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Research article

A single session of exercise as a modulator of short-term learning in healthy individuals

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HIGHLIGHTS

- Evaluated how moderate aerobic exercise modulates short-term learning.
- Response time was not significantly affected by moderate intensity exercise.
- Participants may have improved errors post-exercise relative to other testing time points.

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ABSTRACT

Background: A single session of aerobic exercise is linked to faster motor responses; however, the effect on rate of short-term learning is less clear. The objective was to evaluate the influence of a single bout of aerobic exercise on the rate of short-term acquisition of a shape-letter association task requiring a motor response.

Methods: 23 [11 females, age 20.8 ± 2.7 years] healthy young adults were evaluated using a randomly assigned crossover design which was counterbalanced for order before and after moderate (exercise) and light (control) intensity cycle ergometry. Participants performed 3 blocks, with each block consisting of one round of training and testing. During training, participants were tasked with learning 6 unique shape-letter associations. Subsequent testing required a key press response to a visually presented shape pattern. Response time and error rates were used to assess acquisition over the 3 blocks of testing.

Results: Mean response time was faster post-exercise relative to the other testing periods, and approached statistical significance compared to post-control ($p < 0.07$). However, no significant difference in response time reduction (difference between test block 1 and test block 3) was identified between the four evaluations (pre and post the exercise and control conditions). Error rate reduction (test block 1 minus test block 3) revealed that individuals had the smallest change in error rate post-exercise ($p < 0.05$). Follow-up analyses revealed fewer errors in test block 1 and test block 2 post-exercise which approached statistical significance ($p = 0.06$) suggesting near-perfect error rates were obtained after only 2 testing blocks post-exercise compared to 3 blocks in the other testing periods.

Conclusions: Support for augmentation of short-term learning was mixed as errors were reduced post-exercise while response time was not different between evaluations. Future work should include neurophysiological evaluation and a retention test to better elucidate the influence of aerobic exercise on rate of short-term learning.

1. Introduction

The neurological benefits of regular aerobic exercise are well established and include protection against cognitive decline [1,2] and improved recovery after neurological injury such as stroke [3]. These chronic exercise benefits are likely the accumulation of acute

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effects. Indeed, acute exercise studies have linked a single session of aerobic exercise to positive transient improvements in information processing, cognitive function, and neurophysiology [4,5]. These studies provide support that acute exercise may 'prime' the brain for subsequent performance; however, few studies have focused on how a single session of aerobic exercise immediately influences short-term learning.

Aerobic exercise causes a number of short-term neurobiological changes that may transiently influence cognitive function and behaviour. Exercise is characterized by increased central nervous system arousal driven by up-regulation of catecholamines, including epinephrine and dopamine [5–7]. These changes have been observed in faster information processing reflected behaviorally using stimulus response tasks [4,8] and through augmentation of cortical neurophysiological markers of stimulus processing and allocation of attentional resources [9–12]. Additionally, neurotrophic factors, including brain-derived neurotrophic factor (BDNF), related to synaptic plasticity and implicated in short- and long-term potentiation are acutely up-regulated following an exercise bout [13]. This boost to catecholamines and other factors including neurotrophic growth factors after exercise are linked to better short-term improvement and learning success [14]. Studies discussing behavioural changes in cognitive function, including attention [5] and memory consolidation [2,9,15], have generally relied on response time which is robustly decreased after exercise and may partially reflect an increase in non-specific arousal. Studies attempting to understand the influence of aerobic exercise on cognition must take care to disentangle the effects of this exercise-induced arousal and the simultaneous augmentation of cognitive processing on improvements in behavioural performance. Thus, paradigms dissociating arousal effects (e.g., timed measures) from specific cognitive functions (e.g., acquisition of information) are critical to properly understand the influence of aerobic exercise on cognition.

Previous studies suggest that acute aerobic exercise may augment short-term learning but few studies have directly evaluated this hypothesis. A single session of intense aerobic exercise has been shown to improve immediate learning and retention of a new language [14]. Further, sequence-specific implicit motor learning on a visuomotor tracking task is enhanced following a single-session of high intensity aerobic exercise and is maintained for 24 h [15]. Conversely, exercise either before or after visuomotor skill training does not influence immediate acquisition but does improve retention compared to non-exercising participants [16]. Finally, exercise after learning has also been linked to improved memory consolidation evaluated an hour post-exercise among healthy older individuals and those with mild cognitive impairment [17]. Overall, the findings have generally found a positive effect of aerobic exercise on long-term retention but inconsistencies remain around the impact on immediate acquisition. Previous literature focused on long-term retention and utilized tasks that required between-subject designs [14,16] making it difficult to identify potentially small benefits of exercise to short-term learning.

Tracking short-term learning requires a task where proficiency can be achieved over a relatively short time frame and evaluated simply and objectively Following such a paradigm, a vibrotactile discrimination task successfully displayed short-term learning via reductions in errors and speed of execution over training for a period of approximately 40 min [18]. This study strove to further our understanding of post-exercise facilitation of timed responses separate from alterations in short-term learning. Thus, we developed a visuomotor association task and measured response time and errors while participants learned shape-letter associations over multiple blocks before and after a single session of moderate aerobic exercise and a control condition. We hypothesize that response execution reflected by mean response time would be fastest after the exercise session relative to all other testing sessions. AA second hypothesis was that acquisition of the shape-letter associations would occur faster after exercise as reflected by a larger reduction in both response time and errors over repeated training and testing sessions.

Table 1
Participant characteristics and exercise data (n = 23). Values are mean (standard deviation) or frequency counts.
(BMI, body mass index; kg/m^2, body weight in kilograms divided by height squared in meters; bpm, beats per minute; RPE, rating of perceived exertion).

Characteristic	Mean (SD) or Percent (n)
Age (years)	20.8 (2.7)
Sex (female)	47.8% (11)
BMI (kg/m^2)	23.2 (4.0)
Education (years)	14.7 (2.4)
Time between sessions (days)	3.6 (3.2)
Mean heart rate (bpm)	
Exercise session	128.4 (6.5)
Control session	72.6 (7.8)
Mean heart rate (% max)	
Exercise session	66.4 (3.2)
Control session	37.5 (4.0)
Mean RPM	
Exercise session	57.8 (8.2)
Control session	26.7 (5.5)
Mean RPE (range 0–10)	
Exercise session	4.2 (1.3)
Control session	0.6 (0.7)

2. Materials and methods

2.1. Participants

Twenty-four healthy young adults recruited from the University of Waterloo volunteered to participate in this study. Participants were excluded if they had any neurological, cardiovascular or musculoskeletal impairment that prevented them from exercising or performing the task. Participants signed informed consent forms prior to enrollment and the study received ethics clearance from the University of Waterloo's research ethics board.

All 24 participants completed the full testing protocol; however, one participant's data was unusable due to a technical issue with response recording during one session so 23 participants were included in the following statistical analysis. There were 11 females and 12 males with a mean age 20.8 (SD = 2.7) years. Participants exercised at a mean heart rate (HR) of 128.4 (SD = 6.5) bpm during the exercise session (66.4% of age-predicted maximum) and 72.6 (SD = 7.8) bpm during the control session (37.5% of maximum). See Table 1 for a full breakdown of participant characteristics.

2.2. Procedure

Each participant took part in two sessions which were counterbalanced for the order of sessions between participants and separated by at least one day. Randomization and counterbalancing was done by using a random number generator to assign the initial testing session for participant A and then participant B completed the opposite testing order. The difference between the sessions was the intensity of the exercise component (very light or moderate intensity) which involved 25 min of semi-recumbent cycling, including a 3-min warm-up and 2-min cool-down. Participants were evaluated using the visuomotor task described below before and starting 5 min after the end of the exercise bout.