Received: 29 February 2024 | Revised: 21 August 2024 | Accepted: 25 August 2024

DOI: 10.1111/acps.13757

Acta Psychiatrica Scandinavica WILEY

ORIGINAL ARTICLE

Relationship between nonexercise activity and mood in patients with eating disorders

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Funding information
Schweizerische Anorexia Nervosa Stiftung, Grant/Award Number: 37-14

Abstract

Introduction: Many patients with eating disorders (EDs) engage in excessive and compulsive physical activity (pathological exercise, PE) to regulate negative mood or to "burn calories." PE can lead to negative health consequences. Non-exercise activity (NEA) bears the potential to serve as intervention target to counteract PE and problematic eating behaviors since it has been associated with positive mood effects. However, to date, there is no investigation on whether the positive link between NEA and mood seen in the healthy translates to patients with ED.

Material and Methods: To study potential associations of NEA and mood in ED, we subjected 29 ED-patients and 35 healthy controls (HCs) to an ambulatory assessment study across 7 days. We measured NEA via accelerometers and repeatedly assessed mood on electronic smartphone diaries via a mixed sampling strategy based on events, activity and time. Within- and between-subject effects of NEA on mood, PE as moderator, and the temporal course of effects were analyzed via multilevel modeling.

Results: NEA increased valence ($\beta = 2.12$, $p < 0.001$) and energetic arousal ($\beta = 4.02$, $p < 0.001$) but showed no significant effect on calmness. The effects of NEA on energetic arousal where significantly stronger for HCs ($\beta_{HC} = 6.26$, $p < 0.001$) than for EDs ($\beta_{ED} = 4.02$, $p < 0.001$; $\beta_{interaction} = 2.24$, $p = 0.0135$). Effects of NEA were robust across most timeframes of NEA and significantly

Almut Zeeck and Markus Reichert share authorship.

moderated by PE, that is, Lower PE levels exhibited stronger NEA effects on energetic arousal.

Conclusion: Patients with ED and HC show an affective benefit from NEA, partly depending on the level of PE. If replicated in experimental daily life studies, this evidence may pave the way towards expedient NEA interventions to cope with negative mood. Interventions could be especially promising if delivered as Just-in-time adaptive interventions (JITAIs) and should be tailored according to the PE level.

KEYWORDS

ambulatory assessment, anorexia nervosa, bulimia nervosa, ecological momentary assessment, emotion regulation, pathological exercise, physical activity

1 | INTRODUCTION

Physical activity (PA) presents itself as promising intervention target in the treatment of mental diseases,[1,2] including eating disorders (EDs).[3,4] The benefits of PA are numerous, primarily because it bears transdiagnostic effects, such as mood improvements,[5] but also because it is a cost-effective mean without side-effects that patients can easily integrate into their daily routines.[2,5] In general, and following established definitions,[6] PA can be classified into two categories, exercise, and non-exercise activity (NEA). Exercise is defined as PA that is planned, structured, repetitive, and usually aimed to improve or maintain physical health. NEA is defined as all other daily PA and is often performed automatically, habitually, or spontaneously. For example, NEA includes daily activities such as gardening, cleaning, walking, and stair climbing. NEA has been associated with positive effects on mood in healthy adults and thus could also hold promise for patients with EDs.[7]

For effective NEA interventions in ED treatment, in a first step associations of NEA with mood on a momentary level needs to be investigated in patients with EDs. However, these accounts have not been studied yet. Ambulatory Assessment (AA) presents itself as promising solution to further investigate the effects of NEA on mood. AA allows for repeated real-life assessments of mood via smartphone diaries that can be combined with PA measurements assessed via accelerometers. In the general population and according to most recent reviews of AA studies on the association of NEA and mood, NEA has been shown to be related to increased affective valence and energetic arousal, but to decreased calmness.[8,9] That is, after engaging in NEA in their everyday life, individuals felt better and more content, more energized and awake but less calm and relaxed. Overall, the largest effect sizes have been reported for the association of NEA with energetic arousal.[7,9] Numerous PA related AA studies have been conducted that focus on patient samples with mental disorders. The results show increased PA benefits in these populations, such as reduced anxiety sensitivity, an increase in self-efficacy[5] and reduction of depressive symptoms.[10]

In case NEA shows significant positive effects in patients with ED, it could be used when patients experience negative mood states to either counteract problematic eating behaviors or pathological exercise. This is of utmost importance, given that PA is a "double-edged sword" in the treatment of patients with EDs such as anorexia nervosa (AN) and bulimia nervosa (BN), opposed to for example in the treatment of depression. While PA bears the potential to improve mood, self-esteem and body experience, all of which are core problems associated with EDs,[11] approximately half of the patients show pathological attitudes towards PA and a compulsive, excessive exercise behavior.[12,13] This phenomenon is often referred to as compulsive exercise or (secondary) exercise dependence. We prefer the term "pathological exercise" because it encompasses both obsessive-compulsive features as well as similarities to behavioral addictions.[14] Pathological exercise, which is typically conducted in a fitness-studio or as a lonely running-session, is associated with poorer treatment outcomes and higher relapse rates.[15] The pathology is reflected not only in the quantity of PA (exercising more than is appropriate for the state of malnutrition), but also in its "quality" and function. PA is conducted in a rigid manner and used not only to regulate affective states and tension, but also as a mechanism to "burn" calories and persists despite negative physical and social consequences.[16,17] Previous research using AA in patients with ED showed that negative affect can precede pathological exercise as well as disordered eating[11,18–20] and that exercise was able to effectively moderate negative mood and

dysfunctional cognitions[11]: Mood improved after exercise and the drive for thinness was reduced. Moreover, patients with ED experienced higher emotional and cognitive benefits after exercise compared to healthy participants.[11] We therefore hypothesize that this may also apply to NEA. Investigating whether NEA, with its fewer negative physical and social consequences compared to excessive exercise, could result in the same positive effects on mood in this patient subgroup, is of great interest to researchers and practitioners.

Numerous studies used AA to study PA as it relates to psychopathology[10,21–26] and some specifically with ED patients.[27–30] However, to the best of our knowledge and according to a recent systematic literature review,[9] there is a research gap on NEA and its relation with mood in the everyday life of patients with EDs. With the following study, we focus on the relationship between NEA and mood while comparing patients with ED with healthy individuals. We hypothesize: (1) that NEA prior to e-diary assessments of mood positively predicts valence and energetic arousal ratings and negatively predicts calmness ratings across both groups; (2) that the strongest effect of NEA will be found for the dimension energetic arousal, followed by valence and calmness; (3) that the effect on valence, calmness and energetic arousal will be different for patients with ED and healthy individuals. Lastly, we intend to explore if effects found for patients with ED are dependent on the extent to which exercise pathology is present/absent.

1.1 | Aims of the Study

We aimed to investigate the momentary relationship between nonexercise activity and mood in the everyday life of patients with EDs, applying ambulatory assessment across seven days in both patients with EDs and healthy controls.

2 | METHODS

2.1 | Participants

The study sample comprised 29 female outpatients with an ED and 35 female healthy controls (HCs). For a sample description see Table 1. We estimated whether the level two sample size of $N = 29$ (ED only) together with the amount of level one data points (i.e., on average 91 e-diary assessments per participant) is adequate for detecting the expected main effects. According to latest simulation studies,[31] based on a power of at least 0.80, with medium or high ICCs (as expected in within person analyses), a level 2 sample size of 30 and a level one

TABLE 1 Participant characteristics.

Variable	Patients with eating disorders ($N = 29$) M (SD)	Healthy controls ($N = 35$) M (SD)	*t*-test
Age	26.3 (± 9.0)	24.6 (± 6.5)	$t_{62} = 0.612$; $p = 0.848$
BMI (in kg/m^2)	19.6 (± 2.5) range: 15.1–20.6	22.1 (± 2.6) range: 17.8–29.0	$t_{62} = 1.914$; $p = 0.001$
BDI-II			
Total score	21.79 (± 9.08)	3.40 (± 3.96)	$t_{62} = 3.206$; $p = 0.000$
CES			
Total score	99.93 (± 28.49)	72.31 (± 30.71)	$t_{62} = 1.907$; $p = 0.000$
EDE			
Total score	3.31 (±1.34)	0.37 (±0.65)	$t_{62} = 3.021$; $p = 0.000$
IPAQ			
Sitting	1904.48 (± 2054.45)	2310.00 (± 1461.15)	$t_{62} = -0.921$; $p = 0.361$
Walking (min)	364.83 (± 488.46)	240.06 (± 372.31)	$t_{62} = 1.159$; $p = 0.251$
Moderate activity (min)	329.66 (± 331.12)	285.71 (± 301.22)	$t_{62} = 0.555$; $p = 0.581$
Vigorous activity (min)	374.48 (± 279.86)	410.57 (± 371.46)	$t_{62} = -0.431$; $p = 0.668$
MET-min/week	7422.90 (± 4498.06)	7529.62 (± 3869.53)	$t_{62} = -0.102$; $p = 0.919$

Abbreviations: BDI-II, beck depression index; BMI, body mass index; CES, commitment to exercise scale; EDE, eating disorder examination (expert form); IPAQ, international physical activity questionnaire; *M*, mean; *SD*, standard deviation.

sample size of 90, the minimum detectable effect size is approximately 0.15. Due to the large number of repeated measures per participant, we deemed analyses of within-subject effects to be well powered.

Of the 29 patients with EDs, 51.7% were diagnosed with bulimia nervosa (BN), 38.0% with anorexia nervosa (AN) and 10.3% with other specified feeding or eating disorders (OSFED). Recruitment took place via local newspapers and advertisements on university notice boards. To be included in the study, patients with ED had to be aged 18 years or older, be physically active >60 min per week, and diagnosed with AN, BN or OSFED according to the Eating Disorder Examination Interview (EDE, see below) or DSM 5. Patients with a body mass index (BMI) of less than 16.0 kg/m^2 were excluded to prevent the participation of patients with starvation-induced hyperactivity. Other exclusion criteria were: being an elite athlete, physical impairments inhibiting participation in PAs or being diagnosed with psychosis, bipolar disorder, severe substance dependency or organic brain disorders. HCs were excluded if they had any form of mental illness or showed any ED symptoms according to the (Short Evaluation of Eating Disorders) SEED.[32] Following established procedures in the field,[33] only data from participants with e-diary compliance >30% were included for analyses, since datasets with less than 30% compliance produce systematic bias.[33] In our sample and after exclusions of data below this threshold, compliance rates of participants with an ED ranged from 47.9% to 100% (mean = 80.24%, SD ± 16.11%) and of HCs from 73.4% to 96.8% (mean = 73.04, SD ± 8.48%).

2.2 | Measures

Participants provided their height and weight for BMI (kg/m^2) calculations. ED psychopathology was assessed with the Eating Disorders Examination (EDE)[34,35] and screened for in HCs with the SEED questionnaire (see above). The Commitment to Exercise Scale (CES)[36,37] was used to measure compulsive and excessive features of exercise engagement. Depression was assessed with the Beck-Depression-Index (BDI-II).[38] The International Physical Activity Questionnaire IPAQ[39] was administered to participants for self-assessment of PA (for more details on instruments see Reichert et al. 2019).

2.3 | Ambulatory assessment

Everyday life data were collected over seven consecutive days with smartphone-based e-diaries and accelerometers. We used the smartphones Motorola Moto E XT1021 (Motorola Mobility LLC, Libertyville, Illinois, USA, www.motorola.com) and the accelerometers movisens Move-III (movisens GmbH, Karlsruhe, Baden-Wuerttemberg, Germany, www.movisens.com).

2.3.1 | Mood

To assess mood, we applied an established six-item short-scale[40] based on the Multidimensional Mood Questionnaire[41] that captures mood as a three-dimensional construct comprising valence, energetic arousal, and calmness. This short-scale was specifically developed for the assessment and analyses of within-person dynamics of mood and demonstrated good psychometric properties on the between- and within-person level.[40] The mood items were presented on visual analog scales (response scales range: 0–100) and comprised the following six items: 1. content—discontent (valence), 2. unwell—well (valence), 3. tired—awake (energetic arousal), 4. full of energy—without energy (energetic arousal), 5. relaxed—tense (calmness), 6. agitated—calm (calmness). To assess the reliability of the two-item mood scales, we used the Spearman-Brown method,[42] yielding sound reliabilities at the within-person level (valence: 0.69; energetic arousal: 0.71; calmness 0.67) and the between-person level (valence: 0.97; energetic arousal: 0.93; calmness: 0.98).

2.3.2 | Physical activity

Participants wore Move-III accelerometers attached to the right side of their hip to capture PA in daily life. Move-III accelerometers contain a triaxial acceleration sensor that measures acceleration signals with a sampling frequency of 64 Hz, a resolution of 12 bits within a range of +/−8 g. Acceleration data was parameterized as Movement Acceleration Intensity (MAI), which represents the vector magnitude of the triaxial acceleration signal, high-pass filtered (0.25 Hz) to eliminate gravitational components, and low-pass filtered (11 Hz) to exclude artifacts.[43] MAI refers to raw acceleration data and is, therefore, expressed in units of standard gravity (g). To facilitate interpretation, we express MAI in units of deci-g, which is one-tenth of g. The accelerometers were worn for the entire seven days of assessment during awake times.

2.3.3 | NEA

We applied an event-based sampling strategy to distinguish between exercise activity and NEA. Participants

were instructed to press the buttons "start exercise session" and "finish exercise session" on their smartphone before and after any activity considered exercise (sports activity, exercise sessions or any PA with the intention of managing weight and shape or to enhance performance). Moreover, to ensure that all exercise activities were reported, participants were additionally prompted to report any such activities in each e-diary assessment using the question: "Did you engage in any exercise activity since the last beep?" We consider any PA measured with accelerometers that was not classified as exercise by the participants as NEA.

2.4 | E-diary sampling strategy

To examine mood near real time, we employed a mixed e-diary sampling approach that included an event-based trigger algorithm, an activity trigger algorithm, and a time-based trigger algorithm. The event-based trigger algorithm was intended to assess periods of exercise activities (see NEA). The activity triggered algorithm was specifically developed to trigger e-diary prompts at times when PA was low or high, to avoid missing out on periods of interest. The time-based algorithm ensured e-diary prompts to be triggered at least every 100 min but no more often than every 40 min between 7:30 and 22:30. Additionally, prompts were triggered 30 min after participants indicated that they finished exercising. This combined sampling strategy resulted in nine to 22 triggers per day and resulted in an average of 13.15 (SD 2.72) prompts per day. The prompts were triggered by acoustic, visual and vibration signals, and participants were able to postpone them for up to 15 min. Programming and implementation of the sampling strategy was accomplished using the software movisensXS, version 0.6.3658 (movisens GmbH, Germany, xs.movisens.com).

2.5 | Data analysis

2.5.1 | Main analysis

To test for possible effects of NEA on mood, we conducted three multilevel model analyses, with each of the three mood dimensions, respectively (valence, energetic arousal, and calmness) as outcomes, and incorporated NEA as the main predictor of interest. Equation (1) depicts the model with valence as an exemplified outcome. We nested e-diary assessments (level 1) within participants (level 2). We operationalized NEA by following established procedures and aggregated the accelerometer data across timeframes of 60 min prior to each e-diary assessment and centered it around the participants' individual means to differentiate within-person effects from between-person effects. To avoid any confounding influence of exercise, only data in which no exercise was performed within the 60 min prior to the e-diary assessment were taken into account. We chose the previous 60 min prior to the e-diary assessment as aggregation period because these time intervals were generally shown to be reliable for investigating momentary associations of PA with psychological outcomes. In particular, a recent study[44] revealed that sampling durations of at least 60 min are best suited to achieve acceptable levels of reliability. Moreover, 60 min prior to the e-diary assessment have proven to be appropriate to investigate PA—affective well-being associations in daily life studies in both the healthy and samples with mental disorders.[7,45]

We included time of the day and time of the day squared (both subtracted by the start time of the study for each day) to our multilevel models to control for time of the day effects. We added group (ED vs. HC) as a dichotomous level 2 predictor and included an interaction term between groups and NEA to analyze whether the hypothesized effect of NEA on mood differs between EDs and HCs. We coded the groups as dummy variables (HC = 1 and ED = 0), with ED being the reference group. The coefficients of NEA therefore refer to the effects specific to the reference group (EDs). We included random intercepts in every model, to consider that participants mood varies around the sample mean.

Multilevel model—main analysis:

$$\begin{aligned} \mathrm{Y(valence)}_{ij} = {} & \beta_{00} + \beta_{10} * \text{time of day}_{ij} + \beta_{20} \\ & * \text{time of day squared}_{ij} + \beta_{01} * \text{group}_{j} \\ & + \beta_{30} * \text{NEA}_{ij} + \beta_{42} * \text{group}_{j} * \text{NEA}_{ij} + u_{0j} \\ & + r_{ij} \end{aligned} \tag{1}$$

where subscript j = participant; subscript i = time of measurement; u = random effects of the intercept r = residuals at level 1.

2.6 | Sensitivity analysis on the time course of effects

Since reliability of PA outcomes was shown to depend on sampling duration,[44] we conducted additional sensitivity analyses by aggregating NEA across different time frames. In particular, we aggregated NEA for 15 time frames (i.e., across 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100, 150, and 200 min before each e-diary

assessment) and excluded any data in which participants exercised within each given timeframe. As in the main analysis, NEA is based on the time immediately before the assessments. That is, NEA in a time frame of 60 min represents the mean accelerometer data within the 60 min prior to assessments. Following exactly the same procedure as in our main model, we again centered PA around the participants' means and ran the same model specified above with varying PA time frames. We calculated standardized beta coefficients according to Hox[46] using the formula presented in Equation (2), in which SD represents the standard deviation of the entire sample. To visualize the effects between patients with ED and healthy participants, we plotted the standardized beta coefficients separately for each group, by the extracting simple slopes of the models.

Beta standardization formula:

$$\text{Standardized beta coefficent} = \beta * \frac{SD_{predictor}}{SD_{outcome}} \quad (2)$$

2.6.1 | Exploratory moderation analysis

We further conducted an exploratory moderation analysis to investigate how pathological exercising, operationalized by individual CES scores, influences the relationship between NEA and mood in patients with EDs. Therefore, we ran three multilevel models for the subsample of patients with ED using the three mood dimensions (valence, calmness, energetic arousal) as outcome. We included CES as level 2 predictor and added an interaction term between CES and NEA. Equation (3) displays the model with valence as an exemplified outcome.

Multilevel model—moderation analysis:

$$\begin{aligned} \text{Y (valence)}_{ij} = {} & \beta_{00} + \beta_{10} * \text{time of day}_{ij} + \beta_{20} \\ & * \text{time of day squared}_{ij} + \beta_{01} * \text{CES}_j \\ & + \beta_{30} * \text{NEA}_{ij} + \beta_{42} * \text{CES}_j * \text{NEA}_{ij} + u_{0j} \\ & + r_{ij} \end{aligned} \quad (3)$$

where subscript j = participant; subscript i = time of measurement; u = random effects of the intercept r = residuals at level 1.

3 | RESULTS

3.1 | Descriptive statistics

Overall, patients with ED were more physically active than healthy participants across both, exercise activities and NEAs: patients with ED exercised on average 74 min per day with an average intensity of 3.88 MET, while HCs exercised on average 70 min per day with an average intensity of 2.52 MET. Compared to healthy participants, patients with ED were also more physically active when they were not exercising with an average NEA of 0.74 deci-g (vs. 0.61 deci-g in HCs). Further information on PA differences between groups are displayed in Table 2 and Figure 1. The final dataset consisted of 6109 completed e-diary assessments. As this study specifically examines NEA, our main analysis is based on 5173 e-diary assessments in which no exercise was performed in the previous 60 min.

TABLE 2 Physical activity.

Variable	Patients with eating disorder ($N = 29$) M (SD)	Healthy controls ($N = 35$) M (SD)	*t*-test
Non-exercise activity			
MAI (deci-g)	0.74 (± 0.23)	0.62 (± 0.12)	$t_{62} = 2.665$; $p = 0.009$
MET	1.6 (± 0.18)	1.5 (± 0.09)	$t_{62} = 2.732$; $p = 0.008$
Steps/week	67016.86 (± 33492.54)	48672.06 (± 16850.71)	$t_{62} = 2.838$; $p = 0.006$
Steps /day	9573.84 (±4784.65)	6953.15 (± 2407.24)	$t_{62} = 2.838$; $p = 0.006$
Exercise activity			
MAI (deci-g)	3.62 (± 1.99)	1.98 (± 1.52)	$t_{60} = 3.654$; $p < 0.001$
MET	3.88 (± 1.52)	2.52 (± 1.28)	$t_{60} = 3.810$; $p < 0.001$
Steps/week	28114.50 (± 29399.29)	10381.32 (± 11821.35)	$t_{60} = 3.219$; $p = 0.002$
Steps/day	4016.36 (± 4199.89)	1483.05 (± 1688.77)	$t_{60} = 3.219$; $p = 0.002$

Abbreviations: M, mean; MAI, Movement Acceleration Intensity; MET, metabolic equivalent of task; SD, standard deviation.

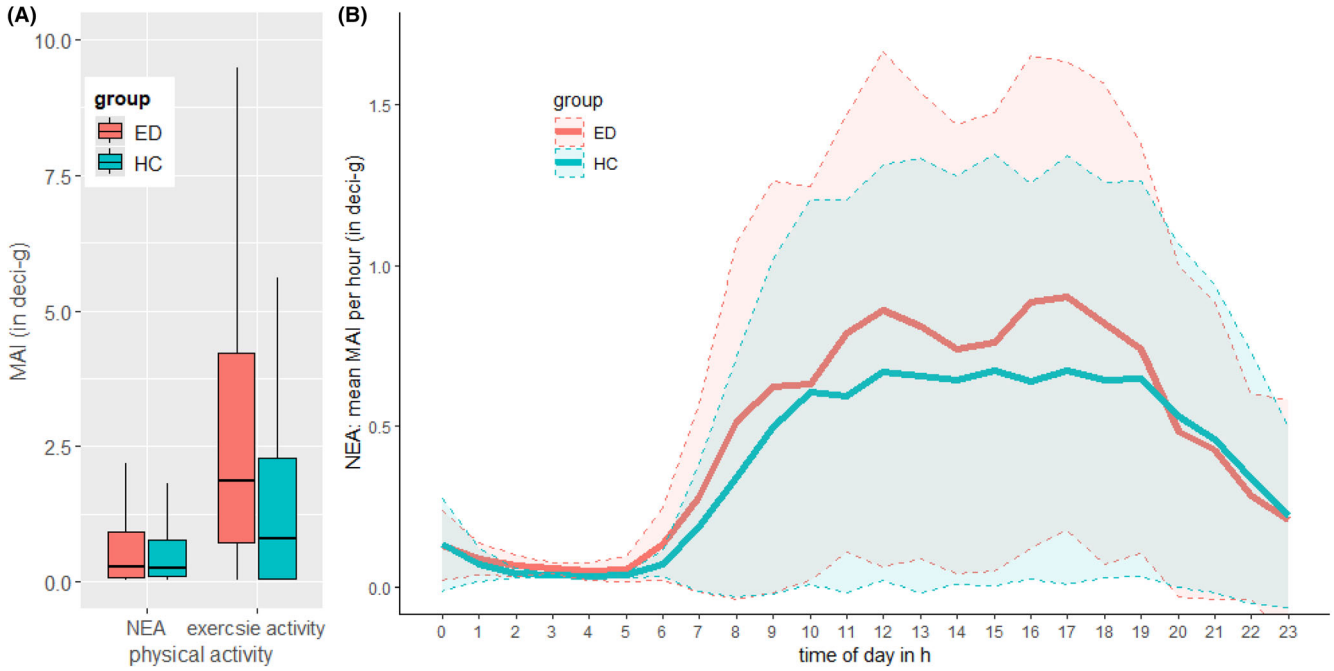

FIGURE 1 Average NEA. Panel A displays differences between patients with EDs and HCs in NEA and in exercise activity; Panel B displays differences between patients with EDs and HCs in NEA across the day. Here, the mean accelerometer data per participant per hour were averaged across each group. The dashed line represents the mean ± one standard deviation, where the standard deviation is the average participants' standard deviation per hour across each group.

3.2 | Main analysis

3.2.1 | Valence

The level 2 predictor group showed a significant effect ($\beta = 26.29$, $p < 0.001$), that is, HCs scored on average 26.29 points higher on valence than patients with EDs across all e-diary prompts. As hypothesized, NEA was significantly and positively associated with valence ($\beta_{ED} = 2.115$, $p < 0.001$; $\beta_{HC} = 1.806$, $p = 0.004$). Specifically, this indicates that patients with EDs scored on average 2.1 points higher on valence (scale range: 0–100) for every deci-g that they were more active during one hour prior to assessment. To illustrate, sedentary behavior is approximately equivalent to 0.07 deci-g and walking (at 3.1 mph) is approximately equivalent to 3.67 deci-g.[47] Translated to practice and on average, walking instead of sitting 60 min was related to a 7.61 point increase in affective valence (range 0–100). The interaction effect between groups (ED vs. HC) and NEA is non-significant ($\beta_{interaction} = -0.309$, $p = 0.695$), which indicates that the effect of NEA on valence is similar for patients with EDs and HCs. Time and time squared did not significantly predict valence ($p = 0.201$ and $p = 0.05$). The multilevel model for valence is displayed in Table 3 and plotted in Figure 2, panel A.

3.2.2 | Calmness

We found a significant difference between groups ($\beta = 24.67$, $p < 0.001$), with HCs scoring, on average, 24.67 points higher on calmness than patients with EDs across all e-diary prompts. However, we found no significant association between NEA and calmness and no significant interaction between NEA and groups. Notably, the control variables time ($\beta = -0.804$, $p < 0.001$) and time squared ($\beta = 0.07$, $p < 0.001$) did significantly predict calmness. The multilevel model for calmness is displayed in Table 3 and plotted in Figure 2, panel B.

3.2.3 | Energetic arousal

The difference between groups was again significant ($\beta = 12.28$, $p < 0.001$), with HCs scoring, on average, 12.28 points higher on energetic arousal than patients with EDs across all e-diary prompts. Energetic arousal was significantly predicted by NEA ($\beta_{ED} = 4.019$, $p < 0.001$; $\beta_{HC} = 6.258$, $p < 0.001$), indicating that for every deci-g that NEA increased during the hour preceding assessment, patients with EDs scored on average 4.019 points higher on energetic arousal (scale range: 0–100). Therefore, as expected, the effect of NEA on

TABLE 3 Multilevel analysis: Fixed effects of NEA on valence, energetic arousal, and calmness.

Predictor	Estimate	95% CI 2.5%	95% CI 97.5%	Std. error	df	*t* value	*p*
Model 1: Valence							
Intercept	48.766	43.4	54.135	2.702	73.81	18.042	< 0.001
Time	−0.241	−0.61	0.129	0.189	4519.961	−1.278	0.2012
Time^2	0.022	0	0.044	0.011	4519.623	1.960	0.0501
Group (HC)	26.294	19.267	33.32	3.532	64.357	7.445	< 0.001
NEA	2.115	1.163	3.067	0.486	4537.419	4.355	< 0.001
Group:NEA	−0.309	−0.856	1.238	0.789	4532.598	−0.392	0.6954
Model 2: Calmness							
Intercept	47.626	42.287	52.968	2.69	75.347	17.704	< 0.001
Time	−0.804	−1.194	−0.414	0.199	4520.621	−4.040	< 0.001
Time^2	0.07	0.047	0.093	0.012	4520.241	5.890	< 0.001
Group (HC)	24.67	17.706	31.63	3.5	64.56	7.049	< 0.001
NEA	0.293	−0.711	1.297	0.512	4540.02	0.573	0.567
Group:NEA	−0.13	−1.761	1.501	0.832	4534.721	−0.156	0.876
Model 3: Energetic arousal							
Intercept	54.126	49.67	58.587	2.249	85.216	24.067	< 0.001
Time	1.904	1.4	2.33	0.217	4524.23	8.783	< 0.001
Time^2	−0.187	−0.213	−0.161	0.013	4523.568	−14.472	< 0.001
Group (HC)	12.282	6.624	17.933	2.842	65.076	4.321	< 0.001
NEA	4.019	2.926	5.113	0.558	4555.07	7.207	< 0.001
Group:NEA	2.239	0.462	4.0162	0.907	4547.344	2.470	0.0135

Note: Time = in h; Time^2 = in h^2; NEA = mean MAI in deci-g; Group is dummy coded with ED as reference Group.

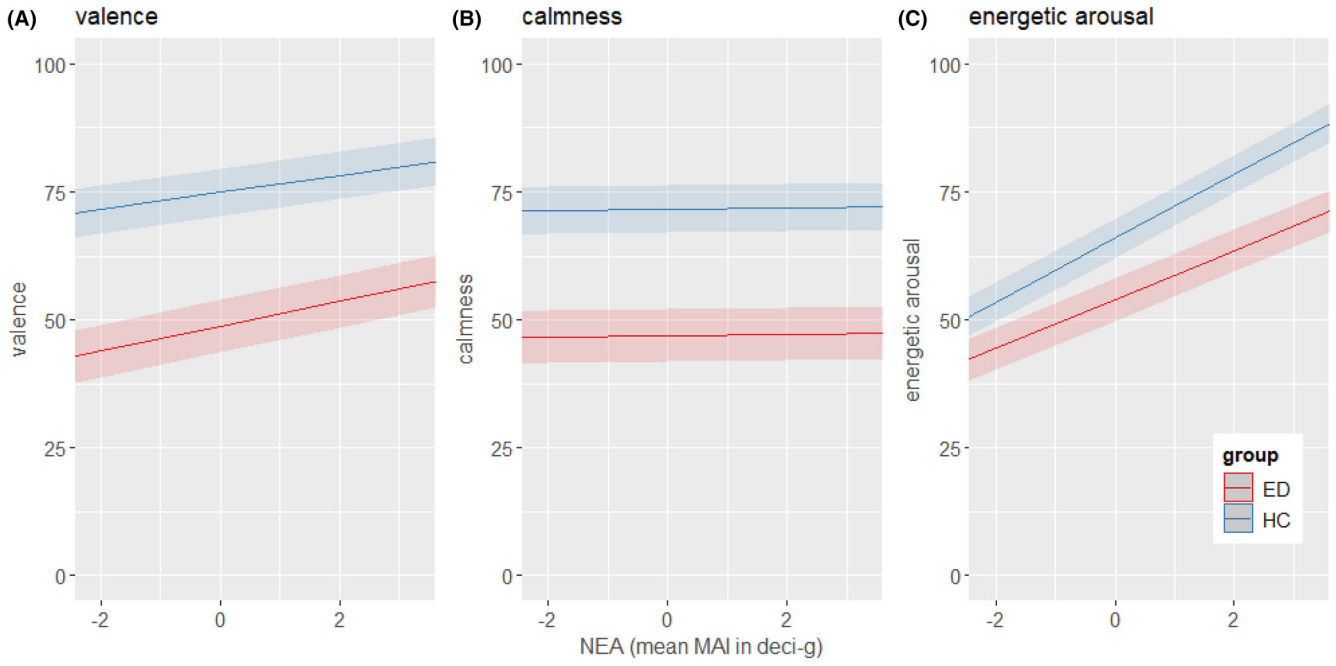

FIGURE 2 Main analysis: Associations of NEA with valence, energetic arousal, and calmness. NEA is participant-mean centered. Thus, the x-axis represents NEA as the relation to the participant mean (x = 0).

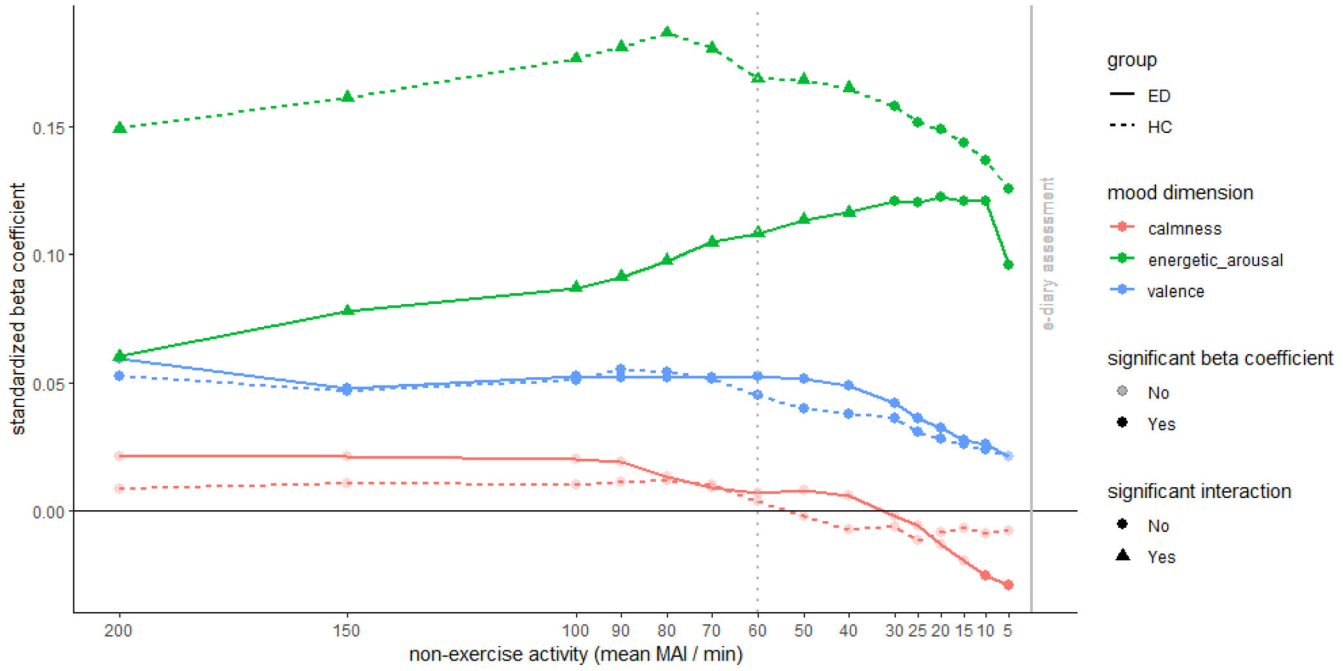

FIGURE 3 Sensitivity analysis: Standardized beta coefficients across different aggregation timeframes of NEA. Dotted vertical line = NEA time frame of the main analysis (60 min aggregation period).

energetic arousal is higher than the effect of NEA on valence. The interaction effect between groups (ED vs. HC) and NEA was significant ($\beta_{\text{interaction}} = 2.239$, $p = 0.0135$), indicating that the effect of NEA on energetic arousal is 2.239 points higher for HCs than for patients with EDs. Again, the control variables time ($\beta = 1.905$, $p < 0.001$) and time squared ($\beta = -0.187$, $p < 0.001$) significantly predicted energetic arousal. The multilevel model for energetic arousal is displayed in Table 3 and plotted in Figure 2, panel C.

3.3 | Sensitivity analysis

To explore whether our findings vary as a function of chosen NEA time frames, we plotted the standardized beta coefficients of multilevel models with varying NEA time frames (Figure 3). On the y-axis, the size of the standardized beta coefficients of NEA are depicted. On the x-axis, different time frames of NEA are displayed. For example, the coefficients at x = 60 correspond to the standardized coefficients of the results presented above, indicated by the dotted vertical line. In this case, NEA is therefore based on the last 60 min before the assessment. Accordingly, the values at position 200 represent the standardized coefficients when NEA was aggregated over the last 200 min prior to assessment. The colors specify the mood dimensions, and the line type distinguishes between the two groups. Beta coefficients that are not significant are hidden by low opacity. To highlight whether the effect of NEA differs significantly between the two groups, significant interaction effects are indicated by triangles. As hypothesized, the plot highlights that the relationship between NEA and energetic arousal is the strongest, followed by valence and calmness. Moreover, it is also evident that the effects of NEA on energetic arousal are consistently higher for HCs than for patients with EDs, with significant interaction effects across most time frames. Moreover, coefficients for shorter aggregation periods are generally smaller than for longer periods. Noteworthy, NEA aggregated over 5 and 10 min prior assessment is significantly negatively associated with calmness in healthy participants.

3.4 | Moderation analysis

CES significantly moderated the effect of NEA on energetic arousal but not on valence and calmness. Thus, patients with lower signs of pathological exercise behavior display a stronger association between NEA and energetic arousal ($\beta_{\text{interaction}} = -0.11$; $p < 0.001$). The results of the moderation analysis for all three mood dimensions are displayed in Table 4 and in Figure 4.

4 | DISCUSSION

For both healthy subjects and patients with ED, we found NEA to be significantly associated with valence and

TABLE 4 Moderation analysis: Fixed effects of NEA on valence, energetic arousal, and calmness, in patients with ED, moderated by CES.

		95% CI					
Predictor	**Estimate**	**2.5%**	**97.5%**	**Std. Error**	**df**	***t* value**	***p***
Model 1: Valence							
Intercept	63.209	45.025	81.417	8.985	29.695	7.035	< 0.001
Time	−0.431	−1.034	0.173	0.308	1989.352	−1.400	0.162
Time^2	0.041	0.004	0.078	0.019	1989.374	2.153	0.031
CES	−0.144	−0.319	0.030	0.086	28.867	−1.678	0.104
NEA	5.410	0.804	10.015	2.348	1998.130	2.304	0.021
CES:NEA	−0.030	−0.071	0.012	0.021	1997.478	−1.396	0.163
Model 2: Calmness							
Intercept	67.553	53.961	81.192	6.730	30.705	10.038	< 0.001
Time	−1.548	−2.171	−0.925	0.318	1992.491	−4.873	< 0.001
Time^2	0.132	0.094	0.170	0.019	1992.527	6.767	< 0.001
CES	−0.190	−0.320	−0.061	0.064	29.093	−2.972	0.006
NEA	3.384	−1.368	8.136	2.420	2006.556	1.398	0.162
CES:NEA	−0.025	−0.068	0.017	0.022	2005.703	−1.165	0.244
Model 3: Energetic arousal							
Intercept	55.481	39.550	71.438	7.879	30.460	7.042	< 0.001
Time	1.412	0.782	2.041	0.321	1991.071	4.396	< 0.001
Time^2	−0.152	−0.191	−0.114	0.020	1991.100	−7.731	< 0.001
CES	−0.001	−0.154	0.151	0.075	29.262	−0.018	0.986
NEA	16.469	11.667	21.270	2.449	2002.498	6.726	< 0.001
CES:NEA	−0.114	−0.157	−0.070	0.022	2001.718	−5.159	< 0.001

Note: Time = in h; Time^2 = in h^2; CES = Commitment to Exercise Scale; NEA = mean MAI in deci-g.

energetic arousal but not with calmness. As expected, the effect on energetic arousal was the strongest, followed by valence. However, surprisingly and contrary to our expectations, there was no significant difference between patients with ED and HCs in the effect of NEA on valence and calmness. The effect of NEA on energetic arousal differed significantly between groups, with HCs benefiting more from NEA than EDs. Our sensitivity analyses demonstrated that the results are robust for the majority of NEA time frames investigated. We further found that the amount of pathological exercise significantly moderated the effect of NEA on mood in patients with EDs; that is, patients with fewer signs of exercise pathology displayed higher effects of NEA on energetic arousal.

Our results reveal positive associations of NEA with mood on a momentary level and thus bear promise for future just-in-time adaptive interventions (JITAIs). JITAIs, an arising type of intervention that offers tailored assistance at the exact time and place of need, are perfectly suited to facilitate PA guidance and barrier management.[48] Here, especially NEA (i.e., daily PA such as gardening, walking and stair-climbing, or sedentary breaks such as short-term movement programs) qualify for momentary real-life interventions served by smartphone applications.[49] The type, duration, and intensity of the NEA should be individually tailored towards patients' preferences with a constant focus on symptom improvement, so that real-time analyses may trigger activity interventions just at the time of increasing symptomatology. For example, interventions might be triggered whenever patients with an ED experience bad mood or report signs of eating pathology (e.g., urge to binge eat or exercise excessively).

Taking an interventional perspective towards expedient and evidence-based JITAIs, valence serves a particularly important role in patients with ED since negative affect and problems with affect regulation are closely related to disordered eating behavior,[50–52] and negative affect has been suggested as a determinant of exercise pathology.[11] Therefore, the potential increase in valence through NEA is a particularly promising result and

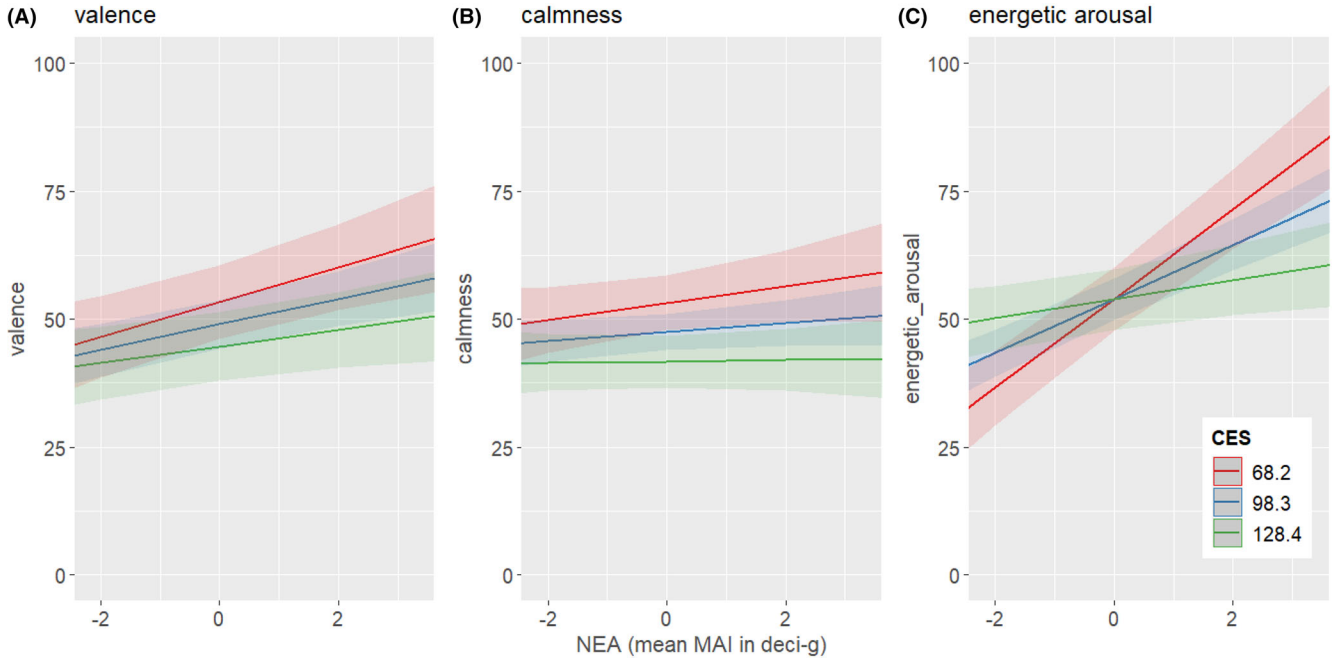

FIGURE 4 Moderation analysis: Associations of NEA with valence, energetic arousal, and calmness, in patients with ED, moderated by CES. NEA is participant-mean centered. Thus, the x-axis represents NEA as the relation to the participant mean (x = 0). Blue = mean CES; red = mean CES − 1 sd; green = mean CES + 1 sd.

possible treatment target, as it demonstrates that mood elevation in patients with ED does not require intensive exercise. In particular, our results show that patients with EDs scored on average 2.1 points higher on valence (scale range: 0–100) for every deci-g that they were more active during one hour prior to assessment. In other words, compared to sitting, walking for 60 min can lead to a 7.61 point increase in affective valence (on a range of zero to 100). Therefore, NEAs like going for a walk or gardening may be promising interventions in patients with EDs in periods of negative mood—for example, when feeling lonely, angry or depressed. Moreover, our sensitivity analysis demonstrated that this effect remains significant even for shorter NEA periods. Our moderation analysis of exercise pathology on the effects of NEA on valence was not significant. However, it revealed a trend within our sample, in which stronger effects of NEA on valence were associated with lower levels of exercise pathology. In JITAIs, encouragements for NEA should therefore be accompanied by interventions aiming to prevent pathological PA, for example, by setting an upper limit of intensity and addressing dysfunctional cognitions. Of note, even NEA might be used in a problematic manner by patients that show exercise pathology.[53] In this patient group, NEA may simply not be "enough" to improve mood and prevent feelings of guilt compared to exercise sessions.

Our main analysis identified no significant effect of NEA on calmness, which is not surprising as past research has shown that the effect of PA on calmness is generally small and often non-significant.[9]

Energetic arousal is typically the mood dimension that is most strongly affected by NEA in community-based samples.[6,7,54,55] In line, our results show energetic arousal to be increased by 6.26 points for healthy participants and by 4.02 points for patients with ED, for every deci-g that NEA increased prior to assessment. Again, this relationship is robust over various NEA timeframes. Moreover, our moderation analysis revealed that the effect of NEA on energetic arousal is influenced by exercise pathology, being strongest in patients without signs of exercise pathology. This might be explained by a presumably higher amount of exhaustion in the group that exercises more excessively, despite malnutrition.

To this end and in sum, we argue NEA to be a potentially promising target in the treatment of patients with ED via JITAIs: For ED patients NEA could be a helpful additional intervention in situations of negative mood and low energy, especially when administered as a JITAI. For ED patients with high levels of pathological exercise behavior, JITAIs should also include interventions related to exercise sessions and include complementary components, addressing the duration and intensity of NEA as well as problematic cognitions such as "going for

a walk is not enough" or "it is not allowed to eat without a planned excessive exercise session." However, there is still a long way to go before tailored and thus expedient PA focused JITAIs become a regular treatment option for patients with EDs and could supplement evidence-based psychotherapies. Before JITAIs become regular treatment options, an in-depth understanding of the causal relationship between PA and its associated characteristics (i.e., duration, intensity, type, exercise vs. NEA) and psychological parameters like mood, tension, body experience and eating-disorder related cognitions (e.g., drive for thinness, body dissatisfaction) in daily life needs to be acquired.

While our study provides promising insights into the within-person relationship between NEA and mood in patients with EDs, it is not free of limitations. First, we conducted an observational study under real-life conditions without experimental control of contextual influences or possible third variables. Thus, our results are purely correlative and therefore do not allow any causal conclusions to be drawn. However, this design offered high ecological validity and made it possible to examine the relationship between NEA and mood under real-life conditions. To investigate causal effects without sacrificing ecological validity, future research could employ ecological momentary interventions, which offer experimental manipulation in everyday life. For instance, the Within-Person-Encouragement-Design (WPED)[56] makes use of smartphone-based randomly assigned encouragements to perform specific micro-interventions; by randomly encouraging participants to perform specific NEA such as taking a walk, causal treatment effects of NEA on mood could be analyzed in everyday life. Second, our female only sample does not allow to generalize any conclusions to male or non-binary patients. However, this allowed us to examine potential effects on mood without confounding gender-specific effects, as emotions are influenced by gender.[57] Third, a higher sampling frequency might have provided even more precise results, since emotion dynamics of patients with ED can be transient.[58] However, because we were tempted to keep participant burden feasible/manageable, we employed a triggered e-diary algorithm to maximize the assessment of within-subject variance. Future studies may engage in high-frequency sampling but therefore limit total assessment times, procedures already applied in other clinical samples to study momentary mood dynamics.[59] Moreover, we have no data on what type of NEA the participants performed and how enjoyable the activity itself may have been. It is possible that distinct types of NEA activities have different effects on individual participants, possibly mediated by pleasure of the NEA. Before NEAs can be implemented within JITAIS, future studies should investigate whether the pleasure of an activity mediates the effect between NEA and mood and which NEAs are particularly suitable for individually tailored interventions. These effects may plausibly be heterogenous between individuals. Finally, using JITAIs to administer NEA may change one of the central psychological characteristics of NEA, that is, its automatic, habitual, and spontaneous nature becomes more planned and structured, which may alter mood responses to NEA delivered by JITAIs. However, since participants do not plan the JITAI-delivered NEA themselves, yet the JITAI-algorithm delivers triggers at rather unforeseeable times and contexts to the user, we do not consider this change in the NEA structure to critically limit its positive mood response. While our observational study design prevented us from researching this question, future studies using NEA-JITAIs should investigate these accounts in-depth.

5 | CONCLUSION

In conclusion, we provide evidence for a positive within-subject association between NEA and mood in the everyday life of patients with ED, with effects comparable in size to healthy individuals. Therefore, we argue that NEA presents itself as a promising target to regulate mood in patients with ED and thus comes with the potential to prevent dysfunctional eating behaviors. Beyond, NEA can be a promising target for the subgroup of patients with pathological exercising, if combined with complementary intervention elements. In sum, the evidence presented argues for future PA-related just-in-time adaptive interventions to bear considerable potential as a promising supplement to standard treatment for EDs, if directionality and causality of findings can be established in studies employing experimental manipulation in everyday life.

ACKNOWLEDGMENTS

Open Access funding enabled and organized by Projekt DEAL.

FUNDING INFORMATION

The Project received funding by the Schweizer Anorexia nervosa Stiftung (No 37-14), ISRCTN-Nr. 14776348.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/acps.13757.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The study was approved by the Freiburg University Ethics Committee (No. 65/13). All participants provided written informed consent.

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How to cite this article: Olfermann R, Schlegel S, Vogelsang A, Ebner-Priemer U, Zeeck A, Reichert M. Relationship between nonexercise activity and mood in patients with eating disorders. *Acta Psychiatr Scand*. 2024;1-15. doi:10.1111/acps.13757