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# Acute Aerobic Exercise Hastens Emotional Recovery From a Subsequent Stressor

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***Objective:*** Despite findings that regular exercise is broadly associated with emotional well-being, more basic research is needed to deepen our understanding of the exercise and emotion connection. This paper examines how acute aerobic exercise in particular influences subjective emotional recovery from a subsequent stressor. Potential mediators and moderators, including level of physical fitness, attentional control, and perseverative negative thinking were explored. ***Method:*** All of the participants ($n = 95$) completed 3 laboratory visits, each including 1 of 3 activities (i.e., cycling, resting, stretching), tests of working memory and attentional control, and an experimental stressor. Self-reported rumination after the stressor and the experience of positive and negative emotions throughout the study were recorded. ***Results:*** In this within-subjects paradigm, as expected, higher rumination in response to the stressor predicted more persistent negative emotion afterward; this effect was attenuated only by prior acute aerobic exercise, in this case, cycling, both 5 min and 15 min poststressor. This effect was unrelated to physical fitness or cognitive performance. Physical fitness level did predict greater attentional control and the capacity to update working memory. ***Conclusion:*** Acute aerobic exercise may facilitate subjective emotional recovery from a subsequent stressor and improve emotional flexibility.

*Keywords:* aerobic exercise, fitness, attentional control, emotion regulation, rumination



Colloquial wisdom and scientific research alike point to broad benefits of exercise for emotional health. Cross-sectional and prospective studies show that habitual exercise is associated with greater well-being, fewer or less severe anxious or depressive symptoms, and lower rates of psychiatric disorders (Ströhle, 2009). The question remains why? What psychological or other processes mediate these effects? Identifiable mechanisms would help develop more targeted, consistently efficacious primary and adjunctive interventions, as well as provide more tangible motivators for adherence to exercise programs, even in the general population. In this article, we focused on *aerobic* exercise specifically, hereafter simply expressed as *exercise*. Exercise can affect many systems in the body, and thus unique and interactive contributions to mental health could be made by neurobiological, cognitive, and psychological factors. For this project, we focused on one potential pathway.

Single bouts of exercise may affect the way people respond to or recover from emotionally stressful experiences, and regular aerobic activity may engender resilience against prolonged or excessive emotional reactions (Flueckiger, Lieb, Meyer, Witthauer, & Mata, 2016; Kishida & Elavsky, 2015; Ströhle, 2009). In fact, longitudinal studies have suggested that regular exercise may protect against the onset of depression or recurrence of depressive symptoms (Teychenne, Ball, & Salmon, 2008). Experiencing negative emotions, such as sadness, is not inherently problematic. And there is, to our knowledge, no evidence to suggest that physically active people are incapable of experiencing negative emotions. Becoming stuck in a negative emotional state—emotional inflexibility—is the problem. Indeed, exercise may lessen the impact of stress responses in that physically fit individuals return to prestress levels more quickly than do nonfit individuals (Blumenthal et al., 1988; Forcier et al., 2006; Jackson & Dishman, 2006) and exercise training may improve individuals' ability to emotionally weather or recover from stress, as well (Bernstein & McNally, 2016; Southwick, Vythilingam, & Charney, 2005).

In the present study, we explored how a session of moderate exercise might influence subjective emotional recovery following a stressor, and examined potential cognitive–affective mechanisms. First, exercise might alter emotional response styles, namely, negative repetitive thinking. Negative repetitive thinking, such as rumination, prolongs and keeps focus on negative experiences (Nolen-Hoeksema & Morrow, 1991; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Habitual negative rumination predicts symptoms of depression and anxiety, and presents a significant risk for developing mood disorders (McLaughlin & Nolen-Hoeksema, 2011). Exercise may promote emotional flexibility, or a person's ability to bounce back from negative mood states, by reducing rumination or its effect (i.e., less persistent negative

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emotion; Craft, 2005). Studies have found that in general, behavioral activation, or increasing engagement in pleasant activities, such as exercise, to reduce avoidance and combat depression, can lessen rumination (Jacobson et al., 1996; Soucy Chartier, Blanchet, & Provencher, 2013). And, physically active individuals have reported greater coping self-efficacy, or perceived ability to cope with stressors or negative mood, a characteristic that could reflect the use of more adaptive regulatory strategies (Craft, 2005; Kishida & Elavsky, 2015). Some authors have even shown that regular exercisers are less vulnerable than their sedentary peers to the prolonged, adverse physiological effects of negative rumination (e.g., excess cortisol production and delayed recovery), and conjectured that exercise may diminish the tendency to ruminate, as well (Craft, 2005; Puterman et al., 2011).

Second, exercise may produce such benefits through the enhancement of cognitive functioning. For example, it may improve one's ability to regulate emotion by improving attentional control. Regular and even single sessions of exercise can enhance these abilities in nonemotional contexts (e.g., Greer, Grannemann, Chansard, Karim, & Trivedi, 2014; Guiney & Machado, 2013). And rumination may reflect impairments in attentional control or information-processing abilities (Koster, De Lissnyder, Derakshan, & De Raedt, 2011). Those who ruminate may feel worse longer because they struggle to update or shift between their perseverative, emotionally charged thoughts and other topics. Put simply, they get stuck in their initial response. Of note, much of the research in this new area is correlational, though some recent work has shown that executive control training with negative stimuli can reduce ruminative response tendencies (Cohen, Mor, & Henik, 2014) and that functional declines in executive control under stress predict depressive symptoms (Quinn & Joormann, 2015). It remains to be tested whether exercise can also improve attentional control in the presence of emotional stimuli (e.g., as opposed to nonemotional ones involving numerical or geometric stimuli) and directly influence emotion regulation.

We employed within-subject experimental methods to examine the hypothesis that exercise positively affects how people process emotional information or experiences. First, we specifically hypothesized that acute sessions of exercise would improve attentional control and diminish rumination, or at least the effects that rumination has on prolonged negative emotion. Should these hypotheses be supported, we would test whether improvements in attentional control abilities mediated the relationship between exercise and rumination, allowing participants to easily disengage or recover from maladaptive thought patterns when appropriate. Furthermore, it was anticipated that fitness level could moderate these effects, such that more fit participants may show better attentional control and working-memory abilities and struggle less with rumination than less fit participants, regardless of what activity they completed at the session onset.

# Method

## Participants

Ninety-five eligible participants (55 women, 40 men, $M_{age}$ = 23.96 years, $SD$ = 4.40, age range = 18–36) enrolled in the study between 2015 and 2016.[1] The ethnic/racial composition of the final sample was 60% Caucasian, 8.42% African American, 18.95% Asian, 12.63% multiracial or other, and 8.42% Hispanic or Latino/Latina. Participants who had a history of major head trauma, neurologic disorder, or cognitive impairment, or endorsed any contraindications for exercise on the seven-item Physical Activity Readiness Questionnaire (PAR-Q; Adams, 1999) were excluded. Harvard University's Committee on the Use of Human Subjects approved the study protocol, and participants provided informed consent prior to initiation of any study procedure.

## Procedure and Materials

The study involved three in-person lab visits. Participants were instructed to refrain from exercise or strenuous physical activity for up to 12 hr prior to testing at each session. Visits were scheduled 5 (±2) days apart and within 2 hr of the initial visit time.

**Baseline measures.** At the first visit, participants completed a battery of self-report questionnaires, including demographics, trait emotion-response tendencies, mood symptoms, and exercise habits. The 22-item Ruminative Responses subscale (RRS) of the Response Style Questionnaire (Treynor, Gonzalez, & Nolen-Hoeksema, 2003) assesses two factors of rumination: reflective pondering and brooding. Higher scores indicate greater proclivity for negative perseverative thinking. The 21-item Depression Anxiety Stress Scales evaluates participants' mood during the past week and is comprised of three scales: Depression, Anxiety, and Stress (DASS-21; Lovibond & Lovibond, 1995). If baseline mood symptoms tend to differ systematically with a person's fitness level, this could bias cognitive performance and emotion-regulation effects, as depression and anxiety are associated with poorer outcomes on both dimensions. Finally, participants completed the George Non-Exercise Test (GNET; George, Stone, & Burkett, 1997), which comprises three questions covering perceived functional ability and habitual physical activity. Data from this measure, body-mass index (BMI, measured in kg/m$^2$) as measured in the lab, and gender can be entered into a regression model to provide estimates of maximal oxygen consumption, or $VO_2$max (ml/kg/min), which reflects cardiorespiratory fitness and the ability to engage in sustained, dynamic, moderate- to high-intensity exercise.

**Acute activity.** Participants completed one of three 25-min activities at each visit: rest (inactive control condition), stretching (active control condition), and cycling (moderate exercise condition). The order of these activity assignments was counterbalanced across participants, such that participants were randomly assigned to one of six possible sequences (e.g., cycling at Visit 1, resting at Visit 2, and stretching at Visit 3). In the rest condition, participants were instructed to sit and rest, but not to sleep or walk around. They were allowed to look through magazines provided. In the stretching condition, participants were told they would complete a full-body stretching exercise. At 5-min intervals, participants were provided with different instructions about how and what to stretch (e.g., neck and shoulder stretches). In the exercise condition, participants cycled on a stationary bike for 25 min, which included 5 min of warm up and at least 20 min of sustained moderate

[1] Prior to examining data, eight additional participants were excluded by consensus: Four experienced difficulty with instructions due to a language barrier, three were noncompliant with study procedures, and one reported a previously undisclosed contraindication to exercise and withdrew after the baseline questionnaire.

aerobic activity (i.e., reaching between 60% and 70% of their estimated maximum heart rate[2]). For comfort, participants were allowed to vary the intensity (e.g., speed, resistance), provided they maintained a heart rate within the target range. Heart rate was monitored throughout with a Polar heart-rate monitor (Polar Electro, Inc., Lake Success, NY) worn around the chest. Heart rate was measured before and after all three activities. The experimenter monitored participants' adherence to the assigned activity at 5-min increments.

**Repeated measures.** At each visit, following the acute activity portion, participants completed computerized tasks to assess various attentional control abilities, underwent a stressor, and concluded with questionnaires assessing their emotional response. State emotional experiences were recorded throughout the study period (i.e., baseline, postactivity, poststressor and delay, end of study); participants indicated how much they felt each of nine different emotions at that moment by using sliding scales ranging from 0 to 100. Content, excited, calm, and cheerful were the positive emotions, and angry, sad, anxious, agitated, and tense were the negative ones. Following the activity and to avoid misattribution of arousal effects,[3] we had participants sit for approximately 5 min to ensure that their heart rate returned to within 10% of their baseline prior to the next phase of the experiment. Participants began the next phase within 6 min.

Cognitive tasks were then administered via OpenSesame, an open-source graphical experimental platform (Mathôt, Schreij, & Theeuwes, 2012). Stimuli were presented on a 16 × 9-in Dell monitor with a resolution of 1366 × 768 pixels and a refresh rate of 60 Hz. Stimuli in all tasks were neutral and negative words drawn from the Affective Norms for English Words (ANEW) list (Bradley & Lang, 1999), which provides valence ratings on a 9-point scale for each word. Words in the two groups did not differ in average length, but did significantly differ in mean valence ratings. Negative words were used to match the valence of the later stressor task. In every task, participants were instructed to move as quickly as possible through the blocks, while still being accurate.

***N*-back.** Participants first completed an *n*-back task of working-memory capacity. Participants completed one practice block and two experimental blocks of 20 trials each. Participants were presented with words one at time and asked to click one button if the word on screen was the same as the word presented *n* (i.e., two or three) trials before, and to click a different button if it was not. Words appeared for 1000 ms each. A fixation cross appeared between stimuli for between 1 and 5 s. The final score is the percentage of correct responses.

**Internal shift task (IST).** In the IST (Beckwé, Deroost, Koster, De Lissnyder, & De Raedt, 2014), participants complete two versions of a test that measures set-shifting and updating, components of attentional control. In one version, instructions were to keep a mental count of the respective number of negative words and neutral words shown on the screen. In the other version, instructions were to keep a mental count of whether words were nouns or adjectives. The same stimuli were used in both versions, and the order of the versions was counterbalanced across participants with a break in between. For both versions, participants completed two practice blocks and nine experimental blocks. Following a 500-ms fixation cross, 10–15 words were presented one at a time (exact number varied across blocks to ensure that individuals could not infer the number of words in the categories by means of subtraction). Participants advanced the screen to the next word by pushing a designated button. This indicated that they had mentally categorized the word and updated their count appropriately. At the end of each block, participants reported their counts. The reaction times (RTs) for all screen advancements were recorded and coded. A switch sequence was a button press when the participant switched from one word category to the other (e.g., "angry" to "garden"). A nonswitch sequence was a button press when the participant saw the same category twice in a row (e.g., "angry" to "anxious"). Switch costs were calculated by subtracting median RTs (to avoid outliers) of nonswitch sequences from switch sequences (Garavan, 1998; Monsell, 1996). Switch costs can be computed for each version alone and for the two versions collapsed together. Higher switch costs reflect reduced attentional control, or more difficulty moving between categories than within categories. Higher accuracy indicates greater capacity for updating items being held in working memory.

**Stressor.** Participants were then led through two stressful tasks, the first of which was embedded at the end of the cognitive tasks. Participants were instructed to solve as many verbal puzzles as possible (e.g., anagrams, word completions). Participants were given limited time to complete each item and 30% of puzzles were not solvable. Participants then completed a serial subtraction task for 2 min in front of the experimenter who indicated when a participant had made an error, but provided no other feedback. After the stressor tasks, participants sat alone quietly for 5 min. This delay was meant to enable, without compelling, rumination about the stressful experience.

Participants completed a final online survey lasting approximately 10 min. They first completed a modified six-item version of State Rumination Questionnaire (SRQ; LeMoult, Arditte, D'Avanzato, & Joormann, 2013) regarding negative perseverative thinking during the previous 5 min and repeated ratings of their emotional experience approximately 5 and 15 min poststressor. In the SRQ, participants rated how much they had been thinking about their performance, how negative and positive their thoughts were, how much they had been criticizing themselves, how much they thought about their negative emotional experience, and to what extent they replayed parts of what happened in their mind. This measure demonstrated good internal consistency, Cronbach's $\alpha = .82$. Participants also watched a brief (1 min) montage of neutral and amusing animal videos before leaving, intended to facilitate emotional recovery.

## Statistical Analysis

The study employed a mixed-effects design. Sample size was based on power analysis (*F* test, repeated measures, within–between interaction) with $\alpha < .05$, power = .95, and suitable for detecting a medium Cohen's *f* effect size of .25. Acute-activity condition (rest, stretch, or cycling) served as a within-subjects factor and fitness level ($VO_2max$) served as a fixed between-subjects factor. Independent sample *t* tests and one-way analyses

[2] Maximum heart rate (MHR) was estimated with the following, commonly used formula. MHR = 208 – (0.7 × Age).

[3] Time between completing the assigned activity and beginning the cognitive tasks was statistically unrelated to emotional response to the later stressor and estimated fitness value. This was true controlling for activity condition.

of variance were conducted to assess whether gender, race, ethnicity, or education level differed by fitness level, and bivariate regressions to assess differences in age, trait rumination, depressive, anxious, and stress-related symptoms, and baseline measures of state emotional experience by fitness level. To explore how physical fitness and acute exercise related to rumination and subjective emotional recovery following the stressor, multivariate regression analyses were conducted using $VO_2$max and acute-activity condition as unique predictors and interaction terms, and state rumination and emotional ratings as criterion variables. In addition, given that previous acute exercise may moderate the effect of poor emotion regulation on subjective emotional recovery, rather than directly altering use of regulatory strategies, a model was included with a Condition × State Rumination interaction term and emotion ratings following the stressor as the criterion variable. To analyze how physical fitness and acute exercise relate to attentional control, multivariate regression analyses were run with attentional control indices as criterion variables. Multivariate models were then conducted including attentional control indices as predictors of emotion ratings and emotion regulation. In the event of positive results, mediation effects would be explored. All models included visit number as a covariate to control for learning effects. The Benjamini-Hochberg procedure for multiple comparisons was applied to control the false discovery rate, which was set to .05 (Benjamini & Hochberg, 1995).

## Results

Baseline characteristics of the sample are presented in Table 1. Participants varied in fitness level, with estimated $VO_2$max values ranging from 14.42 to 61.0, $M = 43.12$, $SD = 8.71$. Consistent with the literature, estimated fitness level significantly differed by gender, with men, $M = 47.77$, $SD = 7.83$, on average having higher estimated $VO_2$max than women, $M = 39.75$, $SD = 7.76$, $t(93) = 4.95$, $p < .001$. Older participants tended to have lower fitness as well, though this effect was neither large nor unexpected, $F(1, 90) = 4.65$, $p = .033$, $B = -.43$. Prior to testing, estimated $VO_2$max did not vary by ethnicity, education, ruminative response style, or mood ($ps > .05$). Fitness level did differ by race, $F(3, 91) = 8.65$, $p < .001$. Caucasian, $M = 45.61$, $SD = 6.96$, and Asian/Asian American, $M = 43.69$, $SD = 8.17$, participants were on average more physically fit than African American participants, $M = 33.82$, $SD = 10.25$, and those who identified as multiracial or other, $M = 36.07$, $SD = 10.25$. Reported analyses below were repeated controlling for sex and race, which did not alter results.

Across all visits, neither baseline negative emotion nor baseline positive emotion differed as a function of condition assignment, fitness level, or interactions thereof, all $ps > .05$. Resting heart rate did not differ as a function of condition, $F(2, 175) = 1.89$, $p = .153$, but average heart rate during the activity portion of the study did, $F(2, 173) = 841.89$, $p < .001$. As intended by the manipu-

Table 1
*Demographics and Baseline Characteristics of the Sample*

| Characteristics | Whole-sample *N* (%) | Estimated $VO_2$max mean ± *SD* | *p* value |
|---|---|---|---|
| Gender | | | <.001 |
| Female | 55 (57.89) | 39.82 ± 7.81 | |
| Male | 40 (42.11) | 47.41 ± 7.87 | |
| Race | | | <.001 |
| Caucasian | 57 (60.0) | 45.44 ± 6.90 | |
| Black/African American | 8 (8.42) | 33.82 ± 10.25 | |
| Asian/Asian American | 18 (18.95) | 43.07 ± 7.97 | |
| Multiracial/other | 12 (11.63) | 36.10 ± 10.32 | |
| Ethnicity | | | .827 |
| Hispanic/Latino/Latina | 8 (8.42) | 44.73 ± 5.93 | |
| Not Hispanic/Latino/Latina | 85 (89.47) | 42.76 ± 8.76 | |
| Unreported | 2 (2.11) | 43.60 ± 17.85 | |
| Education | | | .218 |
| Less than high school | 1 (1.05) | 30.98 ± NA | |
| High school/GED | 11 (11.58) | 39.01 ± 11.46 | |
| Some college | 38 (40.0) | 44.95 ± 6.81 | |
| Technical/associates degree | 3 (3.16) | 43.73 ± 10.14 | |
| College diploma | 27 (28.42) | 41.46 ± 8.95 | |
| Graduate/professional degree | 15 (15.79) | 44.08 ± 9.37 | |
| **Measures** | **Whole-sample mean ± *SD* (range)** | **Estimated $VO_2$max *B*** | ***p* value** |
| Age | 23.96 ± 4.40 (18.0–36.0) | −.43 | .033 |
| RRS | 43.19 ± 13.19 (22.0–85.0) | −.005 | .946 |
| DASS-Depression | 20.04 ± 6.98 (14.0–50.0) | .07 | .579 |
| DASS-Anxiety | 18.00 ± 5.28 (14.0–44.0) | .09 | .583 |
| DASS-Stress | 22.69 ± 7.44 (14.0–56.0) | −.02 | .856 |
| $VO_2$Max | 43.12 ± 8.71 (14.42–61.0) | NA | NA |
| BMI | 24.35 ± 4.78 (16.32–41.88) | −1.15 | <.001 |

*Note.* *p* values were derived from *t* tests and one-way ANOVAs for categorical variables and bivariate regressions for continuous variables. In all cases, maximal oxygen consumption ($VO_2$max; ml/kg/min) was entered as the criterion variable. RRS = Responses Subscale of the Response Style Questionnaire; DASS = Depression Anxiety Stress Scales; BMI = body-mass index (kg/$m^2$).

lation, participants experienced significantly greater average heart rate when they were in the cycling condition than both resting, $B = -53.65$, $p < .001$, and stretching, $B = -51.92$, $p < .001$. Although negative emotion ratings improved from baseline to postactivity, $t(271) = 8.64$, $p < .001$, this change was not dependent on acute-activity condition, fitness level, or interactions thereof, *p*s > .05.

## Exercise and Emotional Response

As intended with the stress induction, participants reported more negative emotion, $t(270) = 9.40$, $p < .001$, following the stressor than before it. However, there were no main or interactive effects of acute-activity condition or fitness level on these changes, *p*s > .05. Similarly, no main or interactive effects of condition or fitness level on state rumination during the delay period survived correction, *p*s > .05. As expected, state rumination following the stressor predicted more negative emotion after the delay period (approximately 5 min poststressor), $F(1, 173) = 50.96$, $p < .0001$, $B = .38$, and at the close of the session (approximately 15 min poststressor), $F(1, 173) = 11.73$, $p < .001$, $B = .15$. In both cases, significant interaction effects emerged, such that exercising at the beginning of the session moderated the impact of rumination on persistent negative emotion, $F(2, 169) = 7.79$, $p < .001$, $F(2, 169) = 7.98$, $p < .001$. Specifically, high rumination led to less severe and lasting negative emotion ratings 5 min poststressor during cycling visits than during rest visits, $B = .38$, $p < .001$, and stretch visits, $B = .24$, $p = .027$. See Figure 1a. Similarly, at the end of the study, participants were less affected by high rumination at cycling visits than rest visits, $B = .32$, $p < .001$, and stretch visits, $B = .17$, $p = .057$ (see Figure 1b). Results were specific to negative emotion and held after controlling for baseline emotional reports, change in emotional ratings following the activity condition, and fitness level. Fitness level ($VO_2$max) was not significant as a unique predictor or interaction term.

## Exercise and Cognitive Performance

There were no main or interactive effects of acute-activity condition on *n*-back or IST performance, *p*s > .05. Estimated $VO_2$max, regardless of activity condition, emerged as a significant positive predictor of IST performance, both for switch costs (i.e., difference in RTs between switch and nonswitch trials) and accuracy (i.e., updating working memory). Higher estimated $VO_2$max was associated with smaller switch costs, which is suggestive of better set shifting, $F(1, 93) = 4.44$, $p = .038$, $B = -3.26$. This effect was largely driven by trials of the emotion-focused version of the task, $F(1, 93) = 5.84$, $p = .018$, $B = -4.35$. In addition, higher fitness predicted greater accuracy overall, $F(1, 93) = 7.08$, $p = .009$, $B = .006$. This effect was significant when trials were limited to the nonemotion version of the task, $F(1, 93) = 7.63$, $p = .007$, $B = .008$. The effect fell short of significance when trials were limited to the emotion-focused version, $F(1, 93) = 3.67$, $p = .058$, $B = .005$. Findings held when postactivity change in negative emotion ratings was controlled for as well, such that higher estimated $VO_2$max still predicted better set shifting overall, $F(1, 93) = 5.82$, $p = .017$, $B = -3.22$, and in the emotion-focused trials, $F(1, 93) = 7.25$, $p = .008$, $B = -4.28$, and better accuracy

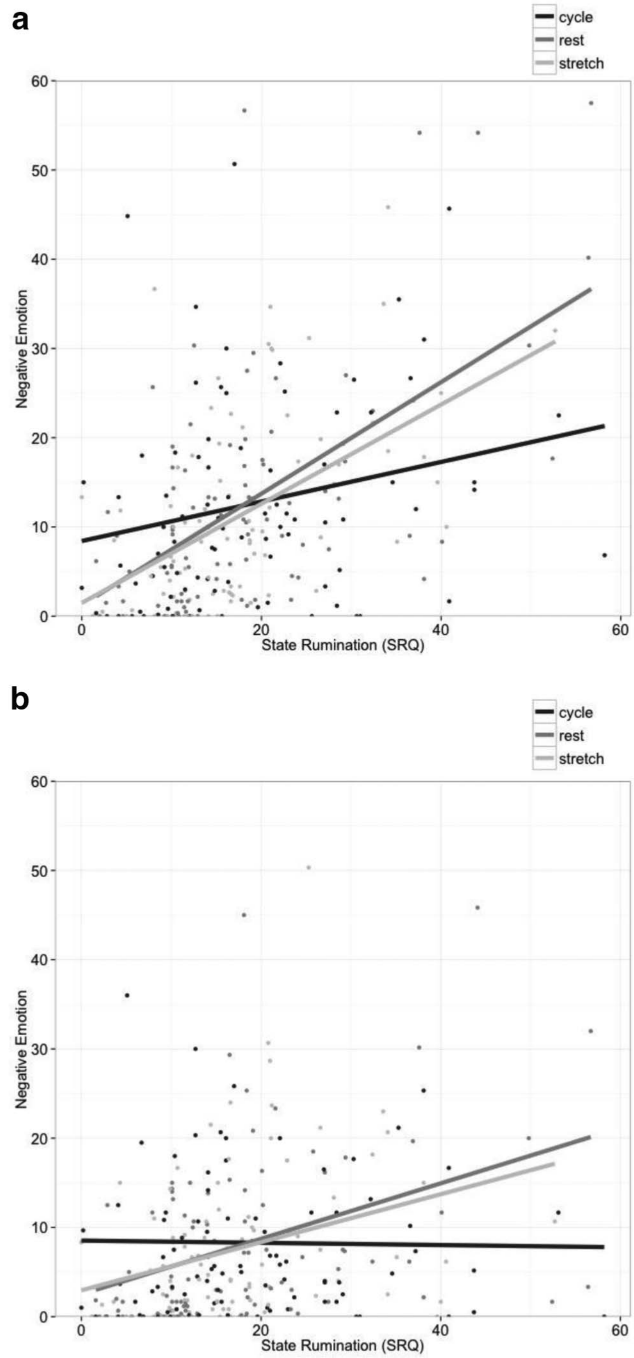


*Figure 1.* (a) Condition by state rumination effects on persistent negative emotion after the stressor. Negative emotion was assessed 5 min following the stressor. (b) Condition by state rumination effects on persistent negative emotion at the end of the session. Negative emotion was assessed at the end of the session following an amusing film clip and approximately 15 min following the stressor. SRQ = State Rumination Questionnaire. Higher SRQ scores indicate more negative perseverative thinking following the stressor and after the session.

overall, $F(1, 93) = 14.47$, $p < .001$, $B = .007$, and in the nonemotion version of the task, $F(1, 93) = 17.02$, $p < .001$, $B = .009$. Here, results for accuracy in the emotion-focused version did reach significance, $F(1, 93) = 6.91$, $p = .009$, $B = .005$.

## Cognitive Performance and Emotional Response

State rumination following the stressor was negatively predicted by working-memory capacity (*n*-back accuracy score), $F(1, 172) = 7.76$, $p = .006$, $B = -7.25$, and accuracy on the IST during nonemotion blocks, $F(1, 168) = 11.83$, $p < .001$, $B = -1.90$. Specifically, better *n*-back scores and better updating on the IST were associated with less negative repetitive thinking. Cognitive predictors of change in negative emotion following the stressor did not survive correction.

# Discussion

Participants who ruminated more following the stressor reported more intense and persistent negative emotions than did participants who ruminated less. However, such lingering negativity was diminished when participants had completed a session of aerobic cycling prior to the stressor. These results suggest that exercise can blunt the subjective emotional impact of a subsequent stressor. Our results parallel findings from a between-subjects experiment showing that an acute session of exercise moderated the effects of anticipated difficulties with emotion regulation on enduring negative emotions (Bernstein & McNally, 2016) and from ecological momentary assessment data showing that the association between stress and reported negative emotions is weakened on days when a person is more physically active than usual (Flueckiger et al., 2016). This effect demonstrates that acute exercise may foster emotional flexibility; appraisals or cognitive response styles that otherwise prolong negative emotional experiences did not do so as strongly following acute exercise.

Such subjective experiences were related to acute aerobic activity, but not fitness level. Although this buffering effect may be specific to acute exercise, subjective emotional appraisals may be especially responsive to acute interventions, thus more easily detectable within an experimental paradigm. More objective measurements, such as psychophysiological or neurological response (e.g., blood pressure, electroencephalogram), may be more sensitive to fitness effects (Dietrich & Sparling, 2004; Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007; Li et al., 2014). Similarly, across an exercise training program, within-person improvements in cognitive–affective as well as fitness domains may emerge. Moreover, the null findings with fitness level may be an artifact of the study design. Most participants were reasonably fit, and participants were not selected on the basis of clinical symptoms. Though roughly one third of participants reported no regular exercise, recruiting for participants interested in a study that involved aerobic activity, average estimated $VO_2$max in the present sample, for both men and women, was higher than the general population and most participants' estimates were at least fair (Heywood, 1998). Accordingly, had there been greater variance on measures of fitness and emotional health, there would have been greater likelihood of detecting additional effects.

Present results show that physical fitness is associated with working memory and task-switching ability with emotional targets; fit participants were more accurate and adept at shifting and updating working memory both when instructions were to focus on the emotionality of the stimuli (i.e., categorizing by valence) and when they were to ignore the emotionality (i.e., categorizing by word class). However, as fitness level was not experimentally manipulated, it is possible that the relationship between physical fitness and attentional control is bidirectional (Daly, McMinn, & Allan, 2015). Interestingly though, one session of moderate exercise was insufficient to improve these performance indices. The overall high fitness level of our sample may have resulted in a ceiling effect, blocking the emergence of acute differences in the absence of a mood induction or cognitive load. In a related way, effects of acute exercise or stronger effects for fitness may have emerged with an older sample for whom there would likely have been a wider range of cognitive performance and thus more room for growth (Prakash et al., 2009; West, Murphy, Armilio, Craik, & Stuss, 2002). Alternatively, the tasks required participants to engage with emotional content, which may require more or different resources than numbers or shapes do (Shafritz, Collins, & Blumberg, 2006). Accordingly, participants may have required a greater boost for any transient changes to emerge.

Still, if attentional control was not a mediating mechanism of the effect of acute exercise, what else could it be? Why were participants high in rumination better able to bounce back following exercise than following rest or stretching? Perhaps, exercise training improves individuals' ability to weather emotional stress through lessened hypothalamus–pituitary–adrenal axis reactivity. For example, one study found that rumination following a stressor increased cortisol production and delayed return to baseline among sedentary participants, but not among physically active participants (Puterman et al., 2011). A related possibility is that exercise-induced bursts of brain-derived neurotrophic factor (BDNF) are protective. Multiple studies have shown that BDNF levels increase following single sessions of moderate to vigorous exercise; on a biological level, BDNF buffers against negative effects of stress, for example by protecting neurons (e.g., hippocampal cells) from excess cortisol (Szuhany, Bugatti, & Otto, 2015). This effect temporally extends beyond the activity, and may leave people subsequently more at ease or perhaps more resilient should they soon encounter a stressor (Szuhany et al., 2015). Future iterations of this paradigm would benefit from including measures of cortisol, psychophysiological stress response, and BDNF production to map such systems onto perceived recovery, acute exercise, and fitness variables. Finally, the effect could have motivational bases as well as neurobiological ones. Having recently completed a session of exercise, individuals may have felt a sense of mastery or increased self-efficacy compared to when they had merely stretched or rested (Asmundson et al., 2013).

Though acute exercise did not improve attentional control performance, variation in some cognitive indices was related to rumination; however, effects were small and not as pervasive as expected. Future studies should explore what other acute interventions may enhance or degrade performance on these measures in real time to establish causality. Results add to the literature postulating that rumination is a function or manifestation of difficulty with attentional control (Koster et al., 2011), indicate accuracy or capacity for updating and shifting as especially relevant abilities, and highlight that other factors in addition to attentional control are importantly involved in driving perseverative thinking. It is possible that larger or clearer findings would emerge in a modified paradigm. Specifically, some research suggests that attentional control ability under stress is a better predictor of clinical outcomes than is ability in neutral situations, as was tested here (Pe, Brose, Gotlib, & Kuppens, 2016; Quinn & Joormann, 2015). In other words, although baseline executive control may be relevant for emotion regulation, the severity of stress-induced declines may more directly relate to impairments in emotional recovery, and exercise could prevent or lessen such declines.

This study has limitations. First, data cannot speak fully to how the exercise session, as compared with stretching and resting, affected participants' stress response beyond the emotion ratings. Examining changes in heart rate and skin conductance during and after the stressor, for example, would be informative complementary data in future research. Relatedly, only nine emotion words were included, which constrained results by excluding other relevant emotions and potentially biasing results, as more negatively valenced words were included than positively valenced words. In addition, this study can only speak to the effects of a brief session of moderate-intensity cycling among young, relatively healthy adults. It is possible that these patterns would not hold across all exercise modalities and intensities and age groups; however, addressing this would require extensive systematic investigation, which was outside of the scope of this project. In addition, the number of trials in each cognitive task was limited, as all tasks had to be completed within the recommended 30-min postactivity window (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009). This constraint could have limited our ability to find all possible behavioral effects. Furthermore, we isolated only one pathway connecting exercise to emotional health, and that was subjective recovery from emotional stressors. Future research would benefit from synthesizing the numerous dynamic and interactive biological and psychological systems touched by exercise.

Overall, results contribute to the young literature on the mechanisms of exercise's therapeutic effects using experimental emotional data, and such findings may ultimately inform clinical efforts for adjunctive or stand-alone interventions. Exercise is accessible, free or inexpensive in many forms, and targets multiple domains of health simultaneously. Specific positive, immediate benefits of physical activity that resonate with people, such as being more capable of bouncing back from stress, may provide better motivation for individuals trying to maintain regular exercise habits than more abstract, long-term benefits like cardiovascular health. Understanding how exercise promotes emotional health acutely and over time will help us develop more targeted methods of improving well-being and motivating healthy behaviors.

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