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Reduced emotional stress reactivity to a real-life academic examination stressor in students participating in a 20-week aerobic exercise training: A randomised controlled trial using Ambulatory Assessment

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ABSTRACT

Objectives: To examine if a preventive 20-week aerobic exercise intervention (AET) can improve emotional stress reactivity during real-life stress.
Design: Randomised controlled trial; within-subject design.
Method: Sixty-one inactive students were randomly assigned to a waiting control and an AET group. To capture the situation-specific, intra-individual data in real life, electronic diaries were used. Participants reported their moods and perceived stress (PS) repeatedly over two days during their daily routines pre- and post-intervention. The pre-intervention baseline assessment was scheduled at the beginning of the semester, and the post-intervention assessment was scheduled at a real-life stressful episode, an academic examination. For the aerobic fitness assessment, both groups completed a cardiopulmonary exercise test on the treadmill before and after the intervention. Multilevel models (MLMs) were conducted to compare within- and between-subject associations.
Results: Significant emotional stress reactivity was evident in both groups during all assessment periods. However, participants in the AET group showed lower emotional stress reactivity compared with their control counterparts after the 20-week training programme during the real-life stress episode (the academic examination).
Conclusions: AET conferred beneficial effects on emotional stress reactivity during an academic examination, which is likely an extremely stressful real-life situation for students.
AET appears to be a promising strategy against the negative health effects of accumulated emotional stress reactivity.

Introduction

Research in psychology has found that reactivity to daily life stress is not only determined by a physiological response but also can be defined as a covariation of stress and affect (Sliwinski, Almeida, Smyth, & Stawski, 2009). Perceived daily life stressors, such as excessive demands at work, have an immediate effect on physical and emotional functioning (Van Eck, Nicolson, & Berkhof, 1998; Zautra, Affleck, Tennen, Reich, & Davis, 2005). For example, the risk of depression and cardiovascular disease increases through the accumulated effects of daily stress (Cacioppo et al., 1998; Carels, Blumenthal, & Sherwood, 2000; Van Eck, Berkhof, Nicolson, & Sulon, 1996). Enhanced emotional reactivity to real-life stress reflected by Negative Affect (NA) predicts physiological (Salovey, Rothman, Detweiler, & Steward, 2000; Van Eck et al., 1996, 1998) diseases and higher vulnerability to psychotic disorders (Collip et al., 2013; Myin-Germeys, van Os, Schwartz, Stone, & Delespaul, 2001). Patients with psychosis showed increased emotional sensitivity to smaller disturbances in daily life (Myin-Germeys, Krabbendam, Delespaul, & van Os, 2003). In addition, the

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emotional component of stress reactivity plays an important role in future stress appraisals (Lazarus & Folkman, 1984).

Physical activity and exercise offer the potential to reduce the risk of stress-induced mental and physical diseases (Warburton, Katzmarzyk, Rhodes, & Shephard, 2007). Until now, the existing link between the health-enhancing effects of physical exercise and the phenomenon of stress has been mostly explained by the so-called 'stress-buffer hypothesis' (Gerber & Pühse, 2009; Hamer, 2012; Sothmann, 2006; Tsatsoulis & Fountoulakis, 2006), which is based on the assumption that the positive health effects of physical activity and fitness serve as a moderator in the relationship between stress and health. In terms of stress reactivity, researchers have mainly examined the physiological parameters (heart rate variability, heart rate, cortisol) of fit versus unfit individuals at baseline and during mental stress tasks in laboratories (De Geus & Stubbe, 2007; Forcier et al., 2006; Gerber, 2008; Jackson & Dishman, 2006; Sothmann, Hart, & Horn, 1991). Because psychology research indicates that emotional and physiological stress reactivity may differ (Campbell & Ehlert, 2012), it is also important to assess emotional stress reactivity. However, existing research that considers the association between exercise and emotional stress reactivity has a number of limitations.

First, most studies have used laboratory-induced stress tasks, and the results of both cross-sectional studies (Klaperski, von Dawans, Heinrichs, & Fuchs, 2013; Rimmele et al., 2007, 2009) and randomised controlled trials are inconsistent (Anshel, 1996; Calvo, Szabo, & Capafons, 1996; Goldin, Ziv, Jazaieri, Hahn, & Gross, 2013; Julian, Beard, Schmidt, Powers, & Smits, 2012; Throne, Bartholomew, Craig, & Farrar, 2000; Zanstra & Johnston, 2011). In a recent cross-sectional study that used the Trier Social Stress Tests (TSST), a laboratory stress test that is more related to naturalistic stressors, Klaperski et al. (2013) found greater decreases in mood in young women who exercised compared with women who did not exercise in response to the TSST. Using a similar study protocol, Rimmele et al. (2009) reported contradictory findings, namely, higher anxiety and lower mood levels in untrained compared with trained men. Puterman et al. (2011) found that activity levels moderated the relationship between rumination and cortisol levels in response to acute stressors, suggesting that active people may be protected against stress-induced rumination. Although laboratory studies deliver important insights under controlled conditions, they often do not result in the same outcomes as those from naturalistic settings (Gauvin, Rejeski, & Norris, 1996; Wilhelm, Grossman, & Müller, 2012).

Second, previous randomised controlled trials used single retrospective pre/post self-report measures of NA and global measures of PS (Baghurst & Kelley, 2014; De Geus, van Doornen, & Orlebeke, 1993; Norris, Carroll, & Cochrane, 1992). However, psychological variables such as stress and affect are fluctuating constructs that change over the course of time (Stone, Smyth, Pickering, & Schwartz, 1996). Moreover, the patterns of responses to daily stressors may vary (Bolger & Schilling, 1991). Thus, repeated real-time assessments of PS and affective states during different situations across contexts represent the dynamic nature of the subjective stress experience more accurately than single pre/post assessments (Lazarus, 2000; Poole et al., 2011; Schlotz et al., 2008).

Finally, the few conducted field studies are cross-sectional and focus on the associations between acute exercise and emotional stress reactivity in daily life (Giacobbi, Hausenblas, & Frye, 2005; Giacobbi, Tuccitto, & Frye, 2007; Steptoe, Kimbell, & Basford, 1998). For example, Giacobbi et al. (2007) asked university students about their daily exercise, conducted threat appraisals in response to stressful events and assessed positive/negative affect via an internet platform during an examination period. During the most stressful days, exercise was significantly related to increased positive affect (PA). In addition, exercise led to decreased NA when events were appraised as being threatening; however, NA increased with accompanied exercise when events were appraised at higher threat levels. In another study, Giacobbi et al. (2005) showed that exercise and daily life events were both independently associated with PA. Increased levels of exercise led to increases in PA on days with more positive and more negative events. Steptoe et al. (1998) found fewer perceived stressful events on exercise days compared with non-exercise days among regular exercisers with low trait anxiety and higher PA on exercise days compared with non-exercise days. Another daily life study showed that walking time during the evening was inversely correlated with perceived stress (PS) ratings before going to sleep, and walking time during the afternoon was inversely correlated with negatively evaluated high activation during the evening (Hallman & Lyskov, 2012). None of the studies addressed the effects of regular exercise on emotional stress reactivity during real life.

To date, there has been a need for inexpensive strategies that are easy to use and effective at preventing the development of mental disorders, such as depression. The potential of exercise as a strategy to reduce the negative effects of repeated enhanced emotional reactivity to real-life stress is still unclear. To overcome the shortcomings of previous studies, we conducted a randomised controlled trial using Ambulatory Assessment. The term "Ambulatory Assessment" encompasses a wide range of methods used to study people in their natural environments, including momentary self-reports, ecological momentary assessments, and observational and physiological methods (Trull & Ebner-Priemer, 2013).

To investigate if a preventive 20-week aerobic exercise intervention could lower emotional stress reactivity during real life, we compared the emotional stress reactivity of students who were participating in aerobic exercise training with a control group (CG) pre- and post-intervention. To maximise within-subject differences in stress reactivity and to demonstrate the treatment effect, we chose the following two real-life assessment periods: We set the pre-intervention baseline assessment to the beginning of the semester because we assumed that students had low stress at this time. The post-intervention assessment was set to the end of the semester (the examination period) and was used as the real-life stressful episode given that academic examinations are a real-life demand that induces noticeable stress in students (Hazlett, Falkin, Lawhorn, Friedman, & Haynes, 1997; Nguyen-Michel, Unger, Hamilton, & Spruijt-Metz, 2006).

Methods

Participants

Sixty-one inactive ($\leq 1\times$ moderately active for 60 min/week) male electrical engineering students ($M_{age} = 21.4$, $SD = 1.6$) were recruited during the semester's first week of lectures. The sample came from two phases (each with 30 participants) that lasted for one winter semester (October 2011 to March 2012 and October 2012 to March 2013). After the study, participants attended a lecture on the potential of exercise to reduce stress. We addressed only subjects in their 3rd or 5th semesters of university studies because they sat for similar exams. Thus, we achieved similar conditions during academic examinations for all participants. To recruit participants, we informed the students about the study during lectures in the first week of the semester. Interested students signed up to be contacted via email to receive an invitation to the study kick-off meeting. Every student received information about the study, and eligible participants who wanted to participate gave written informed consent. Students did not receive financial compensation, but they did receive credits in their courses if they completed all measurements and attended the lecture and the intervention (experimental group).

Measures

The present study was conducted using Ambulatory Assessment, which is the method used for repeated sampling of subjective psychological variables in real time and in the natural environment (Trull & Ebner-Priemer, 2013). All psychological variables were assessed via electronic diaries, which were kept in the Touch Diamond 2 (HTC Germany GmbH, Frankfurt, Germany). Using the software MyExperience movisens Edition (movisens GmbH, Karlsruhe, Germany), mood and stress scales were installed on the diaries, and time stamps and intervals between diary prompts were programmed. Participants answered the questions presented on the diary screens by choosing the appropriate number on the presented scales using the integrated diary touch pen.

Perceived stress

To account for work-related strains during the academic examinations, acute PS was operationalised via one item that assessed perceived control, following earlier studies (Fahrenberg, Brügner, Foerster, & Käppler, 1999; Rau, 2004; Rau, Georgiades, Fredrikson, Lemne, & de Faire, 2001). Participants answered the question 'Is the present situation under your control?' on a 7-point Likert scale (1 = *not at all* to 7 = *absolutely*).

Mood

To assess the current mood state, we applied a short six-item scale based on the Multidimensional Mood Questionnaire (MDMQ; Steyer, Schwenkmezger, & Eid, 1997) that is validated especially for Ambulatory Assessment (Wilhelm & Schoebi, 2007). The scale measures three basic mood dimensions, valence (V: *content-discontent*; *unwell-well*), calmness (C: *agitated-calm; relaxed-tense*) and energetic arousal (E: *tired-awake; full of energy-without energy*), with two items. Wilhelm and Schoebi (2007) reported within-person (V, C = 0.70; E = 0.77) and between-person (V = 0.92; C, E = 0.90) reliability levels. Participants had to rate their current moods based on the statement 'At the moment I feel … ' on a 7-point scale (0 = *not at all* to 6 = *very*) with opposing adjectives as end-points. To ensure that higher scores indicated higher values for V, E, and C, we recoded the three negatively pooled items into positive ones prior to analysis.

Aerobic capacity

Maximum oxygen consumption (VO_2max) is the central parameter for determining aerobic capacity. To be able to detect the effects of exercise on emotional stress reactivity, an effective intervention reflected by significantly enhanced VO_2max was required. Thus, as a manipulation check to assess aerobic capacity, VO_2max was determined through cardiopulmonary exercise testing (MetaMax 3B, cortex-biophysik) on a treadmill until exhaustion, with an initial pace of 6 km/h, a continuous slope of 1% and an increase of 2 km/h per stage every 3 min (Dickhut, Mayer, Röcker, & Berg, 2007). Heart rate was recorded continuously using POLAR heart rate monitors (RS800). Within a standardised interruption of 20 s between stages, an arterial blood sample was taken from the participants' hyperaemic earlobe into a 20 μl end-to-end capillary to analyse blood lactate. At the end of each stage, participants rated their perceived exertion scores (RPE) on the Borg Scale from 6 to 20 (Borg, 1982). All participants achieved a respiratory exchange ratio (RER) of $\geq$ 1.1 and a heart rate of at least 220 beats minus age (Meyer & Kindermann, 1999), and all were appraised as exhausted by an experienced instructor. Thus, for all participants, the achievement of VO_2max was assumed. The RER reflects the ratio between the amount of carbon dioxide produced (VCO_2) and the oxygen consumed (VO_2) during one breath.

Procedure

At the beginning of the study, participants were randomised to a control and an aerobic exercise training (AET) group, stratified by their habitual physical activity levels, which were assessed via questionnaire (Jekauc, Wagner, Kahlert, & Woll, 2013). This study used a wait-list control group; thus, participants who were randomised to the CG received AET after the end of the study. We conducted the cardiopulmonary exercise pretest (CETpre) during the first two weeks of the study (start of the semester) prior to the AET group intervention. After the completion of the pretests (November 1st), the AET for the experimental group began. After 3.5 months of AET (see Fig. 1), we conducted the cardiopulmonary exercise post-test (CETpost) with exactly the same procedure as the pretests. Participants completed the post-tests prior to the exam period to avoid any influence on their performance.

Emotional stress reactivity was assessed pre- and post-intervention for two days each. To maximise within-subject differences in stress reactivity and to demonstrate the treatment effect, we chose the following two real-life assessment periods: We set the pre-intervention baseline assessment to the beginning of the semester because we assumed that students had low stress at this time. The post-intervention assessment was set to the end of the semester (the examination period) and was used as the real-life stressful episode given that academic examinations are a real-life demand that induces noticeable stress in students (Hazlett et al., 1997; Nguyen-Michel et al., 2006). To increase representativeness, we conducted measurements twice during the academic examination period. The time span between the exam and the end of data recording was restricted to at least one and a maximum of two days. Participants chose their first measurement episode (post1) during the first weeks of the exams (weeks 2/3), and the second episode (post2) took place during the middle of the exams.

Participants initialised the first diary prompt of the day when they turned on the diary after awakening. Except for the morning prompt, all diary prompts were initialised automatically by a vibrating signal every 2 h with a varying incidence of the signal of one to 5 min to prevent participants from waiting for the signal. Thus, all diary prompts occurred between 10 a.m. and 10 p.m. If participants missed a signal, reminders were sent after 5, 10, and 15 min. If participants did not answer the last reminder, the prompt was recorded as missing, and the next signal occurred with the next prompt approximately 2 h later.

Intervention

Participants in the experimental group attended a 20-week aerobic running training course. The intervention lasted until participants passed both measurement times during the academic exams. In addition to VO_2max, the main outcomes of the cardiopulmonary exercise test were maximum running speed, lactate threshold and individual anaerobic threshold. Based on these, we calculated individual heart rate zones for each participant (zone I: aerobic; zone II: aerobic-anaerobic) using the software Ergonizer®

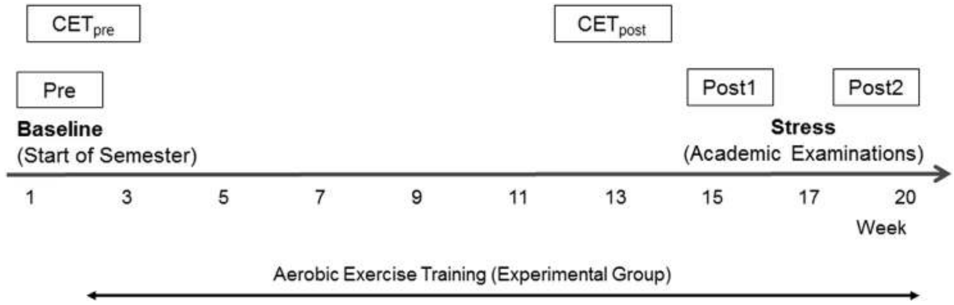

Fig. 1. Illustration of the study design: timeline with pre- and post-assessments of emotional stress reactivity, cardiopulmonary exercise testing (CETpre and post) and the duration of the exercise intervention.

(Sports medicine, Freiburg, K. Röcker) and installed the training schedules and the heart rate target zones on the RS800 heart rate monitors. Skilled exercise science students supervised and instructed the running groups of 7–8 people using the standardised training schedule. Participants completed the training in a group and wore the heart rate monitors to record their training and meet their individual heart rate requirements. To allow for individual but group-based running sessions, the training sessions took place outdoors in an area close to the campus with fixed trails. Training sessions took place during lunch time to allow for short routes and little time loss. Students had to complete two training sessions every week. At the beginning, running sessions lasted approximately 30 min and included walking phases of 2 min. Separate from the continuous increase in training duration (3 min/week) over time, intensity was progressively increased by adding intervals of 3 and 4 min in zone II after week four. Compliance with the intervention was very good in every training group, with no dropouts during the intervention.

Data analysis

To determine whether the aerobic exercise intervention had successfully improved the AET group's aerobic capacity, we conducted an analysis of covariance (ANCOVA) with VO_2max_{rel} after the intervention as the dependent variable (CETpost), VO_2max_{rel} prior to the intervention as the covariate (CETpre) and group (CG/AET) as the treatment factor.

Our repeated assessments of psychological variables during the baseline (pre) and during the exam period (post1 and post2) resulted in data of a hierarchical structure with multiple observations of NA and PS (level 1) nested within persons (level 2). We applied Multilevel models (MLMs) to differentiate between within-subject and between-subject effects and their interactions. In addition, MLMs allow for a different number of observations between participants and provide model estimates even for individuals with missing data (Hoffman & Rovine, 2007). We used IBM SPSS Statistics 20 for Windows to estimate the effects of the independent variables (PS, group and interaction of PS and group) on the dependent variable NA. We ran MLMs for the baseline (pre) and both examination periods (post1 and post2).

To obtain the NA variable, we recoded the valence dimension (V) as follows: (0 = 4; 0.5 = 3.5; 1 = 3; 1.5 = 2.5; 2 = 2; 2.5 = 1.5; 3 = 1; 3.5 = 0; 4 = 0; 4.5 = 0; 5 = 0; 5.5 = 0; 6 = 0). Prior to additional analyses, PS was reverse coded to better illustrate NA; thus, higher values indicated higher PS. To account for individual differences in mean stress, PS was person-mean centred by subtracting the mean PS value across all observations per person from each observation of the person. Group was coded as a dummy variable as either 0 (CG) or 1 (AET group). The following equation displays the integrated form as well as the level 1 and level 2 components of our model separately:

$$NA_{ti} = \Upsilon_{00} + \Upsilon_{10} \cdot WithinPerson_{perceived\ stress} + \Upsilon_{01} \cdot Group + u_{0i} + \Upsilon_{11} \cdot Group \cdot WithinPerson_{perceived\ stress} + \varepsilon_{ti}$$

$$Level\ 1: Y_{ti} = \beta_{0i} + \beta_{1i} \cdot WithinPerson_{perceived\ stress} + \varepsilon_{ti}$$

$$Level\ 2: \beta_{0i} = \Upsilon_{00} + \Upsilon_{01} \cdot Group + u_{0i}$$

$$\beta_{1i} = \Upsilon_{10} + \Upsilon_{11} \cdot Group$$

Level 1 represents the participants' responses (subscript i) as reported on the NA scale (Y_{ti}) in any given diary entry (subscript t). Y_{ti} is a function of the individual intercept β_{0i}, person i's average level of PS, β_{1i}, which is the effect of the within-person PS, meaning the increase in NA with every increase of PS, and ε_{ti} is the residual NA in a situation t for a person i. Finally, β_{0i} displays the effect of the group (level 2) on NA, and β_{1i} is the effect of the cross-level interaction between group (level 2) and PS (level 1) on NA, that is, the effect of group on the extent of change in NA caused by the change in PS.

Results

Sample characteristics

We excluded two participants from the analysis because they did not complete all three assessments (pre, post1 and post2). Participants in the AET and control groups did not differ in person characteristics or cardiopulmonary exercise testing parameters prior to the intervention (Table 1). Aerobic capacity, operationalised

Table 1
Means and standard deviations of person characteristics and results of the cardiopulmonary exercise test.

Variable	Pre		Post	
	AET	CG	AET	CG
	M (*SD*)		*M* (*SD*)	
Age	21.3 (1.5)	21.5 (1.7)		
BMI	23.8 (3.5)	24.6 (4.9)		
VO_2max_{rel} (ml/kg/min)	48.5 (6.5)	49.9 (6.7)	52.8 (6.4)	47.1 (7.3)
RER	1.14 (0.1)	1.14 (0.1)	1.2 (0.1)	1.21 (0.1)
HR_{max} (beats/min)	199.8 (7.8)	201.8 (8.8)	197.7 (8.1)	199.8 (7.9)

Note. CG = control group; AET = Aerobic exercise training group; BMI = body mass index; CET = cardiopulmonary exercise testing; VO_2max_{rel} = maximal oxygen consumption in ml per kilogram bodyweight per minute; RER = respiratory exchange ratio; HR_{max} = maximum heart rate.

via VO_2max_{rel}, increased by 8.7% from pre-to post-intervention in the AET group and decreased by 5.6% in the CG (Table 1). The ANCOVA revealed significance for the factor group, VO_2max_{rel}: $F(1, 56) = 59.8$, $p < .001$, $\eta^2 = 0.52$, indicating a strong effect (Cohen, 1988) of the intervention on aerobic capacity.

Compliance

At the baseline (pre), there were 28 missing data points (2.7%); at post1, 94 out of 960 data points were not answered (9.7% missing); and at post2, 80 out of 944 data points were missing (8.5%). We had data that indicated that during the examination period, students in general woke up later than 11 a.m. and missed the first prompt; thus, we appraised compliance as being good in the present study.

For our analysis, 944 NA and PS data points were available at pre, post1 and post2. Except for the two students who were withdrawn from the analyses, data from both measurement times during the examination period were available for each participant. Unconditional NA models revealed that average NA was 0.24 at pre, 0.25 at post1 and 0.28 at post2. Intraclass coefficients were $\sigma = 0.02$ for pre, $\sigma = 0.41$ for post1 and $\sigma = 0.21$ for post2, indicating that intra-individual variation caused 98%, 59% and 79% of the variance, respectively.

Emotional stress reactivity at baseline

Descriptively, participants of the CG reported slightly higher PS at baseline (pre) compared with the AET group, while values of NA were similar between the groups (Table 3). The MLMs revealed that higher PS (level 1) significantly predicted higher NA, whereas neither the group (level 2) nor the cross-level interaction of group × PS predicted NA at baseline (Table 2). Thus, emotional stress reactivity was evident at baseline, but did not differ between the groups.

Emotional stress reactivity during academic examinations

Descriptively, the participants' average PS ratings increased from baseline to post1 during exams, and the increase was similar in both groups (see Table 3). Although PS was similar during both exam periods (post1 and post2) in the AET group, it increased further from post1 to post2 in the CG. In contrast to the similar baseline NA levels in both groups, the CG showed higher NA at post1 and post2, whereas the AET group rated slightly lower NA at post1 compared with baseline and similar NA compared with baseline at post2. MLMs of the within-subject effects (level 1) revealed that PS (person-mean centred) significantly predicted NA (Table 2). Conditions of higher PS than the person mean related to higher NA ratings, and thus emotional stress reactivity was evident.

Table 3
Means, standard deviations, and minimums and maximums of the psychological variables at each measurement time.

Variable	AET			CG		
	M (SD)	*Min*	*Max*	*M (SD)*	*Min*	*Max*
Pre						
PS	2.06 (0.66)	1.40	3.40	2.20 (0.82)	1.34	4.00
NA	0.23 (0.42)	0.00	1.30	0.26 (0.49)	0.0	1.50
E	3.81 (1.04)	1.95	5.30	3.60 (1.13)	1.48	5.16
V	4.36 (0.82)	2.70	5.41	4.35 (0.91)	2.48	5.51
C	4.42 (0.78)	2.83	5.38	4.47 (0.90)	2.47	5.63
Post1						
PS	2.27 (0.58)	1.57	3.37	2.43 (0.56)	1.62	3.41
NA	0.17 (0.35)	0.00	1.10	0.34 (0.39)	0.09	1.26
E	4.11 (0.84)	2.58	5.22	3.89 (1.02)	2.02	5.28
V	4.39 (0.74)	2.80	5.38	4.23 (0.71)	2.79	5.20
C	4.35 (0.68)	3.02	5.27	4.27 (0.73)	2.93	5.29
Post2						
PS	2.24 (0.61)	1.67	3.33	2.51 (0.59)	1.59	3.62
NA	0.22 (0.30)	0.00	0.93	0.35 (0.43)	0.00	1.24
E	4.23 (0.79)	2.65	5.25	3.87 (0.98)	2.03	5.19
V	4.33 (0.62)	3.12	5.18	4.22 (0.77)	2.85	5.35
C	4.21 (0.64)	2.95	5.12	4.25 (0.73)	2.97	5.34

Note. PS = perceived stress; Pre = baseline; Post1 = first academic exam assessment; Post2 = second academic exam assessment; V = valence; E = energetic arousal; C = calmness; NA = negative affect.

Between-subject effects revealed that during both episodes of academic exams (post1 and post2), the coefficients for the predictor group (level 2) were negative and higher compared with the baseline findings. These results descriptively indicated that AET group participants had lower NA at post1 and post2 (see Table 2) compared with the CG. However, group affiliation did not significantly predict NA during the exams.

In the next step, we added the cross-level interaction between group and PS to the model. This interaction significantly predicted NA. NA values differed between groups, especially when participants perceived stress that was higher than their person-specific means. Table 2 shows that the coefficient for the group × PS interaction was negative (variable coded as control group = 0), indicating that the AET group reacted with less NA in situations of higher PS during the exams and thus had lower emotional stress reactivity (Fig. 2). Although this interaction did not predict NA at baseline, it was a significant predictor of NA at post1. At post2, the cross-level interaction of group × PS was again a significant predictor of NA (Table 2; Fig. 2). Thus, after the 20-week aerobic exercise intervention, AET group participants showed lower emotional stress reactivity to both academic episodes (post1 and post2). At post2, the coefficient for the group × PS interaction in the model was higher compared with post1 (Table 2), descriptively indicating a larger effect of the group × PS interaction at post2 (Fig. 2).

Table 2
Results of the multilevel models for NA as the dependent variable at every measurement time.

Model negative affect									
Variable	Pre			Post1			Post2		
	β	*SE*	*t*	β	*SE*	*t*	β	*SE*	*t*
Intercept	0.25***	0.04	5.86	0.33***	0.08	3.93	0.35***	0.08	4.60
PS	0.21***	0.03	7.24	0.24***	0.03	7.89	0.38***	0.03	10.75
Group	−0.02	0.06	−0.46	−0.16	0.11	−1.35	−0.13	0.11	−1.19
PS × group	−0.05	0.04	−1.17	−0.11*	0.05	−2.33	−0.18***	0.05	−3.55

Note. PS = perceived stress; Pre = Baseline; Post1 = first academic exam assessment; Post2 = second academic exam assessment.
*$p < .05$. ***$p < .001$.

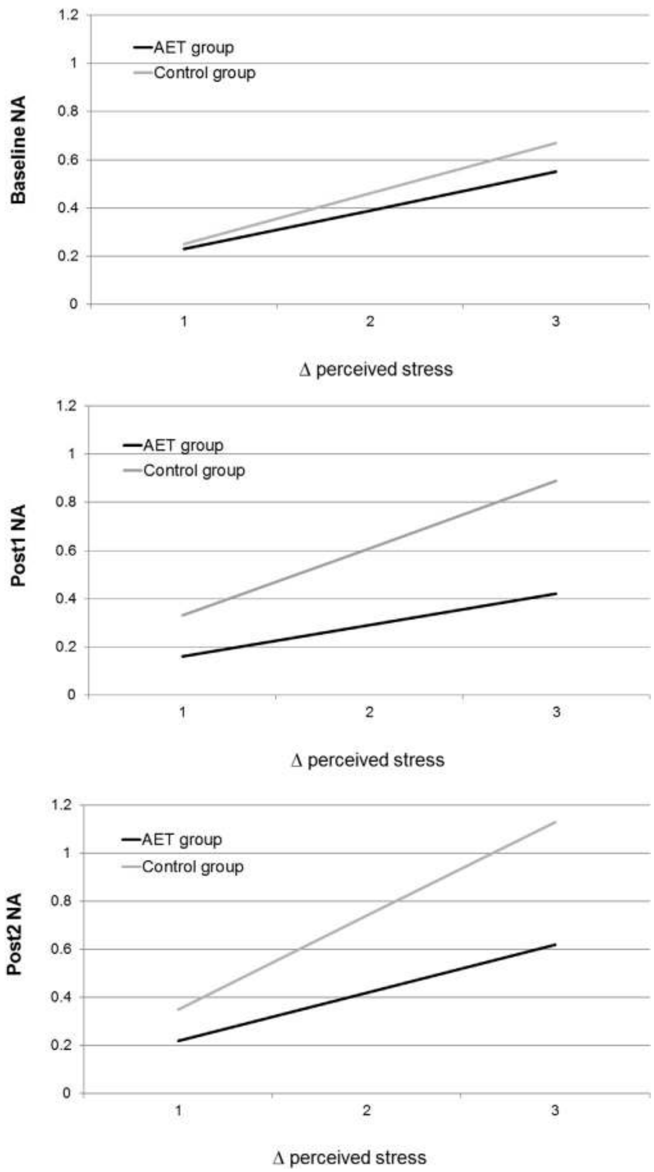

Fig. 2. Emotional stress reactivity (predicted values) by group at baseline (pre) and at both examination periods (post1 and post2). NA = negative affect.

Secondary analyses

Descriptively, the mean values of the three mood dimensions valence, calmness and energetic arousal showed different characteristics in the AET group versus the CG during the non-stressful and examination periods. Mean valence was similar between baseline and both stress periods (post1 and post2) in the AET group. In addition, valence was higher compared with the CG during both examination periods (Table 3), but the MLMs did not reveal significance for the predictor group (Table 2). Although the result was not statistically significant, mean energetic arousal was even higher in the AET group compared with the CG during the stressful period (Table 3). Descriptively, the decrease in calmness from baseline to post1 was lower in the AET group than the CG (Table 3).

To analyse the effects of the group $\times$ PS interaction on energetic arousal, calmness and valence, we calculated single models for each of the three dimensions. Because higher values indicated higher calmness, energetic arousal and valence, the interpretation is more complex. PS significantly predicted valence, calmness and energetic arousal at all times of measurement (Table 4). Thus, participants who rated as having lower PS had higher valence, calmness and energetic arousal ratings. In addition, the analyses revealed a marginally significant effect of the group $\times$ PS interaction on valence at post1, which achieved significance at post2 (see Table 4). The results indicate that under increased PS, the experimental group rated greater valence than did the CG. In addition, at post1, the group $\times$ PS interaction significantly predicted calmness. Under increased PS, the experimental group rated more calmness than did the CG (Table 4), although this result was not confirmed at post2. No significant group $\times$ PS interaction was found for energetic arousal.

Discussion

In the present study, we were able to show that a preventive 20-week aerobic exercise intervention can lower emotional stress reactivity to real-life stress. NA did not differ significantly between participants in the AET and control groups during the exams. This was illustrated by the non-significance of group as a predictor in both statistical models during the stressful episodes. However, the MLMs revealed a significant cross-level interaction of group (control versus AET) and PS on the output NA. The interaction was not significant prior to the exercise intervention, which means that stress reactivity did not differ between groups at baseline. In contrast, the interaction was significant during the academic exams after the aerobic exercise intervention. In conditions of higher PS, AET participants rated lower NA and thus had reduced emotional stress reactivity. The significant reduction in stress reactivity was identified at both episodes during the exams (post1 and post2), with a descriptively higher coefficient at post2. Thus, we confirmed our results of the reduced stress reactivity of the AET group at two different assessment times. Our results are consistent with those from recent cross-sectional laboratory studies that found lower decreases in mood among trained compared with untrained men in response to the TSST (Klaperski et al., 2013).

Because research shows that the accumulated effects of enhanced emotional reactivity (enhanced NA) increase the risk for physical and mental disorders (Cacioppo et al., 1998; DeLongis, Folkman, & Lazarus, 1988; Myin-Germeys et al., 2003; Van Eck et al., 1998), these results are relevant for prevention because they support the hypothesis that exercise buffers stress-induced health risks (Gerber & Pühse, 2009; Hamer, 2012). Participants in the AET group had lower NA during conditions of high PS, and thus they may benefit in the long term from a lower accumulation of NA in response to daily life stress. As a consequence, exercise appears to be a promising prevention strategy for reducing accumulated enhanced emotional reactivity to the considerable stresses in real life. Clinical psychology treatments aim to reduce the effects of stressors that are already present. Exercise training serves as a strategy to influence the effects of stressors before they occur (Salmon, 2001). In addition, exercise is a popular, easily accessible low-cost application for reducing NA and a successful add-on to psychological treatments.

Our secondary analyses revealed that the interaction of PS and group did not show a persistent pattern in predicting the different mood dimensions valence, calmness and energetic arousal. The results for the valence dimension (marginally significant at post1 and significant at post2) indicated improved emotional reactivity. Whereas the valence of mood was more positive in the AET group, the results showed a more complex picture for calmness and energetic arousal. An interesting finding was that the reactivity of the calmness dimension was only evident at post1. The non-significant interaction of group $\times$ PS at post2 raises the question of whether exercise's effects on calmness decrease over periods of prolonged

Table 4
Results of the multilevel models for the three mood dimensions as the dependent variables at every measurement time.

Variable	Pre			Post1			Post2		
	β	*SE*	*t*	β	*SE*	*t*	β	*SE*	*t*
Valence model									
Intercept	4.35***	0.11	39.73	4.23***	0.15	27.38	4.22***	0.16	26.69
PS	0.44***	0.04	9.76	0.45***	0.05	9.28	0.59***	0.05	12.78
Group	0.01	0.15	0.19	0.16	0.21	0.74	0.11	0.22	0.48
PS × group	−0.00	0.07	−0.01	−0.13	0.07	−1.84	−0.24***	0.07	−3.59
Calmness model									
Intercept	4.46***	0.12	36.01	4.29***	0.17	24.54	4.25***	0.17	24.99
PS	0.49***	0.04	11.34	0.50***	0.05	10.50	0.50***	0.05	10.31
Group	−0.04	0.17	−0.20	0.06	0.25	0.23	−0.03	0.24	−0.12
PS × group	0.03	0.06	0.48	−0.25***	0.07	−3.50	−0.09	0.07	−1.23
Energetic arousal model									
Intercept	3.57***	0.13	27.45	3.89***	0.13	28.63	3.85***	0.14	26.76
PS	0.19***	0.06	3.20	0.13*	0.06	2.08	0.33***	0.06	5.12
Group	0.21	0.18	1.16	0.18	0.19	0.96	0.36	0.20	1.77
PS × group	−0.06	0.08	−0.66	−0.00	0.10	−0.03	−0.03	0.09	−0.29

Note. PS = perceived stress; Pre = baseline; Post1 = first academic exam assessment; Post2 = second academic exam assessment.
*$p < .05$. ***$p < .001$.

stress. More research is needed to explain the interplay of stress and exercise regarding the mood dimensions valence, energetic arousal and calmness, for example, to explain the higher energetic arousal of the AET participants observed during the academic examinations.

In the present study, we were able to improve the aerobic capacity of previously inactive students after a 20-week AET by 8.7% on average, with high intra-individual variability (SD 12%). De Geus and Stubbe (2007) stated that the average improvement in VO_2max in long-term training studies was approximately 14% after four months of training. Research shows that VO_2max improvement in response to aerobic exercise training differs greatly (by 0–40%) depending on target group, baseline vagal tone, age, gender, training load and genetic disposition (Hautala, Kiviniemi, & Tulppo, 2009). Although the present study showed VO_2max improvements lower than the 14% change, the results are statistically significant. Furthermore, the AET group showed significantly reduced emotional stress reactivity compared with the CG.

Based on the present results, people may profit from regular exercise, especially when PS is higher. Interestingly, people do not use exercise during stressful times but prefer to spend more time in suboptimal low-effort activities such as watching television (Sonnentag & Jelden, 2009). There needs to be further examination of the effects on long-term health of exercising compared with low-effort activities during real-life stress.

We do not know exactly which factors contributed to the reduced emotional reactivity to real-life stress among participants who attended the 20-week AET. Earlier studies have argued that it is not the effects of regular exercise adaptations but potentially the aggregated positive effects of acute exercise on mood, reduced tension and elevated beta-endorphins that lead to reduced stress (Reed & Buck, 2009; Salmon, 2001). The results of the present study suggest that people profit not only from general mood enhancement but also from lower NA, especially in situations of higher demand. Salmon (2001) stated that the particular value of exercise might be its controllability. Although repeated exposure to uncontrollable stressors may also lead to adaptations, they can be achieved much more quickly through controllable stressors (Maier & Seligman, 1976). The present study operationalised acute stress appraisal through perceived control. Participants in the experimental group may have had lower emotional stress reactivity because they perceived more control even in situations of severe stress. Therefore, one explanation for the emotional benefit of regular exercise would be the adaptations to exercise as the repeated but controllable stressor. The potential of regular exercise to reduce stress reactivity and increase self-control was investigated in an intervention study by Oaten and Cheng (2005). Exercisers showed significant improvement in self-regulatory capacity, decreased PS and emotional distress, and enhanced health behaviours compared with the CG. Interestingly, in an additional study with a non-exercise intervention to increase self-control in preparation for upcoming exams, the authors reported increased physical activity in the experimental group who participated in a self-control programme (Oaten & Cheng, 2006).

Although our study revealed interesting findings regarding the effect of aerobic exercise on emotional stress reactivity in real life, some critical aspects have to be discussed. First, the results of the present study are not representative because we used a sample of young, healthy students with rather low levels of NA and mild levels of PS. Participants enrolled in the study voluntarily, and thus students with severe stress may not have participated. However, as we learned from previous studies that analysed exercise–mood associations, lower baseline values indicated higher effects (Reed & Buck, 2009) and high baseline levels may lead to ceiling effects (Gauvin et al., 1996). However, we found significant results, and thus we are optimistic that the effects may be reproducible in a more representative sample.

Second, although we asked participants to rate PS repeatedly throughout the day, we very likely missed some severely stressful moments. Therefore, using a combined protocol (integrating event-based and time-based sampling strategies as well as physiology-triggered assessments) may be an even more suitable method for future studies (Shiffman, 2007) because PS ratings can thereby be initialised during situations of higher stress.

Finally, there are variables we did not control for that could also have influenced NA and PS; context information such as social contacts, activities and location as well as social support and personality are a few of these variables. Future studies should analyse how these variables counteract or moderate the effects of exercise on emotional reactivity during real-life stress.

Conclusion

The present study revealed relevant results that suggest that exercise is an effective prevention strategy for buffering against stress-induced negative health effects. In addition, we depicted how Ambulatory Assessment benefits research on the stress–exercise association. Even during the examination period, some participants perceived very low levels of stress and at other times, different students experienced more or less stress, indicating inter- and intra-individual variability. Negative affect values were on average above the mean of the NA scale, and thus, the averaged pre-/post-single assessments, such as were used in earlier studies, would not have yielded the present findings. The situation-specific and repeated assessments of the interactions between the predictor group and PS, and the dependent variable NA allowed us to detect more complex results.

We used two assessment episodes during the exams and were able to confirm the results for both points in time. Thus, we could strengthen our results by confirming the results at two different times and to illustrate increased representativeness. The present study showed that it is worth analysing intra- and inter-individual effects when analysing intervention effects. Future studies should investigate in more detail how individuals at different fitness levels react in situations of different stress severity and contexts and how the impacts of acute and regular exercise interact regarding emotional reactivity to stress in real life. Furthermore, it will be interesting to identify the factors that are responsible for successfully reducing emotional stress reactivity through aerobic exercise. Therefore, more studies that use Ambulatory Assessment to evaluate the effects of regular exercise on both physiological and emotional stress reactivity are needed. In addition, continuously monitoring physical activity can capture the influences of the circular associations between physical activity and stress in real-life settings (Bussmann, Ebner-Priemer, & Fahrenberg, 2009).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.psychsport.2015.04.004.

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