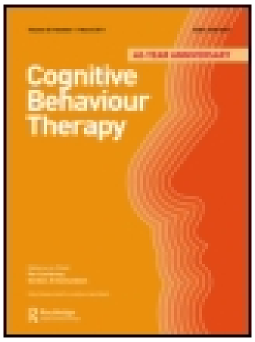

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Working it out: can an acute exercise bout alleviate memory bias, rumination and negative mood?

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ABSTRACT

Although it is well known that exercise reduces depressive symptoms, the underlying psychological mechanisms remain unclear. This experimental study examined the acute effect of exercise on mood, and depressotypic memory bias and state rumination. Trait rumination was tested as a possible moderator. A sample of non-regular exercisers ($N = 100$) was randomized to exercise or rest. After a negative mood induction, the exercise condition cycled for 24 min at moderate intensity, while the rest condition rested. Negative and overgeneral memory bias, as well as positive and negative affect were assessed after exercise/rest. To capture the lingering of negative mood and state rumination, both were assessed multiple times throughout the study. The exercise (as compared to rest) condition reported more positive affect. However, no differences were found on overgeneral memory bias, as well as depression-specific mood or state rumination measured throughout the study. Interestingly, the exercise condition showed more negative memory bias at higher levels of rumination. Individual differences in trait rumination moderated the exercise—memory bias relation, such that exercise increased negative memory bias at higher levels of rumination. It is possible that long-term exercise protocols are necessary to change cognitive processes related to depression.

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Exercise; memory bias; mood; overgeneral memory; rumination

Introduction

Multiple meta-analyses demonstrate the effectiveness of moderate-intensity aerobic exercise for depression (e.g. Krogh et al., 2017; Morres et al., 2019). Nonetheless, it remains unclear how exercise produces these clinical effects (Medina et al., 2015). Knowing the underlying psychological mechanisms may facilitate the goal to apply

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exercise as targeted intervention. A recent review reports that exercise yields improvements in self-esteem, social support, and self-efficacy but also that results are preliminary and more research needed (Kandola et al., 2019). Strikingly, well-studied cognitive psychological mechanisms of other evidence-based treatments for depression are not studied in the light of exercise effectiveness. For example, negative cognitive biases and rumination are mechanisms of common depression treatments including antidepressant medication, Cognitive Behavioral Therapy, and Mindfulness-Based Cognitive Therapy (e.g. Harmer et al., 2009; Powers et al., 2017; Svendsen et al., 2017).

Cognitive biases exist in different cognitive domains, with the strongest evidence for a *negative memory* bias in depression (e.g. Marchetti, Everaert, et al., 2018). A negative memory bias refers to the tendency to recall negative as opposed to positive material (e.g. LeMoult & Gotlib, 2019). Besides the overall negative tone in recollections, these autobiographic memories tend to be *overly general* (Gotlib & Joormann, 2010). Previous research has shown the neuroplasticity-enhancing effects of exercise, that may alter mood and memory biases (Kandola et al., 2019). Specifically, serum-levels of brain-derived neurotrophic factor (BDNF) seem to elevate reliably during both bouts of acute and regular exercise (Szuhany et al., 2015). BDNF is a protein that stimulates neuroplasticity in brain regions like the hippocampus that is critically involved in memory and emotional processing (Kandola et al., 2016). Therefore, it seems possible that exercise improves negative and overgeneral memory bias, which in turn may act as the mechanism of change of exercise for improving mood.

Importantly, memory bias can be aggravated by rumination (e.g. Hertel et al., 2014). Rumination is defined as the process of recurring negative thoughts (Nolen-Hoeksema et al., 2008). As the recurrence of information facilitates future recall (Roediger & Butler, 2011), rumination can strengthen a negative memory bias (Hertel et al., 2014). Moreover, rumination may also interfere with the recall of details, which can lead to generic memories (e.g. Sutherland & Bryant, 2007). Considering that rumination can lead to memory bias, and memory bias is supposed to be depleted through exercise, this effect may partly depend on rumination. Previous research indeed indicates that rumination may be both a mechanism and moderator of the clinically-relevant effects of exercise. To illustrate, Bernstein and McNally (2017a, 2017b) showed that even one bout of exercise prior to a stressor buffered negative mood effects in people with dysfunctional emotion regulation including rumination. They suggested that exercise must have reduced rumination which would otherwise prolong negative affect. However, they did not find that exercise improved attentional control which is necessary to diminish rumination and suggest that this null finding is due to the high fitness level of their sample (Bernstein & McNally, 2017a).

The present study aimed to extend previous research in two ways. First, we assessed the direct effect of exercise on mood, memory bias and state rumination, examining their relevance as possible mechanisms of exercise treatment. Second, we tested whether individual differences in trait rumination moderated the effects of exercise on mood and memory bias. Following experimental approach recommendations (cf. Kazdin, 2007), non-regular exercisers received a negative mood induction and subsequently, cycled at moderate intensity or rested for 24 minutes. Afterwards, negative and overgeneral memory biases were assessed. We hypothesized that the exercise condition would report less negative mood/more positive mood, less state rumination and negative and overgeneral memory bias, as compared to the rest condition. Secondly, we expected that trait rumination would moderate the effects of exercise on mood, memory bias and state rumination, such that effects would be greater among those exhibiting higher relative to those exhibiting lower trait rumination.

Method

Participants

We based our power calculation in G*Power (Faul et al., 2007) on a large to medium effect size, similar to the antidepressant effect of exercise (e.g. Morres et al., 2019). Based on a one-tailored test, an expected medium effect size $d = 0.5$, power of .80 and an alpha of .05, power analysis indicated a sample size of $N = 102$ to detect an effect on our main outcome, negative memory bias. A sample of $N = 100$ participants was eventually included and randomized across two conditions: $N = 50$ to exercise and $N = 50$ to the rest condition. The randomization list was created based on a random number generator before the start of the study and monitored by hand. Upon informed consent completion, each participant was randomized based on the list in the order they entered the study. Participants were recruited via the Radboud University's research participant system. Most of our participants (58%) were students who received study credits for participation. The participant system is however accessible to community members in return for financial compensation. Compensation is based on time investment, where 1 hour equals 1 ECT (i.e. 30 credit hours) or 10€. The experiment lasted approximately two hours.

Participants who reported engaging in exercise no more than once a week and denied any conditions that would make engaging in exercise unsafe (i.e. all answers "no" on the Physical Activity Readiness Questionnaire (PAR-Q; Adams, 1999)) were eligible for participation. Other baseline characteristics are presented in Table 1. This study was approved by the Radboud University's Social Sciences ethics committee and carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki. The study was preregistered at AsPredicted ("MEM_Ex, #18135)".

Table 1. Condition comparisons on demographic variables and baseline questionnaires ($N = 93$).

	Exercise		Rest		
	M	SD	M	SD	Statistics
Age	24.52	9.25	25.82	8.41	$t(87) = -0.70$, $p = .48$
Gender (% female)	72		68		χ^2 (1) = 0.12, $p = .73$
Body Mass Index	22.32	2.79	23.31	3.34	$t(91) = -1.55$, $p = .13$
Physical activity classification (IPAQ categories, %)					
Low	7		2		
Medium	54		53		
High	40		45		
Memory capacity	9.68	2.73	9.69	2.76	$t(90) = -.02$, $p = .98$
Depressive symptoms	8.02	7.95	9.88	7.48	$t(88) = -1.16$, $p = .25$
Trait rumination	40.86	12.34	43.59	11.85	$t(89) = -1.08$, $p = .28$
Positive mood (rat.)	6.73	1.83	6.76	1.51	$t(84) = -0.08$, $p = .94$
Negative mood (rat.)	1.93	1.44	2.08	1.43	$t(90) = -0.50$, $p = .62$

IPAQ refers to International Physical Activity Questionnaire classification, memory capacity refers to the '15 woorden test B' (15 words test) total recall score, depressive symptoms refer to Beck Depression Inventory (BDI-II) total score, trait rumination refers to the Ruminative Response Scale (RRS) total score, positive and negative mood are derived from the mood ratings at baseline.

Conforming to Bernstein and McNally (2017a, 2017b), we later added rumination as possible mediator and moderator.

Procedure

Figure 1 depicts an overview of the procedures. After providing informed consent, participants were randomized. They first completed baseline questionnaires and then received a mood induction to activate negative mood and ruminative thinking (Westermann et al., 1996). For this purpose, they watched a negative film segment (7:27 min) from the movie "Sophie's choice" which has previously been shown to induce a negative mood state (Isaac et al., 2012; Vissers et al., 2010; Vrijsen et al., 2014). Moreover, they were instructed to let the emotionality of the film influence their mood as much as possible and to maintain the sad mood state. After the mood induction, participants either exercised or rested for 24 min. Finally, they conducted the memory bias tasks and the post-assessment. Afterwards, participants could take a shower and were debriefed about the purpose of the study.

Intervention: exercise vs rest

Participants wore a Polar band to measure heart rate. The exercise condition consisted of 2 min of slow-cycling at 10–15 km/hour, 20 minutes of cycling at moderate intensity (i.e. 70–75% of age-predicted max heart rate (HR_{max}); cf. intensity recommendations by Stanton and Reaburn (2014)), and 2 min cooldown (cycling at 10 km/hour). The research assistant monitored the HR_{max} and provided feedback to keep the HR_{max} at moderate intensity. In the rest condition, participants sat stationary on the home trainer for 24 minutes.

Measures

Sample characteristics

To test for baseline differences between conditions, participants provided information on their height in meters, weight in kilograms, age in years, and gender identification via an online platform. The level of physical activity was assessed using the International Physical Activity Questionnaire (IPAQ; Hagströmer et al., 2006). Conform manual,[1]

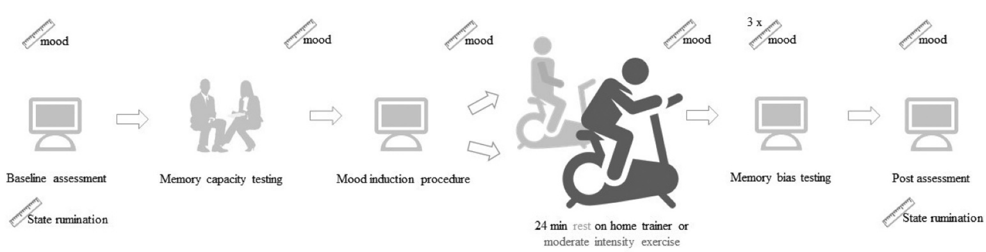

Figure 1. Study procedure. *Note. Mood ratings were assessed using Likert scales, ranging from 1 (not at all) to 9 (very much), administered at baseline (T0), before (T1) and after (T2) the negative mood induction procedure, directly after exercise or rest (T3), after the encoding phase of the SRET (T4), after the distraction (T5), after the recall phase of the SRET (T6), after AMT at the end of the study (T7).*

participants were classified as reporting low, medium or high levels of physical activity. In addition, participants completed the 21-item Beck Depression Inventory-second edition (BDI-II-; Beck et al., 1996), measuring the level of depressive symptoms. Cronbach's alpha was .89 for the BDI-II, indicating high internal consistency.

To compare the two conditions on memory capacity excluding this as a possible confounding factor, the '15 woorden test B' (15 words test; Saan & Deelman, 1986) was used, a memory capacity test for abstract words. In the learning phase, the experimenter read a list of words and the participants had to repeat all the words they remembered. This was repeated five times. After a 15–20 min distraction—during which the V800 Polar band[2] was installed to monitor HR—delayed free recall was tested. Total recall was used as outcome.

Memory bias

To measure negative memory bias, the computerized Self-Referent Encoding Task (SRET; Derry & Kuiper, 1981) was used, which assesses specific explicit verbal memory bias for positive and negative stimuli. Twenty-four Dutch adjectives were selected from the Dutch translation of the Affective Norms for English Words (ANEW; Bradley & Lang, 1999); half were positive and half negative in valence.[3] Words were presented sequentially in fixed random order and had to be rated as self-descriptive or not by pressing either of two keys on the keyboard. After a two min distraction, the participants were given three min to type in all the words they remembered from the previous task. Spelling errors were permitted. The negative memory bias index was calculated by dividing the number of correctly recalled negative words endorsed as self-descriptive by the total number of endorsed and recalled words (cf. Gotlib et al., 2004). The first two and last two words were not included in the test results to reduce primacy and recency effects on the memory bias index.

To assess overgeneral memory, an online version of the autobiographical memory test (AMT: Williams & Broadbent, 1986) was used. Participants were instructed to type in a specific memory for each of ten cue words (five positive and five negative words; presented subsequently 60-s each on the computer screen). Two practice words were presented before the test phase started. The memory needed to be specific and happened once on a particular day. After examples of specific and non-specific responses were given, a practice trial with three cue words with feedback had taken place. Then the test phase started. Two raters coded each response independently as either specific or nonspecific. The interrater reliability was excellent (100%, $k = 1$). The dependent variable was the number of specific responses.

Affect

The 20-item Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) was used to assess positive and negative affective states at the end of the study. Cronbach's alpha was .86 and .85 for the positive and negative scale respectively.

Mood

Positive and negative mood were assessed eight times throughout the study (Figure 1) using Likert scales, ranging from 1 (not at all) to 9 (very much). Participants were asked one question to assess negative mood: "How negative, sad or bad do you feel at the moment?" and one question to assess positive mood: "How positive, happy or good do you feel at the moment?". A single-item rating of mood state has previously been shown to be a valid method (Verster et al., 2021) and is commonly used in experimental studies (e.g. Vrijsen et al., 2018). These ratings were assessed multiple times to capture and eventually control for the effect of the mood induction, as well as the effect of exercise compared to rest at different time intervals (cf. Reed & Ones, 2006).

Rumination

To measure trait rumination, the Dutch version of the 26-item Ruminative Response Scale (RRS; Nolen-Hoeksema & Morrow, 1991) was assessed during baseline, which was our proposed moderator. The scale had high internal consistency, with Cronbach's alpha .93. To measure state rumination, the Momentary Ruminative self-focus Inventory (MRSI; Mor et al., 2013; later Brief State Rumination Inventory (BSRI); Marchetti et al., 2018) was assessed at baseline and during the post-assessment. The MRSI showed high internal consistency as well, with Cronbach's alpha .81 at baseline.

Statistical approach

All analyses were performed in R V4.1.2 (R Core Team, 2021) and Rstudio V1.4.1717. To examine whether the conditions differed at baseline, independent samples *t*-tests and chi-square tests were conducted (Table 1). For seven participants, the negative memory bias index (cf. Gotlib et al., 2004) was missing, due to them not endorsing and subsequently recalling any positive or negative words. Hence, we performed all analyses on $N = 93$.[4] First, using generalized linear mixed models, we tested whether the conditions differed on negative/positive mood throughout the study, with the goal to assess the mood-repair effect after the mood induction. Condition and Rumination represented between-subjects effect, and Time the within-subjects effect. Additionally, conditions and the condition-by-trait rumination interaction were regressed on PANAS affect measure at the end of the study using generalized/linear models. The effect of exercise (compared to rest) as well as the condition-by-trait rumination interaction on memory bias and state rumination were tested using generalized/linear (mixed) models, depending on the distribution of the outcome variables (see supplementary material).

Analyses were performed using the *lme4* package (Bates et al., 2015). Trait rumination was standardized in all analyses. Sum of squares were estimated using the type III approach, in line with the aim of investigating trait rumination as moderator. The statistical level of significance was set at 5% ($p < .05$). Interaction effects were estimated as sum contrasts. We report eta-squared as an effect size for the LM and the odds ratio for the GLM containing memory bias as dependent variable.[5] To disintegrate significant interaction effects, we computed pairwise comparisons of the estimated marginal means (EMMs), using the *emmeans* R package (Russell, 2021). We followed the approach of Allaert et al. (2021) and calculated the EMMs at different levels of trait rumination (M − 1 SD [lower], M [moderate], M + 1 SD [higher]), to preserve the continuous measurement scale of the RRS. To correct for multiple comparisons, the false discovery correction method was used (Benjamini, 2010).

Results

Exercise condition comparison and trait rumination-by-condition interaction on mood

For negative mood, the GLM indicated a significant effect of time $\chi^2(7) = 271.85$, $p < .001$. However, neither the main effect of condition, $\chi^2(1) = 0.23$, $p = .63$, or the condition-by-time interaction, $\chi^2(7) = 6.81$, $p = .45$, nor the trait rumination-by-condition-by-time interaction, $\chi^2(7) = 7.55$, $p = .37$, were significant, indicating that negative mood throughout the study was not different across conditions and independent of the level of trait rumination. For positive mood, the GLM indicated similar results. The main effect of time was significant, $\chi^2(7) = 272.49$, $p < .001$, as well as the main effect of trait rumination, $\chi^2(1) = 11.31$, $p < .001$. Neither the main effect of condition, $\chi^2(7) = 1.68$, $p = .20$, nor the condition-by-time interaction, $\chi^2(7) = 12.48$, $p = .09$, or the trait rumination-by-condition-by-time interaction, $\chi^2(7) = 9.48$, $p = .22$, were significant.

To verify that the mood induction resulted in a negative mood state, we computed the EMMs in both conditions at pre and post mood induction as follow-up. As intended, both conditions significantly increased in negative mood and decreased in positive mood, all $p < .001$.

Exercise condition comparison and trait rumination-by-condition interaction on affect

Moreover, positive and negative affect were assessed with the PANAS. For positive affect, the LM indicated a significant effect of condition, $F(1,89) = 5.25$, $p = .02$, $\eta^2 = .06$, ($M_{\text{exercise}} = 30.18$; $M_{\text{rest}} = 26.69$), where the exercise condition reported more positive affect than the rest condition. Neither the main effect of trait rumination, $F(1,89) = 0.04$, $p = .84$, $\eta^2 = .00$, nor the trait rumination-by-condition interaction, $F(1,89) = 0.07$, $p = .79$, $\eta^2 = .00$, were significant. For negative affect, a GLM was performed. Only the main effect of trait rumination was significant, $\chi^2(1) = 7.92$, $p = .00$, with condition $\chi^2(1) = 0.07$, $p = .79$, and the trait rumination-by-condition interaction $\chi^2(1) = 0.84$, $p = .36$.

Exercise condition comparison and trait rumination-by-condition interaction on memory bias

For negative memory bias, the GLM indicated no significant main effect of condition, $\chi^2(1) = 0.04$, $p = .85$, $OR = 0.97$. However, the main effect of trait rumination was significant $\chi^2(1) = 6.18$, $p = .02$, $OR = 1.48$, as well as the trait rumination-by-condition interaction, $\chi^2(1) = 5.58$, $p = .02$, $OR = 1.43$, which means that the odds participants from the exercise condition experienced more negative memory bias dependent on the level of rumination were greater by a factor of 1.43 than the odds of participants in the rest condition. Follow-up pairwise comparisons of the EMMs, showed no significant group differences at lower $b = 0.45$, $SE = 0.26$, $z = -1.38$, $p = .17$, $OR = 0.42$, or moderate levels of trait rumination, $b = 0.93$, $SE = 0.34$, $z = -0.19$, $p = .85$, $OR = 0.92$. At higher rumination levels, we found a non-significant trend, $b = 1.92$, $SE = 0.72$, $z = 1.74$, $p = .08$ (see Figure 2) and $OR = 2.22$, which might indicate that participants from the exercise condition are twice as likely to experience more negative memory bias at higher levels of rumination compared to rest.

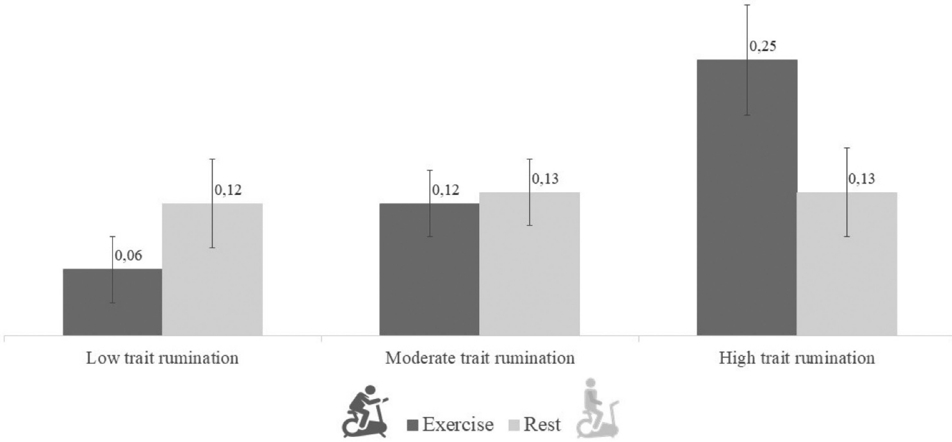

Figure 2. Estimated marginal means of negative memory bias (SRET) per group at different levels of trait rumination. *Note*. The estimated marginal means of memory bias were calculated at different levels of trait rumination, which was measured with the RRS; lower RRS(*M*− 1 *SD*), moderate RRS (M) and higher RRS (*M*+ 1 *SD*). Higher scores indicate more memory bias. The error bars represent the standard error.

In addition, the correlation between trait rumination and memory bias across all participants was significant within the exercise condition, $r = .51$, $t(42) = 3.87$, $p < .001$, indicating the higher the level of trait rumination, the stronger the negative memory bias following exercise. The correlation was not significant within the rest condition, $r = .02$, $t(47) = 0.14$, $p = .89$.

For overgeneral memory, the LM indicated no significant main effect of condition $F(1,89) = 0.69$, $p = .49$, $\eta^2 = .00$, or trait rumination $F(1,89) = -0.42$, $p = .68$, $\eta^2 = .00$, or trait rumination-by-condition interaction, $F(1,89) = 0.65$, $p = .42$, $\eta^2 = .00$.

Exercise trait rumination-by-condition interaction on state rumination

The GLMM showed no significant condition-by-time interaction, $\chi^2(1) = 1.98$, $p = .16$, or trait rumination-by-condition-by-time interaction, $\chi^2(1) = 2.01$, $p = .16$, indicating that there was no effect of exercise on state rumination. In addition, no other effect on state rumination reached statistical significance (i.e. main effects of time, condition and trait rumination, interactions time-by-trait rumination, condition-by-trait rumination), all p-values > .05.

Discussion

This experimental study examined the direct effect of exercise on mood, memory bias and state rumination, to increase understanding of the psychological mechanisms of exercise treatment. In line with previous findings (Bernstein & McNally, 2017a, 2017b), we included trait rumination as moderator. We found that the exercise condition reported more positive affect than the rest condition. No differences were found in negative affect, nor in the mood ratings that were collected throughout the study. In addition, no group differences appeared in overgeneral memory or state rumination. Contrary to our expectation, negative memory bias was stronger in the exercise compared to rest condition, most pronounced at higher levels of rumination. To summarize, an exercise bout yielded more positive affect, but surprisingly also more negative memory bias at higher levels of trait rumination.

More positive affect after exercise is in line with previous research. Exercise causes the immediate release of neurotransmitters that produce a positive mood state (Basso & Suzuki, 2017). Surprisingly, we did not find a difference in negative affect, nor a difference in mood repair based on the mood ratings. The mood ratings require participants to indicate how positive/negative their mood is in general and represent a measure of depression-specific mood. The PANAS on the other hand assesses positive/negative affect, i.e. participants rate how strongly they feel emotions like excitement, alertness or enthusiasm. Finding only a difference in positive affect is in line with previous research that showed that exercise increases high-arousal positive emotions (Hogan et al., 2013). Yet, it is possible that a single exercise bout does not alter mood in general.

Interestingly, the present study also indicates that one exercise bout results in more negative memory bias dependent on the level of rumination (i.e. the odds participants from the exercise condition experienced more negative memory bias dependent on the level of rumination were greater by a factor of 1.43 than the odds of participants in the rest condition). Exercise directly affects the activity in the prefrontal cortex (e.g. Yanagisawa et al., 2010), which is the brain area associated with higher-order cognitions including rumination (Cooney et al., 2010). It is possible that people who are habitual ruminators may ruminate more through an exercise bout, which leads to more focus on negative material and can enhance a negative memory bias. However, this may only be true for people who infrequently exercise, just like the current sample. To experience an antidepressant effect, these people may require a prolonged exercise regimen to sustainably increase prefrontal downregulation over the limbic system. Previous research showed that a prolonged exercise program diminishes rumination (Craft, 2005). Taken together, it seems plausible that—when individuals infrequently exercise, just like the current sample—one exercise bout increases positive affect, but that regular exercise may be needed to decrease rumination and negative memory bias. This may in turn alleviate depressive symptoms over time. Whether rumination and memory bias are in fact mechanisms of change in an exercise treatment protocol for depression should be further examined.

The absence of an increase in state rumination after exercise speaks against the hypothesis put forward in the previous paragraph. The design of the present study may account for this null finding. Specifically, state rumination was assessed at baseline and at the end of the study, right after completing the computer tasks (see Figure 1). State rumination may have declined back to baseline levels during these assessments; we often see that executing computer tasks and especially reporting on depressotypic aspects affects upon mood (e.g. Vrijsen et al., 2016) and perhaps also rumination.

Moreover, we did not find a difference between conditions in overgeneral memory. Previous research showed that an experimental mood induction causes a negative mood but does not necessarily affect overgeneral memory (Haringsma et al., 2010). If overgeneral memory cannot be induced in healthy populations, this would explain why the present study did not find a difference between conditions. Future studies should therefore assess overgeneral memory bias after exercise in clinical populations.

This study has some additional limitations. The laboratory setting is necessary to exert control over the context, but it also degrades the ecological validity. Future research should examine the effects of exercise on mood, rumination and memory bias in daily life. Further, exercising in the lab and receiving feedback on the exercise intensity could have been experienced as unpleasant. Similarly, the rest control condition could have been experienced as boring and unstimulating. Other control conditions, such as low-intensity aerobic exercise or stretching, should be considered in future studies and will also inform about the stability of the current findings. Finally, our sample consisted of relatively young, mostly female, healthy adults, with an infrequent exercise routine, which limits the generalizability of the results to male, older, more active and less healthy samples. Future studies should examine the effects of an acute exercise bout on depressive cognitions in community and clinical samples, to examine the broader (clinical) relevance of the present results.

In conclusion, the present study showed that one exercise bout boosts positive affect, but also results in more negative memory bias at higher levels of trait rumination. Our findings imply that a single bout of exercise is not sufficient to relieve memory bias or rumination, rather it may even aggravate these depressotypic cognitive processes in some individuals. These results may help us understand why around 20% of depressed patients drop out of exercise interventions (Stubbs et al., 2016), even though they experience an immediate mood boost (e.g. Reed & Ones, 2006). If future research can determine how long exercise is needed to improve depressotypic cognitions, this would help patients to stay motivated during exercise treatment and improve the match between patient characteristics and treatment.

Notes

1. For more information on IPAQ see, https://sites.google.com/site/theipaq/scoring-protocol.
2. For more information on Polar see, www.polar.com.
3. Adjectives have previously been validated. See supplementary material.
4. Results remain the same when including all participants in the analyses of overgeneral memory bias, state rumination, mood and affect.
5. No effect size for mixed models is reported given the lack of consensus (cf. Feingold, 2009).

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Disclosure statement

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Data availability statement

The data that support the findings of this study are openly available in the Radboud University Data Repository at https://doi.org/10.34973/rkaz-vt23, reference number: ept_2023_ms_student_exercise_memorybias.

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