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RESEARCH

Effects of Acute High-Intensity Aerobic Exercise on Cognition: the Potential Roles of Motivation and Perceived Energy Levels

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Abstract

High-intensity exercise is theoretically proposed to enhance hippocampal-related cognition and impair prefrontal cortex (PFC)-related cognition when assessed immediately following exercise. However, empirical evidence has not consistently supported these effects. This study was designed to address this discrepancy between theoretical predictions and empirical findings while accounting for the potential influences of psychological factors (i.e., motivation, perceived energy availability, and perceived energy cost) on cognitive outcomes (i.e., n-back and mnemonic similarity tasks) immediately following high-intensity exercise. Fifty-five young healthy adults participated in a within-subject experiment comprising four separate visits. Each visit involved a 20-minute session of either high-intensity exercise or standing on a treadmill (no exercise), followed by tasks assessing either PFC- or hippocampal-related cognition. Subsequently, a 20-minute delayed cognitive assessment for the same cognitive domain was conducted to evaluate both immediate and delayed cognitive performance. Assessments of each psychological construct were conducted after the exercise/rest condition and before the initial cognitive task. Results indicated that acute high-intensity exercise did not significantly influence performance on either PFC- or hippocampal-related cognitive task. However, additional analyses revealed that higher task-related motivation was positively associated with PFC-related performance immediately following exercise. Although participants reported greater perceived mental energy after exercise than rest, this change was not accompanied by cognitive improvements. These findings suggest that psychological factors, particularly state motivation, may play a limited yet meaningful role in shaping cognitive responses to acute high-intensity exercise.

Keywords Executive function · Episodic memory · Psychological mechanism

Introduction

The prefrontal cortex (PFC) is essential for coordinating higher-order cognitive functions, such as working memory, decision-making, and inhibitory control, all of which are fundamental to goal-directed behavior (Friedman & Robbins, 2022). In particular, the dorsolateral PFC plays a significant role in working memory processes that underpin many executive functions (Spencer et al., 2015). The hippocampus, located in the medial temporal lobe, is primarily

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responsible for episodic memory (i.e., the ability to recall personal experiences and specific events) as well as spatial navigation and contextual learning (Burgess et al., 2002). While both the PFC and hippocampus contribute uniquely to cognitive processing, their roles are not entirely distinct. For instance, strategies mediated by the PFC can facilitate encoding and retrieval by organizing information and guiding attentional resources (Simons & Spiers, 2003). Likewise, hippocampal-related memory formation is particularly critical for consolidation and free retrieval processes, especially over short delay intervals (Yonelinas et al., 2024). Moreover, the interaction between these regions is particularly relevant for episodic memory, as PFC-mediated executive strategies can enhance hippocampal encoding and retrieval efficiency (Blumenfeld & Ranganath, 2007). Given these interdependencies, understanding how acute physiological challenges, such as high-intensity exercise, simultaneously influence these regions remains an area of limited exploration. Only a few studies have examined both PFC- and hippocampal-related cognition within the same experimental framework, particularly working memory and episodic memory performance following acute high-intensity exercise (Basso et al., 2015).

Acute aerobic exercise has been shown to enhance cognition through mechanisms such as increased cerebral blood flow, neurogenesis, and the release of neurotrophic factors (Moore et al., 2022). However, this effect may depend on the intensity and timing of exercise, as well as the type of cognitive task involved (Chang et al., 2012; Jung et al., 2022; Loprinzi, 2018). Chang et al. (2012), for example, found that exercise intensity was only a significant moderator when cognition was tested post-exercise, underscoring the importance of the assessment of timing (i.e., cognitive task assessment in reference to when the exercise bout occurs) in understanding intensity-related effects. Most prior studies provide empirical support that acute moderate-intensity exercise generally enhances working memory, when assessments are conducted shortly after exercise (Ospina & Cadavid-Ruiz, 2024). In contrast, acute high-intensity exercise is linked to temporary impairments in PFC-related cognition, especially when tasks are performed during or immediately after exercise (Jung et al., 2024). These impairments are often most pronounced within the first five minutes following exercise, suggesting that PFC-related cognition may be more susceptible to the neurochemical shifts induced by high-intensity exercise (Coco et al., 2020; Hill et al., 2019; Zimmer et al., 2017). Within the framework of the catecholamine hypothesis (McMorris, 2021), various modes of stress, including exercise, have been shown in animal studies to alter catecholamine levels (e.g., noradrenaline [NA] and dopamine [DA]) in prefrontal areas (Arnsten, 2009). When exercise intensity exceeds the optimal catecholamine threshold, it leads to an excessive release of these catecholamines. Animal studies suggest that excessive catecholamine release may lead to overactivation of D_1-receptors and β-adrenoceptors, thereby increasing cyclic adenosine monophosphate (cAMP) activity. This heightened cAMP may inhibit PFC function through intracellular signaling mechanisms and ultimately impair PFC-related cognition (Arnsten, 2009).

While impairments in PFC-related cognition in response to acute high-intensity exercise may be immediate and transient, it may enhance hippocampal-related cognition, particularly when performed before the memory encoding phase, with effects that may persist after exercise cessation (Etnier et al., 2016; Loprinzi et al., 2021a, b, 2023). Several studies suggest that the hippocampus is more resilient to neurochemical changes compared to the PFC, due to differences in receptor sensitivities and signaling pathways (El-Sayes et al., 2019; Firth et al., 2018). Specifically, high-intensity exercise enhances nitric oxide signaling and protein kinase G activation, promoting neurotransmitter release in the hippocampus (Arancio et al., 1996). Increased NA levels, primarily originating from the locus coeruleus and projecting to the hippocampus, stimulate β-adrenoceptors, modulating brain-derived neurotrophic factor (BDNF) receptor (i.e., TrkB) signaling and promoting long-term potentiation (Vega et al., 2006). However, the influence of exercise on hippocampal-related cognition is not uniform across different memory stages. Encoding and retrieval may benefit from exercise-related enhancements in arousal and synaptic plasticity, while consolidation processes could be differentially affected by the timing and intensity of exercise (Dal Maso et al., 2018; Lundbye-Jensen et al., 2017). Furthermore, hippocampal-related cognition may follow a time-dependent trajectory after exercise, with enhancements observed primarily in encoding and retrieval processes immediately post-exercise but diminishing over time, particularly for recognition-based memory tasks (Suwabe et al., 2017). This suggests that the neurochemical environment favoring hippocampal activity may be transient, aligning with previous findings that memory performance, especially in recognition and free recall tasks, can decline after a 20-minute delay (Roig et al., 2016). Thus, the phase of memory processing being targeted by exercise is particularly relevant, as the benefits may be prominent during encoding and retrieval but less so for delayed consolidation.

Psychological factors also play a significant role in modulating cognitive outcomes following exercise. In this study, we specifically assessed state motivation rather than trait motivation, as our interest was in understanding immediate, context-dependent fluctuations in motivation that may modulate cognitive performance following exercise. To capture this transient motivational state, measurements were taken post-exercise, aligning with theoretical frameworks suggesting that motivation can dynamically shift based on perceived exertion and energy availability. Assessing motivation before exercise may not have accurately reflected the motivational state influencing post-exercise cognitive performance, as pre-exercise motivation can be influenced by anticipatory factors unrelated to exertion and fatigue levels (Ekkekakis et al., 2011). McMorris' (2021) interoceptive model provides a framework for understanding how both physiological and psychological factors interact to influence cognition. The model posits that state motivation, defined as a transient psychological drive influenced by situational factors, and perceived energy levels can modulate neurochemical responses to exercise, thereby affecting cognition. Unlike trait motivation, which reflects a stable and enduring predisposition, state motivation fluctuates based on immediate environmental and physiological conditions, such as exercise intensity and fatigue levels. Although the model was originally developed to explain cognitive effects during exercise, its principles can be extended to account for both immediate post-exercise and sustained effects. Neurochemical activities involving DA and NA, stimulated by the ventral tegmental area, substantia nigra pars compacta, and locus coeruleus (Aston-Jones & Cohen, 2005), continue to influence cognition after exercise, particularly as motivation and perceived energy levels persist beyond the cessation of physical exertion. For instance, in a non-exercise condition, high motivation could trigger DA and NA activation, potentially masking the effects of exercise-induced changes in catecholamines. Similarly, perceived energy levels (whether heightened or depleted) could influence cognition through neurochemical pathways involving the orbitofrontal cortex and anterior cingulate cortex (McMorris, 2021). These psychological factors may thus contribute to cognitive changes beyond the immediate effects of exercise.

As noted, acute high-intensity aerobic exercise may theoretically impair PFC-related cognition while enhancing hippocampal-related cognition. However, a recent systematic review examining the effects of high-intensity aerobic exercise on PFC-related cognition found mixed results, with inconsistencies particularly evident within the first five minutes following exercise (Sudo et al., 2022). These mixed results highlight a gap between theoretical expectations based on the catecholamine hypothesis and empirical evidence. For instance, a systematic review and Bayesian meta-analysis by Garrett et al. (2024), consistent with previous meta-analyses in this field (McMorris & Hale, 2012; Oberste et al., 2019), found strong evidence in adults that reaction time on executive function-based tasks improved immediately after high-intensity exercise, though there was no credible evidence for an effect on accuracy, with some studies reporting null (Mehren et al., 2019), beneficial (Basso et al., 2015), or detrimental effects (Coco et al., 2020). This discrepancy indicates a lack of consensus in the field, highlighting the need for further research to clarify accuracy-related effects of acute high-intensity exercise on PFC-related cognition. To address these inconsistencies, we employed a high-intensity exercise protocol with a brief 2-minute rest before the initial cognitive assessment. We also intentionally selected a 20-minute treadmill exercise duration, as past work has shown that 20 min of treadmill exercise is sufficient to enhance cognitive outcomes such as episodic memory (Loprinzi et al., 2021b). Although the timing of their effects on the brain in relation to changes in peripheral concentration remains uncertain (see Skriver et al., 2014 in discussion), key memory-related neurotrophins (e.g., BDNF) peak during this period of acute exercise (Saucedo Marquez et al., 2015). Additionally, key neurotransmitter mechanisms related to the exercise-memory relationship are elevated within the first 15 min post-exercise (Skriver et al., 2014).

While the neurotransmitter mechanisms described above are theorized to mediate these exercise-induced effects, they were not directly examined in the present study and are discussed only as conceptual background. Building on this theoretical foundation, our primary aim was to test the prediction that acute high-intensity exercise impairs PFC-related cognition while preserving or enhancing hippocampal-related cognition. We also assessed whether both types of cognition improve after a 20-minute rest period. Given Loprinzi et al.'s (2023) findings that cognitive performance improves with longer post-exercise recovery, and evidence suggesting that up to 20 min post-exercise may be an optimal window for cognitive recovery (Chang et al., 2012), we predicted that PFC-related cognition would show immediate impairment post-exercise but improve after the 20-minute rest. In contrast, we expected hippocampal-related cognition to improve immediately post-exercise and remain stable or decline slightly during later assessments. Guided by McMorris' (2021) interoceptive model, we further hypothesized that post-exercise increases in state motivation and perceived energy would be positively associated with cognitive performance following high-intensity exercise. Understanding these dynamics can guide the development of exercise protocols that optimize both physiological and psychological benefits for cognition.

Methods

Participants

Participant recruitment occurred via a purposive, non-random sampling approach; participants were recruited from undergraduate and graduate courses at the University of Mississippi. Sampling occurred across a variety of majors (e.g., public health, exercise science, biology, and psychology). Participants were recruited over a one-year period of data collection, resulting in a final sample of 55 participants. The study was conducted in accordance with the Declaration of Helsinki and approved by the University of Mississippi's Institutional Review Board. All participants provided written informed consent prior to participation. Participation was voluntary, with no financial compensation provided.

Eligibility Criteria

Similar to other work (Loprinzi et al., 2023), participants were excluded from participation if they (1) self-reported as a daily smoker; (2) self-reported being pregnant; (3) had a concussion or head trauma within the past 12 months; (4) used marijuana or other mind-altering drugs within the past 30 days; (5) were considered a daily alcohol user (>30 drinks/month for women; > 60 drinks/month for men) or consumed alcohol in the past 12 h; (6) were diagnosed with COVID-19 within the last two weeks; (7) were outside the age range of 18–25 years; (8) had a current diagnosis of a psychological disorder; (9) had been diagnosed with a learning (not including ADHD) or emotional disorder; or (10) answered "yes" to any of the seven questions on the Physical Activity Readiness Questionnaire (PAR-Q), suggesting that they should seek medical advice before exercising. These exclusionary criteria were selected as they may influence memory function. Further, any visits where the participants engaged in exercise on their own within five hours of the visit were rescheduled.

Study Design and Procedures

A 2 (*Condition*: Rest, Vigorous) × 2 (*Cognitive Task*: PFC-related, Hippocampal-related) factorial design was employed, with both factors occurring as within-subject variables. See Fig. 1 for a visual representation of the procedures. Allocation concealment occurred by both the researcher and participant not knowing which condition the participant would complete until arriving in the lab. Randomization of conditions was performed using a computer-generated algorithm.

Participants completed five visits in total. The first visit involved a maximal treadmill exercise test to determine participant's maximal heart rate and endurance capacity (measured by time-to-exhaustion). This session also familiarized participants with the cognitive test protocols to be used in subsequent visits. The maximum heart rate data obtained during this visit was used to calculate the target exercise intensity for the vigorous exercise condition using the heart rate reserve (HRR) formula. Visits 2–5 occurred in random order, at approximately the same time of day (±2 h) at a within-subject level and occurred approximately 24–72 h apart. During these visits, participants completed all four conditions across the visits, with one condition per visit: (1) vigorous exercise followed by a PFC-related task, (2) vigorous exercise followed by a hippocampal-related task, (3) rest followed by a PFC-related task, and (4) rest followed by a hippocampal-related task. The same cognitive task was administered twice during each visit; first immediately after a two-minute rest period following the condition, and again after a 20-minute break during which participants watched a neutral video.

Maximal Exercise Visit (1st session)

The first laboratory visit included familiarizing the participant with the two cognitive tasks (performing practice trials) and, subsequently, completing a maximal exercise treadmill-based assessment. The specific exercise assessment included an individualized protocol (Loprinzi et al., 2023), designed to

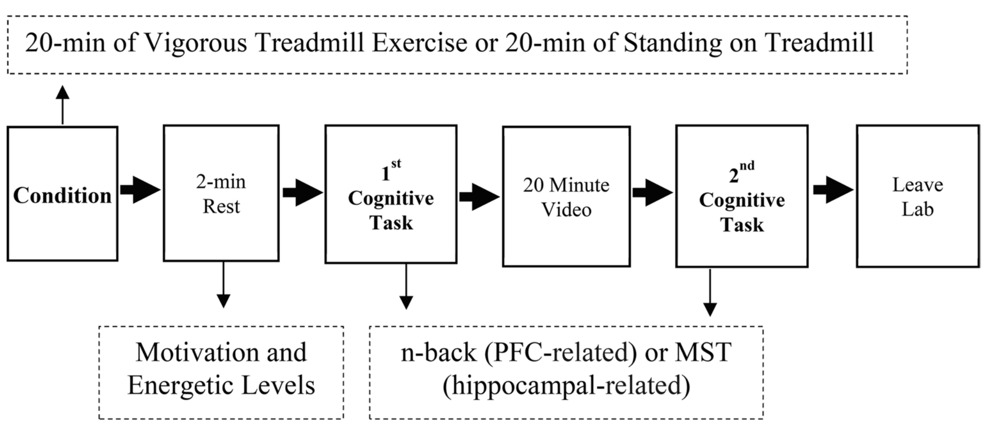

Fig. 1 Experimental study procedures. *Note.* Participants completed this procedure a total of four times, on separate occasions, as both Condition (exercise, rest) and Cognitive Task (PFC-related, hippocampal-related) are within-subject factors. The same cognitive task was always administered for both the immediate and delayed tests. That is, if the n-back task was given for the immediate test, it was also given for the delayed test. During the two-minute rest period between the condition and first cognitive task, participants completed a series of questions related to their motivation and energetic levels. PFC= Prefrontal cortex; MST = Mnemonic similarity task

determine each participant's maximal heart rate accurately. Participants warmed-up for 3-min by walking at 3.5 miles per hour (mph). Following this, they exercised at a constant speed throughout the test while the grade increased by 2% every 2-min. After the warm-up period, the speed was set, and remained, at 5.5 mph for the entire exercise protocol. The maximal treadmill exercise bout ended when the participant elected to stop exercising due to exhaustion or reached 20 min.

Vigorous Exercise vs. Rest

Before commencing the vigorous-intensity exercise on the treadmill, participants were instructed to rest quietly in a seated position for at least three minutes to allow for the measurement of their resting heart rate. Following this initial resting phase, participants performed a 20-minute exercise bout at 80% of their HRR using their maximal heart rate achieved during their maximal exercise bout (visit 1). To increase the likelihood of the participant being able to exercise for a full 20-minutes, the first five minutes of exercise occurred at a reduced intensity, with the goal of reaching the target heart rate (80% of HRR) by the 5-minute mark. The treadmill speed and incline were manipulated throughout to maintain the heart rate within 5 beats per minute of the target heart rate. The HRR was calculated as $[(HR_{max} - HR_{rest})$ * % target intensity] + HR_{rest} (Garber et al., 2011).

To maintain the same context and posture as the exercise condition, the control condition within this factor involved the participant watching a neutral (e.g., nature scenes from National Geographic) arousal video (no sound) while standing on the treadmill for 20 min. During both the exercise and control conditions, participants had the video (sound off) placed in front of the treadmill.

At baseline and throughout the acute exercise bout (every min), heart rate was assessed. Heart rate was measured via a chest-strap Polar heart rate monitor (H10 model). Rating of perceived exertion (RPE) was also measured at the very end of the exercise bout using a 6–20 scale (Borg, 1982).

Cognitive Task (PFC-Related vs. Hippocampal-Related)

The cognitive tasks and the 20-min distractor video between the two cognitive tasks were completed in an enclosed, isolated unit in the laboratory devoid of visual and auditory distraction.

Working Memory (PFC-Related Task)

The PFC-related task involved completing an n-back task via E-Prime (v 3.0); n-back tasks have been shown to activate the dorsolateral PFC in young adults (Yaple et al., 2019). This involved completing 2-back and 3-back tasks in a fixed order, with the 2-back task always preceding the 3-back task. This sequence was chosen to minimize potential fatigue and difficulty carryover effects that might occur if the more demanding 3-back task were completed first. These tasks involved presenting participants with a sequence of letters (one at a time), and participants were instructed to indicate whether the current stimulus (letter) matched the one presented n steps earlier in the sequence (1 = yes, 2 = no). The 2-back and 3-back tasks each included three blocks of 30 trials, comprised of 10 targets and 20 non-targets per block, presented in a randomized order. Each trial consisted of a single letter displayed for 500 milliseconds, followed by a 3000-millisecond response window during which participants made their judgment. *Hits* occurs when the participant correctly (presses "1") indicates that the current stimulus matches the one from n steps prior (i.e., they indicate "yes" when the current stimulus matches the one from n steps prior). *False alarms* (incorrect non-target) occurs when the participant incorrectly (presses "1") indicates that the current stimulus matches the one from n steps prior (i.e., they indicate "yes" when the current stimulus does not match the one from n steps prior). In addition to hits and false alarms, *misses* and *correct rejection* rates were computed; *misses* occurs when the participant incorrectly (presses "2") indicates that the current stimulus does not match that from n steps prior when in fact it does; and *correct rejection* (correct non-target) occurs when the participant correctly (presses "2") indicates that the current stimulus does not match that from n steps prior when indeed it does not match that from n steps prior. Hit rate was calculated as: (# of hits/(# of hits + # of misses). False alarm rate was calculated as: (# of false alarms/(# of false alarms + # of correct rejections).

Episodic Memory (Hippocampal-Related Task)

The hippocampal-related task involved completing a mnemonic similarity task using the same stimuli and procedures developed by Stark and colleagues (Stark et al., 2013). We used version 0.96, including sets 1–4 within the software, with separate sets used for the two conditions and two cognitive assessments (counterbalanced and randomized across participants). Each of the four memory sets included a unique set of matched stimuli.

Participants viewed (on a computer screen) 128 color photographs of everyday objects. Each object appeared on the screen for 2000 milliseconds (500 millisecond inter-stimulus interval) and involved an orienting judgement (whether the object is an indoor or outdoor object); these parameters (i.e., stimulus duration, inter-stimulus interval, and orienting judgement) are consistent with work that has demonstrated an exercise-induced effect on this memory task (Suwabe et al., 2017). Immediately following the study phase, participants commenced the test phase, including viewing 192 items, one at a time. This included 64 repeated/old items, 64 lure items and 64 foil items. For each item, participants indicated if the item was "Old", "Similar", or "New" via button presses. One-third of the images in the test were exact repetitions of the images viewed in the study phase (target); one-third were new images not previously seen (foil); and one-third were images that were similar to those seen during the study phase, but not identical (lures). See Fig. 2 for an illustration of these response options and item types.

Primary memory outcomes of this task included: (1) Item Recognition Accuracy [p (Old | Target) – p (Old | Foil)] and (2) Behavioral Pattern Separation score [p (Similar | Lure) – p (Similar | Foil)]. This behavioral pattern separation score is interpreted as the difference between the rate of "similar" responses given to the lure items minus "similar" responses given to the foils (in order to correct for response bias). Given that prior work (Suwabe et al., 2017) demonstrates that exercise is more strongly associated with behavioral pattern separation for high similarity lures, we computed a sensitivity analysis by categorizing the images based on how similar they were to the target, using the 5 lure bins (most similar to least similar) described elsewhere (Stark et al., 2019). This behavioral pattern separation index is associated with age-related changes in input to and within hippocampal subfields (dentate gyrus and CA3), as well as hippocampal-related memory performance (Yassa & Stark., 2011). Consequently, this test and its associated behavioral pattern score is appropriate for evaluating hippocampal pattern separation.

Additional Assessments

On the first visit, various demographic parameters were assessed, including self-report of age and sex, and measured height and weight for determination of body mass index (kg/m^2). Additionally, weekly engagement in self-reported moderate-to-vigorous physical activity (MVPA) was assessed using the two-item (number of days and average minutes per day) Physical Activity Vital Sign questionnaire (Ball et al., 2016).

During the two-minute rest period between the condition and the first cognitive task, participants completed a series of questions assessing their motivation and energetic levels. Specifically, three loosely-considered constructs were evaluated: Motivation, Perceived Energy Available, and Perceived Energy Cost. These questions were adapted from prior recommendations (Solomon & Manea, 2022), which developed and validated similar measures in the context of cognitive tasks and physical exertion. We do note, from below, relatively low levels of internal consistency, suggesting these items may not be taping into the same underlying construct. As stated, however, these constructs were loosely-considered, and further, differences between the exercise and control conditions were evaluated separately for each specific item (Tables 2 and 3).

Motivation was assessed with two questions: "*How much do you want to undertake the cognitive task?*" (1, not at all, to 7, very much); and "*How well do you think that you will do*?" (1, not at all, to 7, very much). Across the four conditions, McDonald's omega for these two items ranged from 0.54 to 0.81. Perceive Energy Available was assessed with three questions: "*How ready are you to do the cognitive test*? (1, not at all, to 7, very); "*How mentally energetic do you*

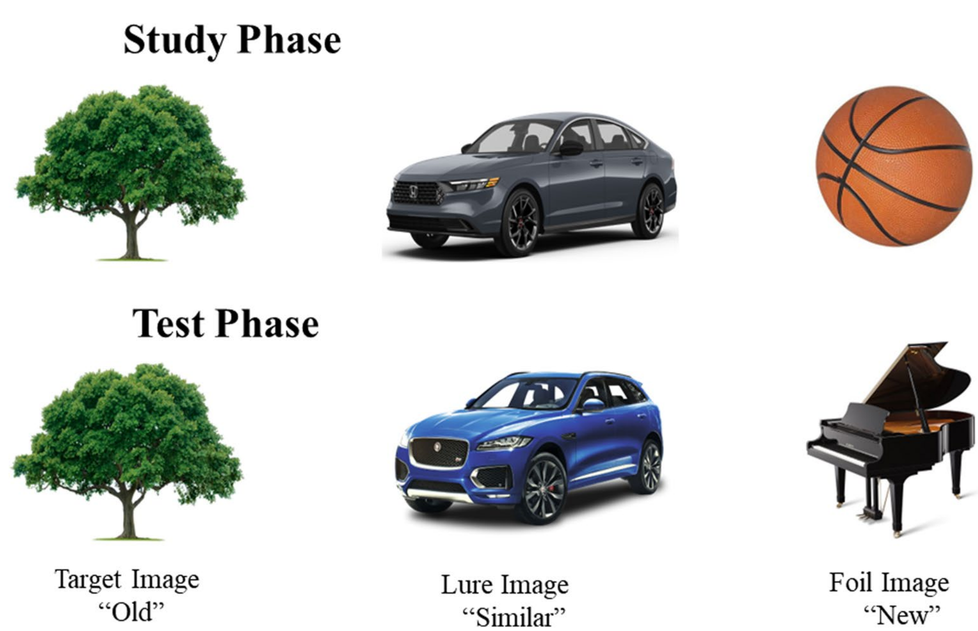

Fig. 2 Mnemonic similarity task illustrating response options and item types

feel?" (1, not at all, to 7, very); and "*How physically energetic do you feel*?" (1, not at all, to 7, very). Across the four conditions, McDonald's omega for these three items ranged from 0.80 to 0.89. Perceived Energy Cost was assessed with two questions: "*How much effort do you think will be required by the cognitive test*? (1, very little, to 7, a lot); and "*How confident are you that you have the cognitive and physical resources to do well on the cognitive test*?" (1, not at all, to 7, very). Across the four conditions, McDonald's omega for these two items ranged from 0.08–0.16.

Statistical Analyses

Our aim was to determine whether high-intensity exercise, compared to a non-exercise baseline, differentially influenced cognitive outcomes, impairing performance on tasks related to the PFC (n-back) while enhancing performance on tasks related to the hippocampus (mnemonic similarity). These cognitive tasks were assessed twice, and we expected that such enhancement and impairment effects would be more pronounced at the first assessment.

All analyses were conducted using Jamovi (v. 2.4). To test these hypotheses, several statistical procedures were performed. For the PFC-related task, a 2 (*Condition*: Rest vs. Vigorous) × 2 (*Time*: 1st vs. 2nd Assessment) × 2 (*nBack*: 2 vs. 3) repeated measures Analysis of Variance (ANOVA) was employed, with proportion accuracy serving as the primary outcome variable. Complementary analyses were also conducted for false alarm rate and d-prime scores to examine response sensitivity. For the hippocampal-related task, a 2 (*Condition*: Exercise vs. Rest) × 2 (*Time*: 1st vs. 2nd Assessment) ANOVA was computed, with separate analyses for item recognition accuracy and behavioral pattern separation scores.

To examine psychological responses, paired-samples t-tests were conducted to compare the mean scores of each psychological factor (motivation, perceived energy, and perceived effort) between the exercise and rest conditions. The means for the two exercise conditions were collapsed together, as were the means for the two control conditions. The predictive effects of these psychological factors on cognitive outcomes were further examined using regression analyses. Specifically, for each Motivation or Energy item, the difference between the exercise and rest conditions served as the independent variable, and the corresponding difference in cognitive performance between the exercise and rest conditions on the PFC- (d-prime for 2-back) or hippocampal-related task (behavioral pattern separation) served as the dependent variable. This approach was applied separately to assess whether exercise-induced changes in psychological states predicted task-specific cognitive outcomes.

All frequentist analyses were supplemented with Bayesian analyses to quantify evidence for one model (e.g., null model) relative to another (e.g., alternative model). Sensitivity analyses were also conducted to explore whether individual differences in physical activity levels (weekly engagement in MVPA) and cardiorespiratory fitness (maximal treadmill duration) influenced cognitive outcomes. MVPA and fitness were included as additional factors in separate interaction analyses within the ANOVA models to test whether these variables moderated the effects of Condition (Exercise vs. Rest) and Time (1st vs. 2nd Assessment) on cognitive performance.

Based on a sensitivity power analysis, with inputs of $\alpha=0.05$, power = 0.80, 55 participants, four conditions/measurements (exercise vs. rest and PFC vs. hippocampal assessments), and an assumed repeated-measures correlation of 0.50, we had sufficient power to detect a small effect ($f=0.159$).

Results

Participant Characteristics

Table 1 displays the demographic and behavioral characteristics of the sample. The participants, on average, were 20 years old (SD = 1.8; range = 18–30), with the sample containing 64% female participants. Participants were physically active, averaging 233 min/week of MVPA.

Manipulation Checks

Target heart rate for the two exercise conditions was set at 80% of HRR, corresponding to an estimated target heart rate of approximately 168.2 bpm in the present sample. The mean heart rates achieved at the endpoints of exercise were 167.3 and 166.8 bpm across the two vigorous-intensity exercise conditions. Figure 3A displays heart rate responses across all four conditions during the 20-minute condition, and Fig. 3B presents the corresponding RPE responses.

Motivation and Perceived Energetic Levels Prior to the First Cognitive Task

After the exercise or rest condition, and immediately before the first memory assessment, participants completed a series of questions assessing their motivation and energetic levels. Across the exercise and rest conditions, seven identical questions were administered. The means for these questions are presented in Table 2, Fig. 3C. Of the seven items assessed, only one reached statistical significance, indicating that participants reported feeling

Table 1 Demographic, behavioral, and performance characteristics of the sample (N = 55)

Variable	Point Estimate	SD
Age, mean years	20.36	1.8
Sex, % female	63.6	
Measured body mass index, mean kg/m^2	23.75	4.3
Physical activity, mean min/week of MVPA	232.91	216.7
Duration lasted on maximal treadmill test, mean seconds	787.91	226.0
Maximal HR achieved during max treadmill visit, mean HR	190.69	10.5
RPE (range = 6–20) at end of max treadmill visit, mean	18.51	1.6

Note. *MVPA* Moderate-to-vigorous physical activity, *HR* Heart rate, *RPE* Rate of perceived exertion

more mentally energetic after exercise than after rest (Q4, p =.02; see Table 2).

Additional regression analyses examined whether differences in motivation and perceived energy between the exercise and rest conditions predicted cognitive performance. Results revealed that two motivation items ("*How much do you want to undertake this test?*" and "*How well do you think you will do?*") significantly predicted PFC-related cognitive performance during the first assessment, indicating that higher motivation was associated with better working memory. However, these effects were not observed for the second PFC assessment or for hippocampal-related outcomes (see Table 3).

Cognitive Performance

Working Memory: n-back Tasks

Table 4 displays the working memory results across the two conditions evaluating PFC-related memory. In a 2 (*Condition*: Exercise vs. Rest) × 2 (*Time*: 1st vs. 2nd Assessment) × 2 (*nBack*: 2 vs. 3) ANOVA with hit rate as the outcome, we observed no main effect for Condition, $F(1,54)$ = 0.036, p =.85, η^2_p < 0.001, BF = 0.110, no main effect for Time, $F(1,54)$ = 0.453, p =.504, η^2_p = 0.008, BF = 0.127, a significant main effect for nBack, $F(1,54)$ = 62.172, p <.001, η^2_p = 0.535, BF = 8.395e+27, no Condition by Time interaction, $F(1,54)$ = 2.431, p =.125, η^2_p = 0.04, BF = 0.241, no Condition by nBack interaction, $F(1,54)$ = 0.073, p =.788, η^2_p = 0.001, BF = 0.154, no Time by nBack interaction, $F(1,54)$ = 0.332, p =.567, η^2_p = 0.006, BF = 0.158, and no three-way interaction between Condition, Time, and nBack, $F(1,54)$ = 1.994, p =.164, η^2_p = 0.036, BF = 0.517. Regarding the significant main effect for nBack, a Bonferroni post-hoc correction test showed that the hit rate was higher for 2Back compared to 3Back, M_{diff} = 0.113, SE = 0.014, t = 7.885, p <.001, BF = 1.654e+23.

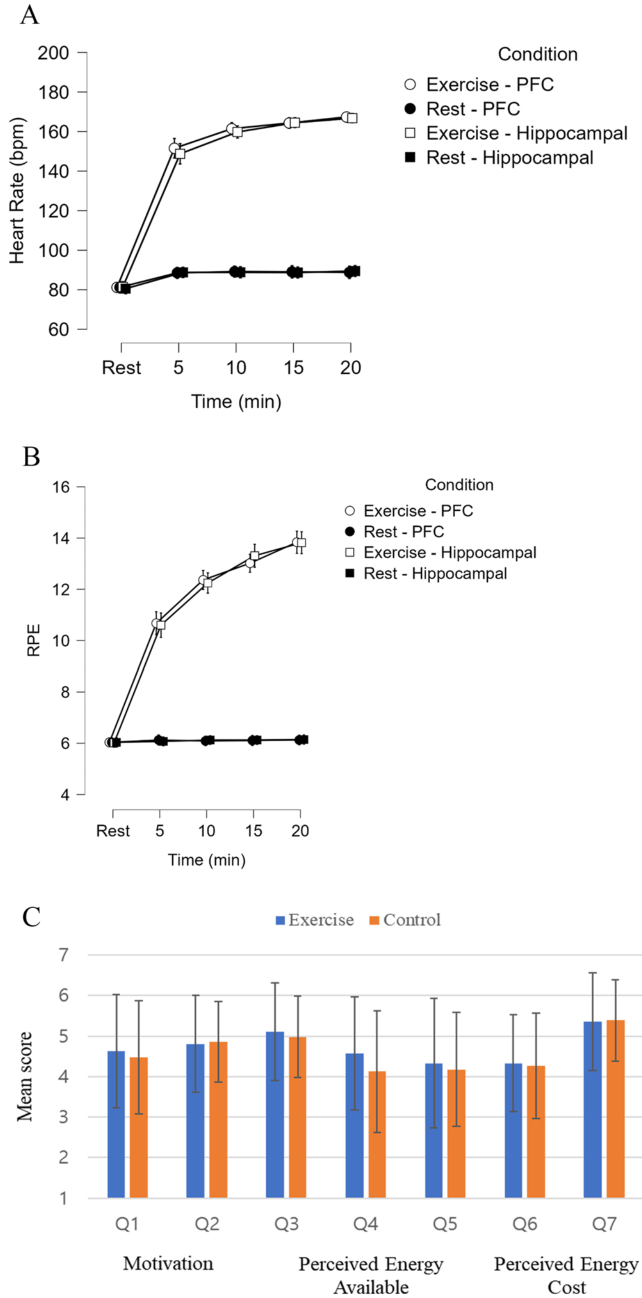

Fig. 3 **A**. Heart rate responses across the four conditions. *Note*. PFC = Prefrontal cortex. **B**. Rating of perceived exertion responses (Range= 6-20) across the four conditions. *Note*. RPE = Rating of perceived exertion; PFC = Prefrontal cortex. **C**. Mean (SE) scores for psychological measures across seven questions for each condition. *Note*. Error bars represent standard deviations. Q = Question item number

Sensitivity Analysis When considering the potential interaction effects of weekly engagement in MVPA, and with hit rate as the outcome, we did not observe a main effect for MVPA, $F(1, 53)$ < 0.01, p =.999, no Condition by MVPA

Table 2 Motivation and energetic levels immediately after exercise but immediately before the cognitive task

Item	Exercise	Control	Results
Motivation			
Q1: "How much do you want to undertake this test?"	4.63 (1.4)	4.48 (1.4)	$t(54) = 0.88$, $p = .383$
Q2: "How well do you think you will do?"	4.81 (1.2)	4.86 (0.99)	$t(54) = 0.33$, $p = .740$
Perceived Energy Available			
Q3: "How ready are you to do the test?"	5.11 (1.2)	4.98 (1.0)	$t(54) = 0.92$, $p = .361$
Q4: "How mentally energetic do you feel?"	4.57 (1.4)	4.13 (1.5)	$t(54) = 2.41$, $p = .020$
Q5: "How physically energetic do you feel?"	4.33 (1.6)	4.18 (1.4)	$t(54) = 0.68$, $p = .501$
Perceived Energy Cost			
Q6: "How much effort do you think will be required by this test?"	4.33 (1.2)	4.26 (1.3)	$t(54) = 0.52$, $p = .607$
Q7: "How confident are you that you have the cognitive and physical resources to do well on this task?"	5.36 (1.2)	5.39 (1.0)	$t(54) = 0.22$, $p = .830$

Note. Point estimates (range = 1–7) are means, with values in parentheses representing standard deviations. Paired t-tests were used to compare means between the exercise and control conditions.

interaction, $F(1, 53) = 0.359$, $p = .552$, $\eta^2_p = 0.007$, no Time by MVPA interaction, $F(1, 53) < 0.301$, $p = .882$, $\eta^2_p < 0.001$, no nBack by MVPA interaction, $F(1, 53) = 3.13$, $p = .082$, $\eta^2_p = 0.056$, no Condition by Time by MVPA interaction, $F(1, 53) = 1.77$, $p = .189$, $\eta^2_p = 0.032$, no Condtion by nBack by MVPA interaction, $F(1, 53) < 0.01$, $p = .993$, $\eta^2_p < 0.001$, no Time by nBack by MVPA interaction, $F(1, 53) = 0.251$, $p = .969$, $\eta^2_p = 0.005$, and no Condition by Time by nBack by MVPA interaction, $F(1, 53) = 1.866$, $p = .178$, $\eta^2_p = 0.034$. Similar respective null effects for these interactions were also observed when considering fitness (duration on max treadmill visit) instead of MVPA, $p = .300$, $p = .563$, $p = .391$, $p = .818$, $p = .700$, and $p = .110$. We also did not observe any condition by time effects when considering the false alarm rate or d-prime ($Z_{Hits} - Z_{False}$).

Episodic Memory: Mnemonic Similarity Task

Item Recognition Table 5 displays the episodic memory results across the two conditions evaluating hippocampal-related memory. In a 2 (*Condition*: Exercise vs. Rest) × 2 (*Time*: 1st vs. 2nd Assessment) ANOVA with item recognition as the outcome, there was no main effect for Condition,

Table 3 Association of motivation and energetic levels on cognitive performance

Item	PFC-Dependent		Hippocampal-Dependent	
	1st	2nd	1st	2nd
Motivation				
"How much do you want to undertake this test?"	0.31 (0.07, 0.55)	0.13 (−0.04, 0.29)	−0.01 (−0.05, 0.04)	−0.01 (−0.05, 0.02)
"How well do you think you will do?"	0.55 (0.24, 0.86)	−0.09 (−0.31, 0.13)	−0.02 (−0.07, 0.02)	−0.003 (−0.04, 0.03)
Perceived Energy Available				
"How ready are you to do the test?"	0.23 (−0.07, 0.53)	−0.11 (−0.30, 0.09)	−0.001 (−0.05, 0.05)	0.005 (−0.03, 0.04)
"How mentally energetic do you feel?"	0.19 (−0.08, 0.46)	−0.01 (−0.19, 0.17)	0.02 (−0.01, 0.05)	−0.004 (−0.03, 0.02)
"How physically energetic do you feel?"	0.06 (−0.16, 0.29)	0.13 (−0.01, 0.27)	0.02 (−0.01, 0.05)	−0.003 (−0.03, 0.02)
Perceived Energy Cost				
"How much effort do you think will be required by this test?"	−0.17 (−0.44, 0.10)	−0.04 (−0.22, 0.13)	−0.02 (−0.07, 0.03)	0.002 (−0.04, 0.04)
"How confident are you that you have the cognitive and physical resources to do well on this task?"	0.22 (−0.17, 0.61)	−0.02 (−0.27, 0.27)	−0.02 (−0.07, 0.03)	−0.01 (−0.05, 0.03)

Note. Estimates are unstandardized beta coefficients from a regression analysis, with values in parentheses representing the 95% confidence interval of the beta coefficient. 1st and 2nd represent the two cognitive assessments. The PFC-related outcome is d-prime and the hippocampal-related outcome is the behavioral pattern separation variable. For the PFC-related outcome, the results in the table are for the 2-back task, as there were similar results for the 3-back task. PFC = Prefrontal cortex.

Table 4 Working memory results across the two conditions evaluating PFC-related cognition

Task	Exercise		Rest	
	1st Cognitive Assessment	2nd Cognitive Assessment	1st Cognitive Assessment	2nd Cognitive Assessment
2-back				
Hit rate	0.908 (0.13)	0.910 (0.15)	0.912 (0.13)	0.913 (0.14)
False alarm rate	0.035 (0.09)	0.027 (0.05)	0.034 (0.06)	0.038 (0.06)
3-back				
Hit rate	0.784 (0.18)	0.811 (0.17)	0.802 (0.15)	0.793 (0.16)
False alarm rate	0.055 (0.09)	0.068 (0.09)	0.063 (0.07)	0.055 (0.06)

Note. Point estimates are expressed as proportions. Values in parentheses are standard deviations.

Table 5 Episodic memory results across the two conditions evaluating hippocampal-related cognition

Task	Exercise		Rest	
	1 st Cognitive Assessment	2nd Cognitive Assessment	1 st Cognitive Assessment	2nd Cognitive Assessment
Item Recognition	0.734 (0.23)	0.747 (0.15)	0.742 (0.22)	0.744 (0.19)
BPS	0.397 (0.26)	0.411 (0.21)	0.405 (0.21)	0.385 (0.20)

Note. Point estimates are expressed as proportions. Values in parentheses are standard deviations. *BPS* = Behavioral pattern separation.

$F(1,54) = 0.018$, $p = .895$, $\eta^2_p < 0.001$, BF = 0.148, no main effect for Time, $F(1,54) = 0.081$, $p = .777$, $\eta^2_p = 0.001$, BF = 0.152, and no interaction between these factors, $F(1,54) = 0.101$, $p = .752$, $\eta^2_p = 0.002$, BF = 0.222.

Sensitivity Analysis When considering the potential interaction effects of weekly engagement in MVPA, there was no Condition by MVPA interaction, $F(1, 53) = 1.04$, $p = .311$, $\eta^2_p = 0.019$, no Time by MVPA interaction, $F(1, 53) = 0.072$, $p = .790$, $\eta^2_p = 0.001$, or a Condition by Time by MVPA interaction, $F(1, 53) = 0.323$, $p = .572$, $\eta^2_p = 0.006$. Similar null interaction effects for fitness (duration lasted on the max treadmill visit) occurred for these three interaction analyses, $p = .504$, $p = .227$, and $p = .878$. Further, null interaction effects for the highest achieved heart rate from the maximal treadmill test occurred for these interaction analyses, $p = .513$, $p = .938$, $p = .653$.

Behavioral Pattern Separation In a 2 (*Condition*: Exercise vs. Rest) × 2 (*Time*: 1 st vs. 2nd Assessment) ANOVA with behavioral pattern separation as the outcome, there was no main effect for Condition, $F(1,54) = 0.183$, $p = .671$, $\eta^2_p = 0.003$, BF = 0.163, no main effect for Time, $F(1,54) = 0.03$, $p = .862$, $\eta^2_p < 0.001$, BF = 0.151, and no interaction between these factors, $F(1,54) = 1.12$, $p = .29$, $\eta^2_p = 0.02$, BF = 0.288.

Sensitivity Analysis When considering the potential interaction effects of weekly engagement in MVPA, there was no Condition by MVPA interaction, $F(1, 53) = 0.221$, $p = .640$, $\eta^2_p = 0.004$, no Time by MVPA interaction, $F(1, 53) = 2.31$, $p = .134$, $\eta^2_p = 0.042$, or Condition by Time by MVPA interaction, $F(1, 53) = 0.106$, $p = .746$, $\eta^2_p = 0.002$. Similar null interaction effects for fitness (duration lasted on the max treadmill visit) occurred for these three interaction analyses, $p = .611$, $p = .742$, and $p = .454$. Further, null interaction effects for the highest achieved heart rate from the maximal treadmill test occurred for these interaction analyses, $p = .531$, $p = .751$, $p = .557$.

We also explored whether Condition and Time interacted with the 5 lure bins (most similar to least similar). In a 2 (*Condition*: Exercise vs. Rest) × 2 (*Time*: 1 st vs. 2nd Assessment) × 5 (*Lure Bin*: 1–5) ANOVA with behavioral pattern separation across lure bins as the outcome, Condition and Lure Bin did not interact, $p = .939$, Time and Lure Bin did not interact, $p = .416$, and there was not a Condition by Time by Lure Bin interaction, $p = .300$.

Discussion

The findings of the present experiment indicate that when acute aerobic exercise was performed before a cognitive task, (1) high-intensity exercise did not have a significant influence on PFC-related cognition or (2) hippocampal-related cognition. Furthermore, associations between psychological factors and cognitive outcomes were largely nonsignificant, though higher motivation, specifically participants' willingness to engage in and perceived confidence toward the task, was associated with better PFC-related performance during the first assessment. This partial pattern provides limited but notable support for the interoception model proposed by McMorris (2021), which posits that psychological readiness may modulate cognitive responses to exercise.

The unexpected finding that high-intensity exercise did not impair PFC-related cognition challenges previous literature, suggesting potential adverse effects of such exercise on working memory when performed before a cognitive task (McMorris, 2016b; Moreau & Chou, 2019; Zimmer et al., 2016). A key distinction may lie between exertion and fatigue: while high-intensity exercise induces significant exertion, it does not necessarily result in cognitive impairment, especially in physically active individuals. Our participants, who were physically active, likely had fitness levels that allowed them to manage the exertion without reaching the level of fatigue that impairs PFC-related cognition. This adaptability may explain why the expected cognitive impairments were not observed. Additionally, consistent performance across both the exercise and rest conditions in the first and second cognitive assessments suggests that the mental load was manageable for this sample, reflecting the cognitive reserve often observed in physically active individuals (Clare et al., 2017; McMorris, 2021; Voss & Jain, 2022; Zijlmans et al., 2022). The timing of cognitive assessments also may play a key role in interpreting the results. Our study included a 2-minute rest period between the exercise and the first cognitive assessment, which may have allowed some recovery of PFC function. While prior research indicates that longer recovery periods can enhance cognitive performance (Loprinzi et al., 2023), our findings suggest that even a brief recovery can mitigate potential impairments in cognitive tasks following high-intensity exercise. This challenges the conventional view that such exercise leads to immediate deficits in PFC-related tasks. Instead, our results suggest that a short recovery period (as brief as 2 min) may be sufficient for individuals to recover from transient cognitive declines. This aligns with findings by Jung et al. (2024), which demonstrated immediate cognitive recovery within just a minute after a 15-minute bout of high-intensity exercise. This rapid recovery may be attributed to the sympathoadrenal medullary response. The brain's quick adjustments to physiological fluctuations, such as changes in cerebral blood flow and neurotransmitter levels, may stabilize or even enhance cognition shortly after such exercise has ended (Ando et al., 2024; McMorris, 2016a; Winter et al., 2007). This interpretation also aligns with the Reticular-Activating Hypofrontality model proposed by Dietrich and Audiffren (2011), which posits that acute exercise temporality downregulates prefrontal activity to reallocate neural resources toward motor and subcortical regions, followed by a compensatory recovery phase that may facilitate cognitive stabilization. Although our primary focus is on high-intensity exercise, prior studies examining moderate-intensity exercise have reported mixed findings, including immediate deficits or no change in PFC-related cognition (Crush & Loprinzi, 2017; Soga et al., 2015). These inconsistencies suggest that the cognitive effects of acute exercise may vary nonlinearly across intensity levels, and that our findings could, in some cases, appear inconsistent with the catecholamine hypothesis. Considering these results in relation to our data provides insight into the complex nature of how exercise intensity modulates cognition.

Contrary to our expectations, acute high-intensity exercise did not enhance hippocampal-related cognition. One possible reason is that cognitive function, including memory, tends to be at its peak in young adulthood, leaving limited potential for observable improvements in task performance (Garrett et al., 2024). Indeed, prior reviews and meta-analyses have indicated that the effects of exercise on cognition vary with age (Erickson et al., 2019), showing the greatest benefits in younger children and older adults (Ludyga et al., 2016). However, we do note that prior work has demonstrated a favorable effect of acute exercise on hippocampal-related memory performance (Loprinzi et al., 2021a, b). Nevertheless, it is important to note that such effects may depend on baseline levels of task performance. Consistent with prior work using the same mnemonic similarity task (Loprinzi & Caplan, 2025), participants in our sample exhibited baseline recognition accuracy comparable to normative data from young adults, suggesting that ceiling-level performance may have limited the detection of exercise-related gains. Another plausible explanation may relate to participants' psychological states, particularly levels of motivation and perceived energy. According to the interoceptive model (McMorris, 2021), physiological and psychological factors interact to determine cognitive outcomes following exercise. Motivation and energy perception can modulate the brain's functional connectivity (Spielberg et al., 2012) and influence neurochemical pathways (Varazzani et al., 2015), thereby impacting cognition. In situations where there is no difference in cognitive outcomes between exercise and rest conditions, high motivation may prompt the dorsolateral PFC to increase the tonic release of catecholamines like DA and NA. This increase may, in turn, facilitate greater phasic release of these catecholamines, enabling highly motivated individuals to maintain comparable levels of cognitive performance at rest to those observed following exercise. This interpretation is supported by prior research showing that motivational and energetic states influence cognitive control and memory processes through dopaminergic and noradrenergic pathways (Bouret et al., 2012; Westbrook & Braver, 2015), suggesting that psychological states may dynamically modulate post-exercise cognition.

Although our sample reported significantly higher perceived mental energy after exercise, few psychological constructs differed between the exercise and rest conditions. As shown in Table 3, motivation demonstrated small but significant associations with PFC-related outcomes during the first assessment, whereas perceived energy showed no meaningful relationships with cognitive performance. One possible explanation, as proposed by McMorris (2021), is that highly motivated participants in the rest condition may have exhibited a neurochemical environment comparable to that induced by exercise, particularly with respect to catecholamine levels (DA and NA), thereby masking any additional cognitive benefits of exercise. The significant differences in performance between the 2-back and 3-back tasks, with consistently better scores on the 2-back task, reflect its lighter cognitive load and indicate resilience to cognitive fatigue caused by acute physiological stress. This further supports the idea that participants with high motivation and cognitive reserve showed little difference in performance between rest and exercise conditions. The absence of significant differences in hit rates and false alarm rates (see Table 4) might be due to a ceiling effect, where optimal catecholamine levels are already present in the rest condition, limiting additional exercise-induced cognitive gains. While these findings are theoretically plausible, future research should empirically test this hypothesis by manipulating motivation levels in the rest condition and measuring catecholamine changes to better isolate the effects of exercise on cognition. For instance, employing relaxation techniques or tasks that reduce motivation could help clarify how exercise influences cognition, especially in populations with variable motivation levels, such as older adults, who may experience fluctuations due to age-related factors (Basso & Suzuki, 2017).

Since the current study did not measure alterations in catecholamine levels or neuronal activation patterns, it is challenging to explain the lack of cognitive enhancement from a neurophysiological perspective. This limitation highlights a gap in our study, as neuroimaging data could have provided direct evidence of exercise-induced changes in structural/functional connectivity and their impact on cognition (Stimpson et al., 2018). Despite this, our findings suggest that increases in perceived mental energy from acute high-intensity exercise do not necessarily lead to cognitive improvements, particularly those linked to the hippocampus, especially when motivation levels are already high in a non-exercise context. Additionally, high motivation in the rest condition may contribute to the null effects observed in PFC-related cognition, suggesting a broader role of psychological factors in modulating cognitive processes after exercise. This speculation points to the need for further investigation into how different psychological states affect various cognitive domains in the context of acute exercise, which could deepen our understanding of the psychological mechanisms through which exercise influences cognitive tasks probing working memory and episodic memory.

The lack of significant findings in our study, consistent with those reported by Loprinzi and Caplan (2025), may be partially explained by differences in the cognitive processes underlying the employed tasks. Specifically, they proposed that exercise may differentially influence hippocampal pattern separation and PFC-related conceptual processing, such that mnemonic discrimination tasks relying on hippocampal subfields (e.g., dentate gyrus, CA3) are less responsive to acute high-intensity exercise, whereas tasks engaging executive or conceptual processing may be more sensitive to such modulation. We employed a recognition memory test as the hippocampal-related task, which, in some instances, has been shown to be less sensitive to the effects of exercise in older adults (Moutoussamy et al., 2022). While recognition memory is influenced by hippocampal function, it depends less on hippocampal-mediated retrieval processes than free recall tasks. Recognition memory is often preserved even in individuals with neurodegenerative conditions, particularly when the targets are easily verbalized, as in our paradigm. Given this, our task may not have been sensitive enough to detect subtle exercise-induced enhancements in hippocampal activity. Our results suggest that this insensitivity may also apply to young adults, indicating that recognition tasks might not be the most suitable measure for capturing exercise-related hippocampal changes across age groups. Furthermore, the working memory task (i.e., n-back) used to assess PFC-related cognition may have contributed to the observed null effects, as prior research suggests that acute exercise has minimal impact on working memory in healthy adults (Rathore & Lom, 2017). Another factor concerns the exercise modality used in our study, which involved treadmill-based running. A recent meta-analytic review by Garrett et al. (2024) observed that cycling may produce more pronounced benefits for tasks assessing executive functioning post-exercise. Widely used in exercise-cognition research, cycling has been shown to enhance domains such as inhibition (Kunzler & Carpes, 2020), planning (Hung et al., 2013), task-switching (Bae & Masaki, 2019), and decision-making speed (McMorris, 2009). Therefore, the choice of cognitive tasks and exercise modality in our study may not have been ideal for detecting cognitive shifts associated with acute exercise. This underscores the need for further research employing a more targeted selection of cognitive tasks and exercise modalities that are more sensitive to exercise-induced cognitive changes to better understand the acute exercise-cognition interaction.

The strengths of this study are noteworthy. First, the median sample size in the literature on exercise and cognition for within-subjects pretest–posttest designs is typically around 20 participants (Pontifex et al., 2019). Importantly, our study included a relatively large sample of 55 participants, which may enhance the reliability and generalizability of our findings. Another key strength of our study lies in its innovative approach to assessing motivation and perceived energy levels in the context of acute exercise and cognition. This approach allowed us to capture participants' psychological readiness and subjective energy levels during cognitive tasks, offering valuable insights into the interaction between mental states and cognitive outcomes. If the expected results were not observed, it is plausible that individual differences in these psychological factors may have contributed to the variability in findings, potentially explaining the heterogeneous results often seen in literature. This perspective highlights the importance of integrating psychological considerations into analyses of acute exercise and cognition, which can deepen our understanding of the mechanisms underlying exercise-induced cognitive changes.

Despite these strengths, our study has several limitations that warrant attention to enhance our understanding of the interoception model in the context of acute exercise and cognition. First, we did not measure extracellular concentrations of DA and NA, which may interact with motivation in higher-order cognitive processes. Future research should use techniques such as positron emission tomography (PET), microdialysis, or neuroimaging methods (e.g., EEG, fMRI, fNIRS) to infer DA- and NA-related brain activity and provide a more empirical basis for understanding how psychological and physiological factors jointly influence cognition in response to acute exercise. Second, our assessment of motivation relied solely on subjective reports. Given that DA and NA modulate motivation (Elliott et al., 2000), incorporating objective indicators of motivation pathway activation would offer a more comprehensive perspective. Moreover, we assessed state motivation only after exercise, which may have emphasized participants' transient motivational states rather than trait-level differences. Including a pre-exercise assessment could help distinguish between state and trait motivation. In addition, motivation and perceived energy were measured only before the first cognitive task to capture the immediate post-exercise state and were not reassessed before the second task to avoid procedural interference or additional delays that could alter the natural recovery trajectory. Future studies should include repeated assessments to clarify how psychological states fluctuate across multiple post-exercise cognitive tasks. Furthermore, for the n-back task, only accuracy data (hit rate and false alarm rate) were available. Given that reaction time can provide complementary information about working memory performance, the omission of this data represents a methodological limitation that may have constrained the detection of potential exercise-related cognitive effects. Finally, other psychological factors, such as perceived effort costs and resources availability, were not examined. When individuals perceive sufficient resources to meet anticipated effort costs, cognition may be optimized through a balanced tonic-phasic catecholamine response. Conversely, when resources are perceived as insufficient, excessive tonic activity may suppress phasic release, potentially impairing cognition (McMorris, 2021). Future work should examine these variables as potential mediators, alongside motivation and perceived energy.

Conclusion

Our findings suggest that when acute high-intensity aerobic exercise is performed before a cognitive task, it neither impairs PFC-related nor enhances hippocampal-related memory. However, the absence of cognitive impairment is noteworthy, particularly in the context of exercise prescription. Given the well-documented benefits of physical activity for brain and cognitive health, incorporating high-intensity exercise into daily routines may serve as an effective strategy for enhancing both physical and mental well-being. Furthermore, our findings highlight that motivational factors may play a limited yet meaningful role in modulating PFC-related cognitive performance following exercise, emphasizing the importance of integrating psychological variables when evaluating the cognitive effects of acute exercise. Future research should continue to examine these interactions by combining physiological and psychological assessments within a single framework to provide a more comprehensive understanding of the mechanisms through which acute exercise influences diverse cognitive domains.

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Declarations

Competing interests The authors declare no competing interests.

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