Frankfurt am Main. *Bewegungstherapie und Gesundheitssport*, *27*, 247–251.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders* (5th ed. ed.). Washington, DC: Author.

Belak, L., Gianini, L., Klein, D. A., Sazonov, E., Keegan, K., Neustadt, E., … Attia, E. (2017). Measurement of fidgeting in patients with anorexia nervosa using a novel shoe-based monitor. *Eating Behaviors*, *24*, 45–48. https://doi.org/10.1016/j.eatbeh.2016.11.005

Bolger, N., & Laurenceau, J.-P. (2013). *Intensive longitudinal methods: An introduction to diary and experience sampling research*. New York, USA: Guilford.

Bratland-Sanda, S., Sundgot-Borgen, J., Ro, O., Rosenvinge, J. H., Hoffart, A., & Martinsen, E. W. (2010). Physical activity and exercise dependence during inpatient treatment of longstanding eating disorders: An exploratory study of excessive and non-excessive exercisers. *International Journal of Eating Disorders*, *43*(3), 266–273. https://doi.org/10.1002/eat.20769

Brockmeyer, T., Grosse Holtforth, M., Bents, H., Kämmer, A., Herzog, W., & Friederich, H.-C. (2012). Starvation and emotion regulation in anorexia nervosa. *Comprehensive Psychiatry*, *53*, 496–501.

Brockmeyer, T., Skunde, M., Wu, M., Bresslein, E., Rudofsky, G., & Herzog, W. (2014). Difficulties in emotion regulation across the spectrum of eating disorders. *Compr Psychiatry*, *55*, 565–571. https://doi.org/10.1016/j.comppsych.2013.12.001

Cranford, J. A., Shrout, P. E., Iida, M., Rafaeli, E., Yip, T., & Bolger, N. (2006). A procedure for evaluating sensitivity to within-person change: Can mood measures in diary studies detect change reliably? *Personality & social psychology bulletin*, *32*(7), 917–929. https://doi.org/10.1177/0146167206287721

Cronbach, L. J., Gleser, G. C., Nanda, H., & Rajaratnam, N. (1972). *The dependability of behavioral measurements. Theory of generalizability for scores and profiles*. New York: John Wiley.

Derogatis, L. R. (1979). *Symptom Checklist-90-Revised (SCL-90-R)*. Lyndhurst, NJ: NCS Pearson.

Dick, R., Penzel, T., Fietze, I., Partinen, M., Hein, H., & Schulz, J. (2010). AASM standards of practice compliant validation of actigraphic sleep analysis from SOMNOwatch versus polysomnographic sleep diagnostics shows high conformity also among subjects with sleep disordered breathing. *Physiol Meas*, *31*(12), 1623–1633. https://doi.org/10.1088/0967-3334/31/12/005

Dittmer, N., Voderholzer, U., von der Muhlen, M., Marwitz, M., Fumi, M., Monch, C., … Schlegl, S. (2018). Specialized group intervention for compulsive exercise in inpatients with eating disorders: Feasibility and preliminary outcomes. *J Eat Disord*, *6*(27), 1–11. https://doi.org/10.1186/s40337-018-0200-8

Engel, S. G., Wonderlich, S. A., Crosby, R. D., Mitchell, J. E., Crow, S., Peterson, C. B., … Gordon, K. H. (2013). The role of affect in the maintenance of anorexia nervosa: Evidence from a naturalistic assessment of momentary behaviors and emotion. *Journal of Abnormal Psychology*, *122*(3), 709–719. https://doi.org/10.1037/a0034010

Fairburn, C. G., & Beglin, S. J. (1994). Assessment of eating disorders: Interview or self-report questionnaire? *International Journal of Eating Disorders, 16*(4), 363-370. https://doi.org/10.1002/1098-108X(199412)16:4<363::AID-EAT2260160405>3.0.CO;2-#

Fietz, M., Touyz, S., & Hay, P. (2014). A risk profile of compulsive exercise in adolescents with an eating disorder: A systematic review. *Advances in Eating Disorders*, *2*(3), 241–263. https://doi.org/10.1080/21662630.2014.894470

Fox, J. (2003). Effect displays in R for generalised linear models. *Journal of Statistical Software*, *8*(15), 1–27.

Franke, G. H., Ankerhold, A., Haase, M., Jäger, S., Tögel, C., Ulrich, C., & Frommer, J. (2011). Der Einsatz des Brief Symptom Inventory 18 (BSI-18) bei Psychotherapiepatienten. [The usefulness of the Brief Symptom Inventory 18 (BSI-18) in psychotherapeutic patients]. *Psychotherapie, Psychosomatik, medizinische Psychologie*, *61*(2), 82–86. https://doi.org/10.1055/s-0030-1270518

Franko, D. L., Keshaviah, A., Eddy, K. T., Krishna, M., Davis, M. C., Keel, P. K., & Herzog, D. B. (2013). A longitudinal investigation of mortality in anorexia nervosa and bulimia nervosa. *American Journal of Psychiatry*, *170*(8), 917–925. https://doi.org/10.1176/appi.ajp.2013.12070868

Garner, D. M., Olmstead, M. P., & Polivy, J. (1983). Development and validation of a multidimensional eating disorder inventory for anorexia nervosa and bulimia. *International Journal of Eating Disorders*, *2*, 15–34. https://doi.org/10.1002/1098-108X(198321)2:2<15::AID-EAT2260020203>3.0.CO;2-6

Goodwin, H., Haycraft, E., & Meyer, C. (2014). Emotion regulation styles as longitudinal predictors of compulsive exercise: A twelve month prospective study. *J Adolesc*, *37*(8), 1399–1404. https://doi.org/10.1016/j.adolescence.2014.10.001

Grühn, D., Kotter-Grühn, D., & Röcke, C. (2010). Discrete affects across the adult lifespan: Evidence for multidimensionality and multidirectionality of affective experiences in young, middle-aged and older adults. *Journal of Research in Personality*, *44*(4), 492–500. https://doi.org/10.1016/j.jrp.2010.06.003

Gummer, R., Giel, K. E., Schag, K., Resmark, G., Junne, F. P., Becker, S., … Teufel, M. (2015). High levels of physical activity in anorexia nervosa: A systematic review. *European Eating Disorders Review*, *23*(5), 333–344. https://doi.org/10.1002/erv.2377

Haas, P., Schmid, J., Stadler, G., Reuter, M., & Gawrilow, C. (2017). Zooming into daily life: Within-person associations between physical activity and affect in young adults. *Psychology & Health*, *32*(5), 588–604. https://doi.org/10.1080/08870446.2017.1291943

Harris, P. A., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., & Conde, J. G. (2009). Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of Biomedical Informatics*, *42*(2), 377–381. https://doi.org/10.1016/j.jbi.2008.08.010

Haynos, A. F., Crosby, R. D., Engel, S. G., Lavender, J. M., Wonderlich, S. A., Mitchell, J. E., … Le Grange, D. (2015). Initial test of an emotional avoidance model of restriction in anorexia nervosa using ecological momentary assessment. *Journal of Psychiatric Research*, *68*, 134–139. https://doi.org/10.1016/j.jpsychires.2015.06.016

Haynos, A. F., & Fruzzetti, A. E. (2011). Anorexia nervosa as a disorder of emotion dysregulation: Evidence and treatment implications. *Clinical Psychology: Science and Practice*, *18*(3), 183–202.

Haynos, A. F., Roberto, C. A., Martinez, M. A., Attia, E., & Fruzzetti, A. E. (2014). Emotion regulation difficulties in anorexia nervosa before and after inpatient weight restoration. *The International journal of eating disorders*, *47*(8), 888–891. https://doi.org/10.1002/eat.22265

Hechler, T., Rieger, E., Touyz, S., Beumont, P., Plasqui, G., & Westerterp, K. (2008). Physical activity and body composition in outpatients recovering from anorexia nervosa and healthy controls. *Adapt Phys Activ Q*, *25*(2), 159–173.

Hilbert, A., Tuschen-Caffier, B., Karwautz, A., Niederhofer, H., & Munsch, S. (2007). Eating Disorder Examination-Questionnaire. *Diagnostica*, *53*(3), 144–154. https://doi.org/10.1026/0012-1924.53.3.144

Hoek, H. W. (2006). Incidence, prevalence and mortality of anorexia nervosa and other eating disorders. *Curr Opin Psychiatry*, *19*(4), 389–394. https://doi.org/10.1097/01.yco.0000228759.95237.78

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70.

Holtkamp, K., Hebebrand, J., & Herpertz-Dahlmann, B. (2004). The contribution of anxiety and food restriction on physical activity levels in acute anorexia nervosa. *Int J Eat Disord*, *36*(2), 163–171. https://doi.org/10.1002/eat.20035

Jacqmin-Gadda, H., Sibillot, S., Proust, C., Molina, J.-M., & Thiébaut, R. (2007). Robustness of the linear mixed model to misspecified error distribution. *Computational Statistics & Data Analysis*, *51*(10), 5142–5154. https://doi.org/10.1016/j.csda.2006.05.021

Kanning, M. K., & Schoebi, D. (2016). Momentary affective states are associated with momentary volume, prospective trends, and fluctuation of daily physical activity. *Frontiers in Psychology*, *7*, 1–8. https://doi.org/10.3389/fpsyg.2016.00744

Kappel, V., Thiel, A., Holzhausen, M., Jaite, C., Schneider, N., Pfeiffer, E., … Salbach-Andrae, H. (2012). *Eating Disorder Inventory-2 (EDI-2) Normierung an einer Stichprobe normalgewichtiger Schüler im Alter von 10 bis 20 Jahren und an Patientinnen mit Anorexia nervosa*. *58*(3), 127–144. https://doi.org/10.1026/0012-1924/a000069

Karr, T. M., Cook, B., Zunker, C., Cao, L., Crosby, R., Wonderlich, S. A., & Mitchell, J. (2017). Examining physical activity and affect using objective measures: A pilot study of anorexia nervosa. *The Sport Journal*. https://thesportjournal.org/article/examining-physical-activity-and-affect-using-objective-measures-a-pilot-study-of-anorexia-nervosa/

Keyes, A., Woerwag-Mehta, S., Bartholdy, S., Koskina, A., Middleton, B., Connan, F., … Campbell, I. C. (2015). Physical activity and the drive to exercise in anorexia nervosa. *Int J Eat Disord*, *48*(1), 46–54. https://doi.org/10.1002/eat.22354

Klein, D. A., Bennett, A. S., Schebendach, J., Foltin, R. W., Devlin, M. J., & Walsh, B. T. (2004). Exercise "addiction" in anorexia nervosa: Model development and pilot data. *CNS Spectr*, *9*(7), 531–537. https://doi.org/10.1017/s1092852900009627

Kleinman, E. (2017). EMAtools: Data management tools for real-time monitoring/ecological momentary assessment data. R package version 0.1.3 (Version 0.1.3). Retrieved from https://CRAN.R-project.org/package=EMAtools

Kolar, D. R., Hammerle, F., Jenetzky, E., Huss, M., & Burger, A. (2016). Aversive tension in female adolescents with anorexia nervosa: A controlled ecological momentary assessment using smartphones. *BMC Psychiatry*, *16*, 97. https://doi.org/10.1186/s12888-016-0807-8

Kolar, D. R., Huss, M., Preuss, H. M., Jenetzky, E., Haynos, A. F., Burger, A., & Hammerle, F. (2017). Momentary emotion identification in female adolescents with and without anorexia nervosa. *Psychiatry Research*, *255*, 394–398. https://doi.org/10.1016/j.psychres.2017.06.075

Lavender, J. M., De Young, K. P., Wonderlich, S. A., Crosby, R. D., Engel, S. G., Mitchell, J. E., … Le Grange, D. (2013). Daily patterns of anxiety in anorexia nervosa: Associations with eating disorder behaviors in the natural environment. *Journal of Abnormal Psychology*, *122*(3), 672–683. https://doi.org/10.1037/a0031823

Lavender, J. M., Tull, M. T., DiLillo, D., Messman-Moore, T., & Gratz, K. L. (2017). Development and validation of a state-based measure of emotion dysregulation. *Assessment*, *24*(2), 197–209. https://doi.org/10.1177/1073191115601218

Lefcheck, J. S. (2016). piecewiseSEM: Piecewise structural equation modelling in r for ecology, evolution, and systematics. *Methods in Ecology and Evolution*, *7*(5), 573–579. https://doi.org/10.1111/2041-210X.12512

Liao, Y., Shonkoff, E. T., & Dunton, G. F. (2015). The acute relationships between affect, physical feeling states, and physical activity in daily life: A review of current evidence. *Frontiers in Psychology*, *6*, 1–7. https://doi.org/10.3389/fpsyg.2015.01975

McCulloch, C. E., & Neuhaus, J. M. (2011). Misspecifying the shape of a random effects distribution: Why getting it wrong may not matter. *Statistical science*, *26*(3), 388–402.

McNeish, D. (2016). On using Bayesian methods to address small sample problems. *Structural Equation Modeling: A Multidisciplinary Journal*, *23*(5), 750–773. https://doi.org/10.1080/10705511.2016.1186549

Meyer, C., Taranis, L., Goodwin, H., & Haycraft, E. (2011). Compulsive exercise and eating disorders. *Eur Eat Disord Rev*, *19*(3), 174–189. https://doi.org/10.1002/erv.1122

Munro, C., Randell, L., & Lawrie, S. M. (2017). An integrative bio-psycho-social theory of anorexia nervosa. *Clin Psychol Psychother*, *24*(1), 1–21. https://doi.org/10.1002/cpp.2047

Noetel, M., Miskovic-Wheatley, J., Crosby, R. D., Hay, P., Madden, S., & Touyz, S. (2016). A clinical profile of compulsive exercise in adolescent inpatients with anorexia nervosa. *J Eat Disord*, *4*, 1–10. https://doi.org/10.1186/s40337-016-0090-6

Pedisic, Z., & Bauman, A. (2015). Accelerometer-based measures in physical activity surveillance: Current practices and issues. *Br J Sports Med*, *49*(4), 219–223. https://doi.org/10.1136/bjsports-2013-093407

Penas-Lledo, E., Vaz Leal, F. J., & Waller, G. (2002). Excessive exercise in anorexia nervosa and bulimia nervosa: Relation to eating characteristics and general psychopathology. *Int J Eat Disord*, *31*(4), 370–375. https://doi.org/10.1002/eat.10042

Peterson, C. M., Van Diest, A. M. K., Mara, C. A., & Matthews, A. (2019). Dialectical behavioral therapy skills group as an adjunct to family-based therapy in adolescents with restrictive eating disorders. *Eating Disorders*, 1–13. https://doi.org/10.1080/10640266.2019.1568101

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., & Team, R. C. (2018). nlme: Linear and nonlinear mixed effects models. R package version 3.1-137. Retrieved from https://CRAN.R-project.org/package=nlme

R Core Team (2013). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

R Studio Team. (2016). *RStudio: Integrated development for R (Version 1.1.447)*. Boston, MA, USA: RStudio Inc. Retrieved from https://rstudio.com/

Sala, M., Brosof, L. C., Rosenfield, D., Fernandez, K. C., & Levinson, C. A. (2017). Stress is associated with exercise differently among individuals with higher and lower eating disorder symptoms: An ecological momentary assessment study. *International Journal of Eating Disorders*, *50*(12), 1413–1420. https://doi.org/10.1002/eat.22799

Schlegel, S., Hartmann, A., Fuchs, R., & Zeeck, A. (2015). The Freiburg sport therapy program for eating disordered outpatients: A pilot study. *Eat Weight Disord*, *20*(3), 319–327. https://doi.org/10.1007/s40519-015-0182-3

Schwerdtfeger, A., Eberhardt, R., & Chmitorz, A. (2008). Gibt es einen Zusammenhang zwischen Bewegungsaktivität und psychischem Befinden im Alltag? *Zeitschrift für Gesundheitspsychologie*, *16*(1), 2–11. https://doi.org/10.1026/0943-8149.16.1.2

Schwerdtfeger, A., Eberhardt, R., Chmitorz, A., & Schaller, E. (2010). Momentary affect predicts bodily movement in daily life: An ambulatory monitoring study. *J Sport Exerc Psychol*, *32*(5), 674–693. https://doi.org/10.1123/jsep.32.5.674

Seidel, M., Petermann, J., Diestel, S., Ritschel, F., Boehm, I., King, J. A., … Ehrlich, S. (2016). A naturalistic examination of negative affect and disorder-related rumination in anorexia nervosa. *Eur Child Adolesc Psychiatry.*, *25*, 1207–1216. https://doi.org/10.1007/s00787-016-0844-3

Selby, E. A., Cornelius, T., Fehling, K. B., Kranzler, A., Panza, E. A., Lavender, J. M., … Le Grange, D. (2015). A perfect storm: Examining the synergistic effects of negative and positive emotional instability on promoting weight loss activities in anorexia nervosa. *Front Psychol*, *6*, 1260, 1–13. https://doi.org/10.3389/fpsyg.2015.01260

Smink, F. R. E., van Hoeken, D., & Hoek, H. W. (2012). Epidemiology of eating disorders: Incidence, prevalence and mortality rates. *Current Psychiatry Reports*, *14*(4), 406–414. https://doi.org/10.1007/s11920-012-0282-y

Smyth, J., Wonderlich, S., Crosby, R., Miltenberger, R., Mitchell, J., & Rorty, M. (2001). The use of ecological momentary assessment approaches in eating disorder research. *The International journal of eating disorders*, *30*(1), 83–95. https://doi.org/10.1002/eat.1057

Stiglmayr, C. E., Grathwol, T., Linehan, M. M., Ihorst, G., Fahrenberg, J., & Bohus, M. (2005). Aversive tension in patients with borderline personality disorder: A computer-based controlled field study. *Acta Psychiatr Scand*, *111*(5), 372–379. https://doi.org/10.1111/j.1600-0447.2004.00466.x

Svaldi, J., Griepenstroh, J., Tuschen-Caffier, B., & Ehring, T. (2012). Emotion regulation deficits in eating disorders: A marker of eating pathology or general psychopathology? *Psychiatry Res*, *197*(1-2), 103–111. https://doi.org/10.1016/j.psychres.2011.11.009

Terry, A., Szabo, A., & Griffiths, M. (2004). The Exercise Addiction Inventory: A new brief screening tool. *Addiction Research & Theory*, *12*(5), 489–499.

Thiel, A., Jacobi, C., Horstmann, S., Paul, T., Nutzinger, D. O., & Schüßler, G. (1997). Eine deutschsprachige Version des Eating Disorder Inventory EDI-2. *PPmP: Psychotherapie Psychosomatik Medizinische Psychologie*, *47*, 365–376.

Vansteelandt, K., Rijmen, F., Pieters, G., Probst, M., & Vanderlinden, J. (2007). Drive for thinness, affect regulation and physical activity in eating disorders: A daily life study. *Behaviour Research and Therapy*, *45*(8), 1717–1734. https://doi.org/10.1016/j.brat.2006.12.005

Watson, D., & Clark, L. A. (1994). *The PANAS-X: Manual for the Positive and Negative Affect Schedule Expanded Form*. https://doi.org/10.17077/48vt-m4t2

Wen, C. K. F., Schneider, S., Stone, A. A., & Spruijt-Metz, D. (2017). Compliance with mobile ecological momentary assessment protocols in children and adolescents: A systematic review and meta-analysis. *Journal of Medical Internet Research*, *19*(4), 1–14, e132. https://doi.org/10.2196/jmir.6641

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis* (2nd ed.). New York: Springer.

Zeileis, A., & Grothendieck, G. (2005). zoo: S3 infrastructure for regular and irregular time series. *arXiv preprint math/05055 27*, *14*(6), 1–27. https://doi.org/10.18637/jss.v014.i06

Ziemainz, H., Stoll, O., Drescher, A., Erath, R., Schipfer, M., & Zeulner, B. (2013). Die Gefährdung zur Sportsucht in Ausdauersportarten. *Deutsche Zeitschrift für Sportmedizin*, *64*.

Zipfel, S., Löwe, B., Reas, D. L., Deter, H.-C., & Herzog, W. (2000). Long-term prognosis in anorexia nervosa: Lessons from a 21-year follow-up study. *The Lancet*, *355*(9205), 721–722. https://doi.org/10.1016/s0140-6736(99)05363-5

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Kolar DR, Neumayr C, Roth M, Voderholzer U, Perthes K, Schlegl S. Testing an emotion regulation model of physical activity in adolescents with anorexia nervosa: A pilot ecological momentary assessment. *Eur Eat Disorders Rev*. 2020;28:170–183. https://doi.org/10.1002/erv.2706