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Exercise as a buffer against difficulties with emotion regulation: A pathway to emotional wellbeing

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ABSTRACT

Though exercise is associated with emotional health, it remains unclear what psychological processes account for this relationship. The present study explores emotional recovery from and responses to stress as links. It extends prior research by exploring whether poor response tendencies, such as a ruminative response style, could mediate the relationship between regular exercise and clinical symptoms, and whether acute exercise facilitates emotional recovery from a stressor in a heterogeneous sample comprising sedentary as well as active individuals and those reporting mood and anxiety symptoms. Participants completed questionnaires, performed 30 min of cycling or stretching, and underwent a stressful speech task. State affect and difficulties with emotion regulation and rumination were measured at various time points. Minimal regular exercise predicted more depression, anxiety, and stress, and cross-sectional data suggest that poor stress response tendencies (more habitual rumination and low coping self-efficacy) could partially mediate these relationships. Relative to stretching, prior exercise did not affect initial reactions to the stressor or reports of struggling to regulate one's emotions. However, it attenuated the effects that rumination and difficulties with emotion regulation had on delaying emotional recovery. Results suggest that enhanced emotional resilience to the prolonged effects of stress accounts, at least in part, for the emotional benefits of regular exercise. There appear to be benefits afforded by even single sessions of exercise and cumulative benefits from regular activity for coping with stress.

Exercise is good for one's mental health as abundant research indicates. Cross-sectional studies show that regular exercise is associated with greater emotional wellbeing, fewer or less severe symptoms of depression, and lower anxiety (Goodwin, 2003; Harvey, Hotopf, Overland, & Mykletun, 2010; Ströhle, 2009). Prospectively, regular exercisers are less likely to develop emotional disorders in their lifetime than are non-exercisers (Harvey et al., 2017; Ströhle, 2009). And for those individuals diagnosed with depression and related psychopathology, exercise programs—particularly those involving moderate aerobic activity—tend to have significant treatment effects comparable to psychotherapy and antidepressants (Kvam, Kleppe, Nordhus, & Hovland, 2016; Schuch, Vancampfort, Richards, et al., 2016). Furthermore, in randomized controlled trials of exercise interventions dropout is lower for exercise than other conditions (Stubbs et al., 2016) and such programs can improve both physical and psychological quality of life as well as reduce symptoms of emotional disorders (Schuch, Vancampfort, Rosenbaum, et al., 2016).

Despite these replicated, positive findings, it remains unclear what psychological processes are altered by exercise that enhance resilience, emotional stability, and improve mood. Identifying such mechanisms could aid targeted use of exercise for effective prevention and early intervention, provide tangible motivation to exercise regularly, and illuminate critical processes driving dysregulated mood. Because exercise alters multiple bodily systems, its beneficial effects on mental health likely arise from a dynamic network of interacting neurobiological, physical, cognitive, and psychosocial factors (Hopkins, Davis, VanTieghem, Whalen, & Bucci, 2012; Moylan et al., 2013). This project focuses specifically on the ability to weather and recover from stress as the pathway of interest. Clinical depression and emotional disorders more generally reflect difficulty altering, upregulating, or stabilizing one's mood after it has declined. Becoming stuck in negative mood states heightens risk for depression onset, maintenance, and relapse (Joormann & Vanderlind, 2014).

There are many studies on the effects of acute exercise on positive and negative affect. Exercise has a general "feel-better" effect (Biddle & Ekkekakis, 2012), not only increasing pleasure and other positive emotions, but also reducing anxiety and other distressing emotions (Yeung, 1996). And recent decades have seen growing specificity of this effect. For example, although some studies have found null or negative results (Backhouse, Ekkekakis, Biddle, Foskett, & Williams, 2007), it

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appears that improvements in self-reported affect most reliably accompany physical activity that is below one's ventilatory or lactate threshold. Additionally, whereas declines in pleasure are more likely during activity that is above threshold, such differences in state affect tend to disappear in post-activity reports (Ekkekakis, Parfitt, & Petruzzello, 2011). An intriguing moderator, however, is self-selection of exercise intensity. Self-selection tends to increase the likelihood of the "feel-better" effect, regardless of actual intensity (Ekkekakis et al., 2011; ZeRVAS, Ekkekakis, Emmanuel, Psychoudaki, & Kakkos, 1993). Importantly, much of this research has examined how people feel after exercising without any subsequent interruptions. Few studies have examined the effect of a single bout of exercise immediately prior to a stressor. In the present study, we aim to clarify how this "feel-better" effect manifests when people encounter emotional perturbations *after* exercising.

Experimental and observational research suggests that exercise changes how people react to and process experimentally- or naturally-induced emotional experiences. Rather than preventing or blunting initial negative emotional responses, exercise appears to facilitate emotional recovery. For example, in both between- and within-subjects experiments, a bout of prior aerobic activity attenuates the duration of negative affect following a stressor, apparently by helping individuals to overcome or be less impacted by emotion regulation difficulties (Bernstein & McNally, 2016, 2017). This hastening of recovery from negative emotion is consistent with studies showing that physically fit individuals return to their resting physiological state more easily after a stressor than do their non-fit peers, that exercise training can improve people's ability to physiologically withstand stress, and that physically active individuals are more resilient against the negative effects of rumination on cortisol reactivity than are sedentary individuals (Blumenthal et al., 1988; Calvo, Szabo, & Capafons, 1996; Puterman et al., 2011). Furthermore, in naturalistic, ecological momentary assessment studies, regular voluntary physical activity appears to lessen the effect of perceived stressors on negative affect even among underactive individuals, especially if a bout of physical activity is proximal to the reported stressor (Flueckiger, Lieb, Meyer, Witthauer, & Mata, 2016b; Puterman, Weiss, Beauchamp, Mogle, & Almeida, 2017). It also reduces emotional inertia, meaning that people who exercise do not necessarily have less frequent or intense negative emotions, but rather may be better able to recover from negative emotions when they arise (Bernstein, Curtiss, Wu, Barreira, & McNally, 2018).

In the present study, we extended this research in three ways. First, to explore enhanced coping in response to stressors as a pathway through which exercise counteracts mood symptoms, we examined the relationship among regular exercise, mood symptoms, and two examples of emotion response tendencies that could prolong stress-induced negative affect. Specifically, we hypothesized that participants reporting more frequent moderate to vigorous exercise would report less habitual rumination (repetitive, passive, self-focused thinking about one's experience), enhanced coping self-efficacy (confidence in one's ability to manage stressful situations and one's responses effectively), and fewer or less severe symptoms of depression, anxiety, and stress. Furthermore, we expected that less habitual rumination and greater coping self-efficacy to, at least partially, mediate the relation between regular exercise and mood symptoms. Both rumination and low coping self-efficacy are linked to prolonged negative affect following distressing events in and out of the lab (Chesney, Neilands, Chambers, Taylor, & Folkman, 2006; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008) and negatively associated with an active lifestyle (Craft, 2005; Kishida & Elavsky, 2015; Steptoe, Edwards, Moses, & Mathews, 1989).

Second, using a psychosocial stressor as an ecologically valid mood induction, we aimed to replicate findings showing that prior aerobic activity facilitates emotional recovery following a stressor. Consistent with prior research, aerobic exercise (i.e. being assigned to the cycling condition as compared to the stretching condition) should moderate the impact of poor coping on persistent negative affect. In other words, prior exercise should help those individuals who would otherwise struggle to bounce back after the stressor. Third, we recruited a sample with a wider, more representative range of exercise habits from sedentary to physically active individuals, and included those at risk for developing emotional disorders (i.e. participants reporting low mood, high anxiety, and high stress). Such diversity is important as most experimental research has concerned active, healthy participants, potentially limiting the generalizability of the results.

1. Method

Participants completed one in-person experimental session. The visit began with self-report questionnaires after which participants were randomly assigned to perform 30 min of moderate cycling or stretching. Participants then underwent a stressful speech task followed by a recovery period during which we assessed state rumination and reported difficulties with emotion regulation. State affect was measured at various points throughout the study period.

1.1. Participants

One hundred four young adults (60 women, $M_{age} = 19.94$, $SD = 2.05$, age range: 18–31) were included in our analyses. Prior to examining data, we excluded five additional participants due to non-adherence to the protocol, experimenter error, and technical difficulties. The ethnic and racial composition of the final sample was 62.5% Caucasian or white, 4.81% African American or black, 16.35% Asian or Asian American, 0.96% Native American or American Indian, 11.54% multiracial, 3.85% other or unreported, and 15.38% identified as Hispanic or Latino. Participants were recruited through the Harvard University Study Pool and included students and community members. Harvard University's Committee on the Use of Human Subjects approved the protocol, and participants provided written informed consent prior to beginning the study.

Eligible participants were at least 18 years old and able to read and sign the consent form. For safety and to avoid potential confounds related to extreme attitudes towards physical activity, we excluded potential participants if they were pregnant or possibly pregnant, answered "yes" to any question on the Physical Activity Readiness Questionnaire (PAR-Q) (Adams, 1999; Thomas, Reading, & Shephard, 1992) indicating physical or medical contraindications to exercise, or scored above the clinical cut-off (≥ 24) on the Exercise Addiction Inventory: Short Form (EAI) (Terry, Szabo, & Griffiths, 2004) suggesting risk for exercise addiction.

1.2. Procedure and materials

1.2.1. Baseline measures

Participants began the experimental session with a brief battery of self-report questionnaires, which included demographics (e.g. age, gender, ethnicity, race), trait rumination, coping self-efficacy, symptoms of depression and anxiety, and exercise habits. Resting pulse, height, and weight were also measured at baseline. The 22-item Ruminative Responses Subscale of the Response Style Questionnaire (RRS) captured the proclivity to ruminate following negative emotional experiences (Treynor, Gonzalez, & Nolen-Hoeksema, 2003). Higher RRS scores indicate more habitual and extreme rumination. Coping self-efficacy was assessed with the 26-item Coping Self-Efficacy Scale (CSE; Chesney et al., 2006). Participants are asked to rate how much they believe they could perform various behaviors related to coping on a scale from 0 ("cannot do at all") to 10 ("certain can do"). Scores range from 0 (no self-efficacy) to 260 (maximum self-efficacy). Participants also completed baseline measures of mood and anxiety symptoms. The Depression Anxiety Stress Scales, 21-item (DASS-21) yields three subscales: depression, anxiety, and stress (Lovibond & Lovibond, 1995).

The depression subscale captures low or sad mood, feelings of worthlessness and hopelessness, anhedonia, and psychomotor slowing, for example. The anxiety subscale includes somatic symptoms (e.g. trembling, sweating, dry mouth, shortness of breath, racing heart), situational anxiety, general anxiety, and panic. The stress subscale reflects chronic feelings of irritability, nonspecific hyperarousal, being on edge or fidgety, tension, being easily startled or upset, and impatience. Finally, regular exercise habits were evaluated via the third item from the George Non-Exercise Test (George, Stone, & Burkett, 1997); responses range from 0 (“avoid walking or exertion”) to 10 (“vigorous activity; run over 25 miles per week or spend over 8 h per week in comparable physical activity”).

1.2.2. Experimental manipulation

Participants were randomly assigned to one of two activity conditions. Participants in the exercise group cycled for 30 min at a moderate pace, which included 5 min of warm-up and 25 min of sustained activity at 60–70% of their estimated maximum heart rate (Norton, Norton, & Sadgrove, 2010). To estimate maximum heart rate, we used the following formula: 208 – (0.7 × Age) (Tanaka, Monahan, & Seals, 2001). Participants assigned to the control group were led through 30 min of stretching. Heart rate was recorded throughout the activity conditions via a Polar heart rate monitor worn around the chest while the experimenter monitored for adherence to the assigned activity. After the 30 min, participant heart rate had to return to pre-activity level (within 10% of baseline) before moving forward.

1.2.3. Stressor

The stressor procedure was based on the Trier Social Stress Test (Kirschbaum, Pirke, & Hellhammer, 1993). Participants were instructed to spend 5 min preparing to give a 5-min speech for an imagined fellowship interview about why they are a good friend. Participants were not allowed to use any notes made while preparing when they delivered their speech. The experimenter provided neither positive nor negative feedback while observing.

1.2.4. Emotional response

Difficulties with emotion regulation or coping during the 5 min following the speech were measured in three ways. Modified versions of the difficulties engaging in goal-directed behavior (DERS-Goal) subscale and limited access to emotion regulation strategies (DERS-Strategies) subscale from the Difficulties in Emotion Regulation Scale (DERS) were administered (Gratz & Roemer, 2004). Similar to the adapted scale used by McLaughlin, Mennin, and Farach, (2007), these questionnaires asked participants to rate how much each statement applies to them *right now* rather than in general, thus serving as a state-level measure. Like the baseline coping self-efficacy scale, the DERS items ask participants to assess how well they perceive themselves to be coping. Example DERS-Goal items include “I have difficulty concentrating” and “I would have difficulty thinking about anything else right now.” Example DERS-Strategies items include “I believe I will remain this way for a long time” and “I believe that there is nothing I can do to make myself feel better.” Additionally participants completed a measure of state rumination with a modified 8-item State Rumination Questionnaire (SRQ) (LeMoult, Arditte, D'Avanzato, & Joormann, 2013); example items include how much they had been thinking about their performance, how negative their thoughts were, and how much they thought about their negative emotional experience. Higher scores indicate more difficulty accessing regulatory strategies, more difficulty with goal-directed behavior, and more rumination.

1.2.5. Positive mood induction

To help participants upregulate their mood before leaving, the study concluded with a brief (< 3 min) clip from the film *When Harry Met Sally* as this clip reliably increases positive affect (Gross & Levenson, 1995).

1.2.6. Repeated measures

Participants indicated state level global positive and negative affect by rating how much they felt various emotions on visual analogue scales ranging from 0 (not at all) to 100 (completely) (Bernstein & McNally, 2016; Leen-Feldner, Zvolensky, Feldner, & Lejuez, 2004). Specific negative emotions included anxious, tense, sad, and angry. Positive emotions included content, excited, and happy. The order of emotions presented was randomized each time this measure was administered: at baseline, after physical activity, immediately after the stressor, after a recovery period (approximately 10 min after the speech), and at the end of the study (approximately 15 min after speech).

1.3. Statistical analysis

Baseline demographic and clinical characteristics of the sample were calculated as means with standard deviations (SD) for continuous variables and counts with proportions for categorical variables. We used independent sample *t*-tests to assess potential group differences in age, body mass index (BMI), resting heart rate, trait rumination, coping self-efficacy, symptoms of depression and anxiety, exercise habits, and state affect at baseline. We conducted chi-square analyses to test potential group differences in gender, race, and ethnicity. We also used *t*-tests to confirm that, as intended, participants in the exercise condition experienced significantly increased average heart rate during the activity period than the stretching group and that the stressor increased negative affect.

We then used linear regressions to evaluate how regular exercise habits related to baseline clinical variables, including trait rumination, coping self-efficacy, depression, anxiety, and stress, as well as how rumination tendencies and coping self-efficacy related to mood symptoms. To explore whether enhanced emotional response tendencies might, at least in part, account for the effects of regular exercise on mood, we planned to test for mediation effects in the event of positive results.

In our experimental data, we first used multilevel models to examine changes in negative and positive affect as a function of time and condition. We then examined a three-way interaction between time, group assignment, and state measures of rumination and difficulties with emotion regulation (DERS) to explore effects on recovery following the stressor. Models were repeated to control for baseline affect and regular exercise habits. Maximum likelihood estimation procedures were used and subjects were treated as random factors (random intercept). Time was operationalized as an ordinal variable, with measurements taken at four points: pre-stressor, immediately post-stressor, 10-min post-stressor, and at the end of the study. Group assignment was a categorical variable, encompassing cycling and stretching conditions. Finally, state rumination and DERS measures were continuous variables.

2. Results

A summary of baseline demographic and clinical characteristics of the sample is included in Table 1. Fifty-two individuals were randomized to each condition. At baseline, groups did not differ in age, race, ethnicity, gender, or body mass index (BMI), nor did they differ in terms of symptoms of depression, anxiety, or stress, reports of habitual rumination, and state positive or negative affect at the start of the visit ($ps > .05$). However, participants randomly assigned to the cycling condition did report greater coping self-efficacy at baseline ($M = 204.37$, $SD = 38.79$), than did their peers who were assigned to stretch ($M = 186.44$, $SD = 36.18$), $t(101.5) = 2.44$, $p = .02$. Within the whole sample, 24.04% of participants reported less than 30 min per week of exercise and 21.15% reported no activity or only light activity. Additionally, 18.27% of the sample exceeded the clinical cut-off for at least mild symptoms of depression (DASS-Depression score ≥10),

Table 1
Demographic and baseline characteristics of the sample.

Characteristic	Whole Sample N (%)	Cycling N (%)	Stretching N (%)	Group Difference (p-value)
Gender				.84
Female	60 (57.79)	29 (55.77)	31 (59.62)	
Male	44 (42.31)	23 (44.23)	21 (40.38)	
Ethnicity				.49
Hispanic/Latino	16 (15.38)	10 (19.23)	6 (11.54)	
Not Hispanic/Latino	85 (81.73)	41 (78.85)	44 (84.62)	
Unreported	3 (2.88)	1 (1.92)	2 (3.85)	
Race				.35
Caucasian/White	65 (62.50)	34 (65.38)	31 (59.62)	
African America/Black	5 (4.81)	2 (3.85)	3 (5.77)	
Asian American/Asian	17 (16.35)	5 (9.62)	12 (23.08)	
Native American/American Indian	1 (.96)	1 (1.92)	0 (0.0)	
Mixed Race	12 (11.54)	7 (13.46)	5 (9.62)	
Other/Unreported	4 (3.85)	3 (5.77)	1 (1.92)	
Characteristic	**Whole Sample Mean ± SD**	**Cycling Mean ± SD**	**Stretching Mean ± SD**	**Group Difference (p-value)**
Age	19.94 ± 2.05	19.65 ± 1.30	20.23 ± 2.57	.15
Regular exercise	7.04 ± 2.97	6.90 ± 2.91	7.17 ± 3.06	.65
RRS	43.55 ± 12.26	42.83 ± 13.44	44.27 ± 11.05	.55
DASS-Depression	5.77 ± 6.22	5.12 ± 6.80	6.42 ± 5.58	.29
DASS-Anxiety	4.69 ± 4.59	4.19 ± 4.84	5.19 ± 4.31	.27
DASS-Stress	10.69 ± 7.41	10.31 ± 7.85	11.08 ± 7.01	.60
CSE	195.4 ± 38.40	204.37 ± 38.79	186.44 ± 36.18	.02
BMI	23.29 ± 3.40	23.45 ± 3.46	23.13 ± 3.37	.63

Note. Regular exercise = item #3 from the George Non-Exercise Test, higher scores indicate more regular exercise, RRS = Ruminative Responses Subscale of the Response Style Questionnaire, DASS = Depression Anxiety Stress Scales, CSE = Coping Self-Efficacy Scale, BMI = body mass index.

25.96% exceeded the clinical cut-off for at least mild symptoms of anxiety (DASS-Anxiety score ≥ 8), and 28.85% exceeded the clinical cut-off for at least mild stress symptoms (DASS-Stress score ≥ 15).

2.1. Regular exercise

More frequent regular exercise was significantly associated with fewer or less severe symptoms of depression (DASS-Depression), $F(1,102) = 4.16$, $p = .04$, adjusted $R^2 = 0.03$, $B = -0.41$, anxiety (DASS-Anxiety), $F(1,102) = 3.94$, $p = .049$, adjusted $R^2 = 0.03$, $B = -0.30$, and stress (DASS-Stress), $F(1,102) = 11.23$, $p = .001$, adjusted $R^2 = 0.09$. $B = -0.79$. Additionally, regular exercise was associated with less habitual rumination (RRS), $F(1,102) = 8.52$, $p = .004$, adjusted $R^2 = 0.07$, $B = -1.15$, and greater coping self-efficacy (CSE), $F(1,102) = 8.20$, $p = .005$, adjusted $R^2 = 0.07$, $B = 3.52$.

Lower RRS scores were also significantly related to lower scores on DASS-Depression, $F(1,102) = 39.32$, $p < .001$, adjusted $R^2 = 0.27$, $B = 0.27$, DASS-Anxiety, $F(1,102) = 29.20$, $p < .001$, adjusted $R^2 = 0.21$, $B = 0.17$, and DASS-Stress, $F(1,102) = 47.02$, $p < .001$, adjusted $R^2 = 0.31$, $B = 0.34$. When both exercise habits and RRS score were simultaneously entered into the models, RRS score remained a significant predictor ($ps < .001$) of DASS-Depression, $F(2,101) = 19.75$, $p < .001$, adjusted $R^2 = 0.27$, $B = 0.26$, and DASS-Anxiety, $F(2,101) = 14.80$, $p < .001$, adjusted $R^2 = 0.21$, $B = 0.17$, whereas exercise habits was no longer a significant predictor ($ps > .05$), suggesting full mediation. We tested these indirect effects by using a bootstrap estimation approach with 1000 samples. Results indicated that the indirect effect was significant for DASS-Depression, average causal mediation effects (ACME) = −0.30, CI[-0.55, −0.09]. $p < .001$, and DASS-Anxiety, ACME = −0.19, CI[-0.35, −0.06]. $p < .001$. RRS score remained significant in predicting DASS-Stress, $F(2,101) = 26.35$, $p < .001$, adjusted $R^2 = 0.33$, $B = 0.31$; however, exercise habits also remained significant when DASS-Stress was the criterion, though its effect lessened, $B = -0.43$, $p = .04$, suggesting partial mediation. The bootstrap estimation showed that this indirect effect was significant as well, ACME = −.36, CI[-0.62, −0.11]. $p < .001$. Because the RRS includes item that overlap with symptoms of depression and general low mood, we repeated analyses including only the RRS brooding subscale (Treynor et al., 2003). The pattern of results remained unchanged.

Similarly, greater CSE scores predicted lower scores on DASS-Depression, $F(1,102) = 41.22$, $p < .001$, adjusted $R^2 = 0.28$, $B = -0.09$, DASS-Anxiety, $F(1,102) = 13.76$, $p < .001$, adjusted $R^2 = 0.11$, $B = -0.04$, and DASS-Stress, $F(1,102) = 32.35$, $p < .001$, adjusted $R^2 = 0.23$, $B = -0.09$. When both exercise habits and CSE score were simultaneously entered into the models, only CSE score remained a significant predictor ($ps < .001$) of DASS-Depression, $F(2,101) = 20.70$, $p < .001$, adjusted $R^2 = 0.28$, $B = -0.08$, and DASS-Anxiety, $F(2,101) = 7.51$, $p < .001$, adjusted $R^2 = 0.11$, $B = -0.04$, also suggesting full mediation. Results of the bootstrap estimation indicated that the indirect effect was significant for DASS-Depression, ACME = −.30, CI[-0.55, −0.07]. $p = .01$, and DASS-Anxiety, ACME = −0.13, CI[-0.27, −0.03]. $p = .01$. CSE score remained significant in predicting DASS-Stress, $F(2,101) = 19.27$, $p < .001$, adjusted $R^2 = 0.26$, $B = -0.08$; again, exercise habits also remained significant when DASS-Stress was the criterion, though its effect lessened, $B = -0.49$, $p = .03$, suggesting partial mediation. The bootstrap estimation showed that this indirect effect was significant as well. Results should be interpreted cautiously as data were cross-sectional.

2.2. Acute exercise

Per the intended manipulation, average heart rate was significantly higher during the 30 min of cycling ($M = 124.67$ bpm, $SD = 6.20$) relative to stretching ($M = 85.54$ bpm, $SD = 13.36$), $t(65.46) = 18.50$, $p < .001$. Groups did not differ in their resting heart rate, $p > .05$. Additionally, groups did not differ in how the physical activity (i.e. cycling or stretching) altered their reported negative affect or positive affect immediately after, $ps > .05$. There were also no interaction effects with exercise habits, $ps > .05$. The stressor successfully increased negative affect, $t(101) = 2.19$, $p = .03$, and decreased positive affect, $t(103) = 2.74$, $p = .007$, for the whole sample. When considering how negative and positive affect changed after the speech task (i.e. pre-speech, immediately post-speech, 10 min after, end of study), there was no significant condition by time interaction for negative affect, $F(3,300) = 2.55$, $p = .06$, or positive affect, $F(3,303) = 1.31$, $p = .27$. Additionally, there were no group differences in DERS-Goal, DERS-Strategies, or SRQ scores following the stressor, $ps > .05$. This was true both with and without regular exercise habits, CSE score, and baseline affect included in the models.

However, consistent with past research, interaction effects emerged when considering difficulties with emotion regulation reported after the stressor. A significant three-way interaction emerged between time since the stressor, condition, and state rumination, $F(3,294) = 9.70$, $p < .001$. Activity condition moderated the effect that more rumination had on change in negative affect since the stressor at the end of the study, $B = 0.77$, $p < .001$; a trend in the same direction emerged for just 10-min post-stressor, $B = 0.29$, $p = .09$. In this model, the contrast between baseline and immediately post-stressor was also significant, $B = 0.60$, $p < .001$. Overall, participants reporting more rumination in response to the stressor reported more negative affect at all time points post-stressor and those in the cycling condition also reported a greater increase in negative affect post-stressor. Regardless of prior activity condition, participants reporting low levels of state rumination reported declines in negative affect following the stressor. Whereas participants reporting high levels of state rumination in the cycling condition also reported decreases in negative affect from post-stressor to the end of study, those in the stretching condition did not report a significant decline. Results held controlling for baseline negative affect and exercise habits. Results are presented in Fig. 1. For ease of visual interpretation, state rumination is depicted as a binary variable (high, low) based on a median split. Although negative affect reported at individual time points visually may appear to differ between conditions at high levels of state rumination, none of these differences was significant. It is the steeper negative slope of change from the stressor to the end of the study among high ruminators that differentiates the cycling group from the stretching group. Significant three-way interactions similarly emerged when we examined DERS subscales. Activity condition moderated the effect that more difficulty accessing regulatory strategies (DERS-strategies), $F(3,294) = 5.81$, $p < .001$, had on change in negative affect since the stressor at the end of the study, $B = 2.07$, $p < .001$. A trend in the same direction emerged for difficulty with goal directed behavior (DERS-goal), $F(3,294) = 2.23$, $p = .09$, at the end of the study, $B = 1.42$, $p = .02$. There were no significant differences between negative affect at baseline and immediately post-stressor by condition, DERS-strategies, or DERS-goal scores, $ps > .05$.

A similar pattern emerged for positive affect. There was a three-way interaction between time, condition, and state rumination, $F(3,297) = 4.93$, $p = .002$. Activity condition moderated the effect of state rumination on change in positive affect since the stressor at the end of the study, $B = -0.61$, $p = .01$; a trend in the same direction emerged for 10-min post-stressor only, $B = -0.46$, $p = .06$. Participants reporting low levels of state rumination reported scant change in positive affect across the study, regardless of activity condition. Participants reporting high levels of state rumination in the cycling condition showed an upward trajectory in positive affect across the recovery period, whereas participants in the stretching condition did not. Results held controlling for baseline negative affect and exercise habits. The interaction was not significant for DERS-strategies, $F(3,297) = 1.73$, $p = .16$, or DERS-goal, $F(3,297) = 1.93$, $p = .12$.

3. Discussion

Among young adults widely varying in their exercise habits and risk for mood and anxiety problems, results were consistent with past research showing that more frequent aerobic exercise is associated with fewer or less severe symptoms of depression, anxiety, and general stress. This study also replicated findings that more active individuals reported greater coping self-efficacy, or perceived ability to cope with stressors or negative mood, than did less active peers (Craft, 2005; Kishida & Elavsky, 2015). Furthermore, regular exercisers reported a less ruminative response style as well. Although data were cross-sectional and therefore unable to confirm causality, results align with hypotheses that less habitual rumination and greater coping self-efficacy could in part mediate the effects of exercise habits on mood symptoms and stress. Findings lend further support to the overarching hypothesis that enhanced ability to adaptively respond to or recover from stress or negative mood states is a significant pathway through

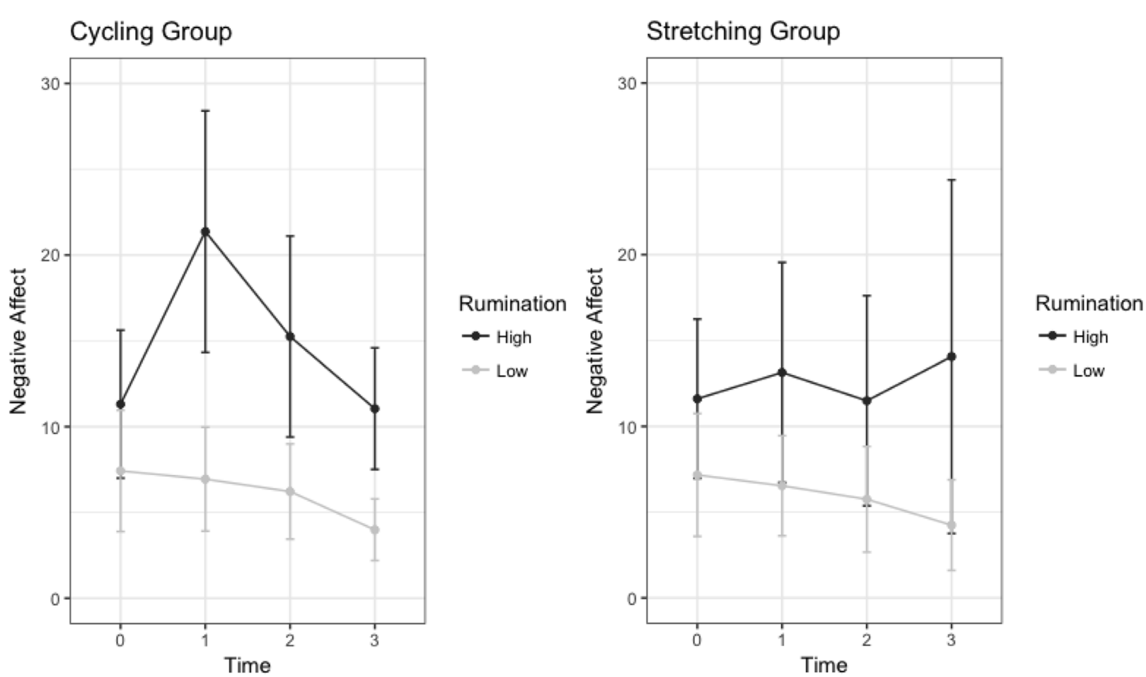

Fig. 1. The effect of state rumination on emotional recovery moderated by activity condition.
Note. 95% confidence intervals shown. Time: 0 = pre-stressor, 1 = immediately post-stressor, 2 = 10-mintes post-stressor, 3 = end of study. Rumination (based on median split): Low = SRQ less than or equal to 16, High = SRQ greater than 16.

which exercise promotes better emotional health. This suggests that regular exercise may alter the way people process and respond to their emotions, rather than necessarily directly elevating mood.

However, there are limitations to cross-sectional, retrospective data. For example, instead of regular exercise leading to less psychopathology, it is possible that clinical symptoms predict less coping self-efficacy and more rumination, which in turn interfere with exercise routines, or that relationships are bidirectional. For this reason, we also included complementary experimental data. This study did not find that cycling differentially raises mood relative to stretching, or that a single session of exercise, relative to stretching, prevents or blunts initial negative emotional reactions to the stressor; participants assigned to both cycling and stretching reported similar increases in negative affect and decreases in positive affect immediately after the speech. Furthermore, despite finding that regular exercise was associated with less trait rumination and greater coping self-efficacy, there were no effects of regular exercise or acute exercise on state rumination, perceived difficulties engaging in goal directed behavior, or reported access to emotion regulation strategies after the stressor. Instead, participants in the cycling group who did report patterns of rumination and difficulties with emotion regulation appeared to be less affected by them. That is, participants who did not ruminate or report other difficulties coping with the stressor did not differ in their patterns of emotional recovery based on previous physical activity. This is unsurprising as acute exercise was hypothesized to benefit mood by enhancing emotional recovery; without deficits therein, one would not expect to see changes. Among participants who did ruminate or report other regulatory difficulties, those who previously cycled were more likely than peers who had stretched to report sharper declines in negative affect and, to a lesser extent, increases in positive affect by the end of the study. In this way, acute exercise appears to provide a buffer against regulatory difficulties that would typically prolong or exacerbate negative emotions after a stressor has ended. Results are consistent with past studies concerning exercise-enhanced response to stressors (Bernstein & McNally, 2016, 2017; Flueckiger, Lieb, Meyer, Witthauer, & Mata, 2016a; Puterman et al., 2017).

The high variability in affective reports, particularly among those reporting high rumination and difficulty with emotion regulation, encourages caution in interpreting results. Affective reports across groups of people, though typically yielding positive results for exercise, can also obscure those individuals who show opposite effects (Backhouse et al., 2007). However, we can also be more confident as this pattern is consistent with prior studies. Additionally, it was surprising that high ruminators in the cycling condition initially reported greater negative emotional reactivity to the stressor than those in the stretching condition. This could result in a floor effect such that we found a steep decline in negative affect during the recovery period only in this group *because* of its initial increase. However, this initial difference in reactivity did not emerge for those reporting difficulties with emotion regulation strategies or with goal-directed behavior. Additionally, high ruminators in the stretching condition showed an upward trend in negative affect, and high ruminators in both conditions reported levels of negative affect consistently above the floor and above low ruminators. Thus, it cannot fully account for the pattern of results.

Taken together, results suggest that higher coping self-efficacy among regular exercisers is well-founded and that aerobic exercise engenders emotional resilience to stress (Mata, Hogan, Joormann, Waugh, & Gotlib, 2013; Salmon, 2001). The fact that relative to the stretching group, the cycling group did not report greater positive affect or less negative affect following physical activity should not be interpreted to mean that acute exercise cannot directly improve state affect or alter emotional reactivity, as there is robust evidence that self-selected exercise intensities in particular, and those at the sub-maximal level, often induces pleasurable feelings (Ekkekakis et al., 2011; Yeung, 1996). Instead, we interpret these null results as support for the claim that post-activity improvements in mood cannot fully account for the broad emotional benefits of exercise. It is plausible that physically fit individuals also receive regulatory boosts, when needed, from individual sessions of exercise and consequently experience cumulative benefits over time in the form of overall faster recoveries and fewer symptoms of anxiety or depressed mood, as baseline measures indicate.

Interestingly, though regular exercisers reported ruminating less in their day-to-day lives and greater confidence in their ability to cope effectively with stressors, they showed no differences in state rumination or reported difficulties regulating their emotions after the experimental stressor; furthermore, there were similarly no direct effects of acute exercise on state rumination or perceived regulatory difficulties. Using rumination as an example, we suspect that regular exercisers might be reporting lower scores on the trait measure of rumination because rumination does not affect them as negatively as it does more sedentary individuals and thus does not stand out as much in their minds as something typically problematic for them. Indeed, studies have suggested that physical activity can reduce the intensity or accessibility of maladaptive coping strategies—such as rumination and worry (Bahrke & Morgan, 1978; Craft, 2005) and in the present study, state rumination had a less prolonged effect on mood among participants who had recently exercised. Lower trait rumination scores could be further driven by differences in the duration of rumination among regular and non-regular exercisers. In the present study, there was limited post-event processing time. Though group differences still emerged in how rumination and perceived difficulties with emotion regulation during this time affected emotional recovery, it is possible that had post-event rumination (and other regulatory difficulties) been measured over a longer period of time, regular exercisers or participants in the exercise condition would have stopped ruminating sooner or reported declines in the intensity of such thoughts. There is some evidence that aerobic exercise fosters more mindful or acceptance-oriented mindsets and balanced appraisals of stressors (Mothes, Klaperski, Seelig, Schmidt, & Fuchs, 2014; Ulmer, Stetson, & Salmon, 2010), which could further dampen the impact of ruminative or other maladaptive responses to the stressor (Ramel, Goldin, Carmona, & McQuaid, 2004). Thus, exercise—regular and acute— may not alter one's propensity to start ruminating, but rather reduce the duration, intensity, or effects of bouts of rumination.

Our study has limitations. First, we examined 30 min of moderate cycling as compared to stretching. It is unknown whether results would generalize to other types of exercise or other durations, or whether there are shared benefits of cycling and stretching that were occluded by our design. Encouragingly though, similar results occur for 30 min of running (Bernstein & McNally, 2016) and for cycling relative to both stretching and resting (Bernstein & McNally, 2017). However, the parameters for defining moderate aerobic exercise in this study relied on estimated maximum heart rates. Because this approach can yield inaccurate estimates for some individuals, it is likely that some participants engaged in activity that was either light or vigorous for them. Had we conducted a maximal heart rate test on a separate day, different findings may have emerged. Moreover, there is substantial evidence that exercise intensity— and whether it is self-selected or imposed— strongly influences acute emotional effects (Ekkekakis et al., 2011; ZeRVAS et al., 1993). Thus, follow-up studies are needed to examine the dose-response nature of these effects. Second, given the time constraints of the study, we could not tease apart how reported regulatory difficulties would have unfolded over longer periods of time or in the absence of the positive film clip. However, the end-of-study results following this positive stimulus are valuable as this type of distraction can be an adaptive emotion regulation strategy. Furthermore, some participants still did not report improvements afterwards, indicating that many participants might still have benefited from the regulatory boost afforded by prior aerobic exercise. Third, all data were self-report measures. Though subjective experiences are an important outcome measure for this line of work, future studies could benefit from including complementary measures (e.g. brain-derived neurotrophic factor) that could uncover additional relevant exercise effects that are not perceptible to participants or could elucidate mechanisms subserving the observed effects (Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007; Szuhany, Bugatti, & Otto, 2015).

Despite these limitations, this study contributes to a growing understanding of how and for whom exercise improves emotional wellbeing. Data showed that the benefits of acute exercise for emotional recovery extend to participants ranging from sedentary to highly active and from no risk to high risk for emotional disorders. In this domain, a single session of exercise appears to protect against acute emotion regulation failure and thus foster emotional recovery. Regular exercisers might experience better emotional health and resilience, at least in part, because on a day-to-day basis they are bouncing back from stress more easily that they would without this fitness boost. Identifying psychological changes like these are important as social and primarily physical health benefits (e.g. parasympathetic vagal tone) cannot account for large proportions of exercise's positive effects (Harvey et al., 2017). Notably, participants in the study were largely able to adjust the intensity of their exercise throughout the 30 min period. This self-selection factor could be relevant to our findings, especially as how people appraise their efforts and the subsequent effects, in addition to or sometimes in spite of actual physical exertion, influences subsequent wellbeing (Biddle & Ekkekakis, 2012).

As most clinicians will attest, changing patients' habitual patterns of emotion regulation or responding—such as rumination—is challenging and often aversive. However, as such maladaptive response styles are strong predictors of onset and relapse for depression and related emotional disorders, targeted interventions are necessary (Watkins et al., 2007). Explicitly recommending aerobic exercise for individuals with such maladaptive tendencies could be a preventive measure to buffer against more chronic coping deficits or their consequences. Indeed, an estimated 12% of new cases of depression could be prevented if the whole population exercised for at least one hour per week (Harvey et al., 2017; Mammen & Faulkner, 2013). Such recommendations could also be an adjunctive strategy to support ongoing cognitive and behavioral treatments and enhance clinical outcomes with exercise serving as a behavioral activation tool to combat problematic action tendencies, foster resilience, engage psychosocial resources, enhance self-efficacy, or improve cognitive function (Hogan, Catalino, Mata, & Fredrickson, 2015; Stathopoulou, Powers, Berry, Smits, & Otto, 2006), We hope the present results demonstrating a particular, immediate benefit of even single sessions of exercise could provide more tangible and immediate motivation for people to exercise and encourage more research to further clarify dosing recommendations, potential neurobiological, cognitive, and motivational mechanisms of these effects, and how best to apply findings for clinical application.

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