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Effectiveness of Studying When Coupled with Exercise-Induced Arousal

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ABSTRACT

International Journal of Exercise Science 12(5): 979-988, 2019. The basis of learning is knowledge of discrete information such as terms and definitions that can be developed through memorization. A strong knowledge base is something students strive to develop through self-directed study. Little research has investigated the role of simultaneous exercise and memorization on recall ability with a delay in recall of at least 24 hrs. The purpose of this study was to evaluate the effect of an exercise bout on memory by requiring participants to recall words 24 hrs after exposure to three different interventions: memorization while cycling, memorization after cycling, and memorization without cycling. 21 physically active young adults completed the crossover design in randomized order. During testing sessions, participants were given a unique list of 100 words and were instructed to memorize as many words as possible. They returned 24 hrs later to recall the words. The average number of words recalled for each intervention were: memorization while cycling, 51.5 ± 19.8 words; memorization after cycling, 45.1 ± 22.4 words; memorization without cycling, 45.7 ± 23.3 words. Mixed-measures ANOVA revealed that exercise did not alter recall ability (p = 0.121). However, statistical contrasts showed that the number of words recalled following memorization during cycling was higher than number of words recalled during the other interventions (p = 0.043). The results indicate that exercise has no adverse effect on memorization ability. Simultaneous memorization and exercise produced a greater ability to recall words than memorization after or without exercise.

KEY WORDS: Memory, recall, physical activity, cognition

INTRODUCTION

Cognition is composed of several distinct processes including executive functioning, long-term memory, and motor learning. Research has demonstrated that all facets of cognition can be altered by both acute (4, 8, 13, 16, 21-23, 26) and chronic (12, 13, 16, 25) physical activity. Differences in cognition have been exhibited for various modes, intensities, and durations of exercise. There are two leading factors theorized to influence the exercise-cognition relationship: attention and arousal. Attentional theories suggest that exercise itself demands attention and therefore only residual attention is dedicated to cognitive function. Different modes of exercise require varying levels of concentration for safe performance. Hence, activities requiring high attention, such as treadmill running (which requires focus on balance, obstacles, and form), result in decreased cognitive capacity, whereas activities like stationary cycling result in no change in cognition (9, 15). Arousal theories stem from research suggesting that there is an optimal level of arousal during exercise that can contribute to cognitive preservation or facilitation. This ideal level of arousal can be achieved by manipulating duration or intensity of an exercise bout (5, 6, 15-17).

Because there are several aspects of cognition that may be differentially influenced by exercise, it can be difficult to draw conclusions regarding the best way to maximize the cognitive benefits of exercise. In general, ergometer cycling seems to be the best mode for cognitive enhancement (15, 22, 23), with only one study suggesting that intense treadmill running led to enhanced memorization speed (26). Regarding physiological arousal, moderate-intensity exercise is suggested to be favorable for cognition (6, 16, 17, 22). For optimal cognitive outcomes, the duration of exercise also must be optimized. Chang et al. (5) reported that an aerobic training session consisting of a 5-min warm-up, 20-min work period, and 5-min cool down improved general cognition. Meta-analyses have reported that exercise must last at least 20 min for cognitive enhancement to be experienced during exercise (6, 15).

The effect of mode, intensity, duration, or any other aspect of exercise on cognitive function is dependent upon the type of cognition tested. Researchers have identified benefits of acute and chronic exercise on attention and concentration (4, 16), executive function (12, 13, 22, 25), and motor learning (23). However, most of these assessments, while perhaps correlated with ability to learn and perform well scholastically, do not directly contribute to learning. It can be challenging and time-demanding for researchers to develop an environment that would truly mimic the academic environment and level of rigor experienced at the university level. However, it is possible to assess a simple type of learning, which is necessary for higher level cognitive processes. Bloom indicated that all learning is predicated by knowledge, further described as "the retention of specific, discrete pieces of information like facts and definitions (1)." Hence, a simple but effective way to imitate basic academic study is to provide a memorization task with a delayed recall assessment.

Three pertinent studies were identified that assessed long-term memory with a delayed recall test. Winter et al. (26) required participants to undergo a moderate-intensity endurance run, high-intensity running intervals, or control activity prior to audiovisual vocabulary instruction in a foreign language, and it was determined there was no difference between the three conditions one week and at least eight months after initial material presentation. Coles and Tomporowski (8) tested delayed recall before and after 40 min of moderate cycling on an ergometer, ergometer sitting, or watching an educational documentary. It was determined that moderate exercise preserved recall capacity whereas the two rest conditions resulted in declined recall ability after a 12-min delay. In perhaps the most relevant study, Schmidt-Kassow et al. (24) assessed the ability to learn vocabulary in a foreign language during, after, or in the absence of 30 min of light-moderate intensity ergometer cycling. Exercise condition was shown to significantly alter memory, with simultaneous exercise and learning resulting in improved vocabulary recall compared to the control condition 48 hrs later (28.4 ± 9.8 words after simultaneous exercise and study vs. 20.9 ± 7.9 words after relaxed study). Study after exercise did not differ from either of the other experimental conditions (26.6 ± 11.7 words). While

Schmidt-Kassow et al. did evaluate simultaneous study and exercise, the exercise bout was at a relatively low intensity, and all vocabulary was presented aurally as opposed to visually. However, students may be more apt to study visually from textbooks or notes. To better understand the efficacy of study during exercise, research is needed to assess the effect of an acute bout of concurrent moderate-intensity exercise and memorization using visual study materials on recall ability after an extended period.

Therefore, the purpose of this study was to determine if the timing of moderate-intensity cycling, an activity anticipated to be in agreement with both attentional and arousal theories of cognition, modulates memory and learning by assessing the ability of recreationally-active individuals to memorize words under three different conditions - simultaneous study and moderate-intensity exercise, study following moderate-intensity exercise, and study without exercise - and to recall these words 24 hrs later. Based upon prior research, it was anticipated that exercise would not inhibit learning and that one or both exercise conditions would result in augmented recall.

METHODS

Participants

Participants were recruited from summer university courses using flyers and word of mouth. Recreationally active adults, ages 18 to 30 years, were enrolled if they participated in at least 45 min of physical activity three times per week (i.e., 135 min total). A total of 21 participants were evaluated: 11 men and 10 women (see Table 1).

Table 1. Participant characteristics.

Variables	Men (*n* = 11)	Women (*n* = 10)
Age (years)	24.1 ± 1.58	21.6 ± 2.95
BMI (kg/m^2)	23.8 ± 4.24	25.0 ± 4.13
RHR (bpm)	59.4 ± 10.43	60.3 ± 7.2

Note: Data is presented as mean ± SD. BMI= body mass index; kg= kilogram; m=meter; RHR= resting heart rate; bpm= beats per minute

Protocol

Approval for this study was obtained from Utah State University's institutional review board (IRB # 5919, approved 6/2/2014) and each participant provided written informed consent prior to beginning any research activity. Participants were required to complete a physical activity questionnaire to determine eligibility. All exercise was completed on a Monark cycle ergometer (Monark 824E, Vansbro, Sweden) while the participant wore a Polar heart rate monitor (FT1, Polar Electro, Inc., Kempele, Finland) in a quiet, climate controlled laboratory with less than 45% relative humidity and between 18-23° C. Prior to participation, participants recorded their resting heart rate (RHR) immediately after waking in the morning for use in Karvonen's formula for heart rate reserve (HRR) (14), which was used to determine exercise intensity. The complete study design is depicted in Figure 1.

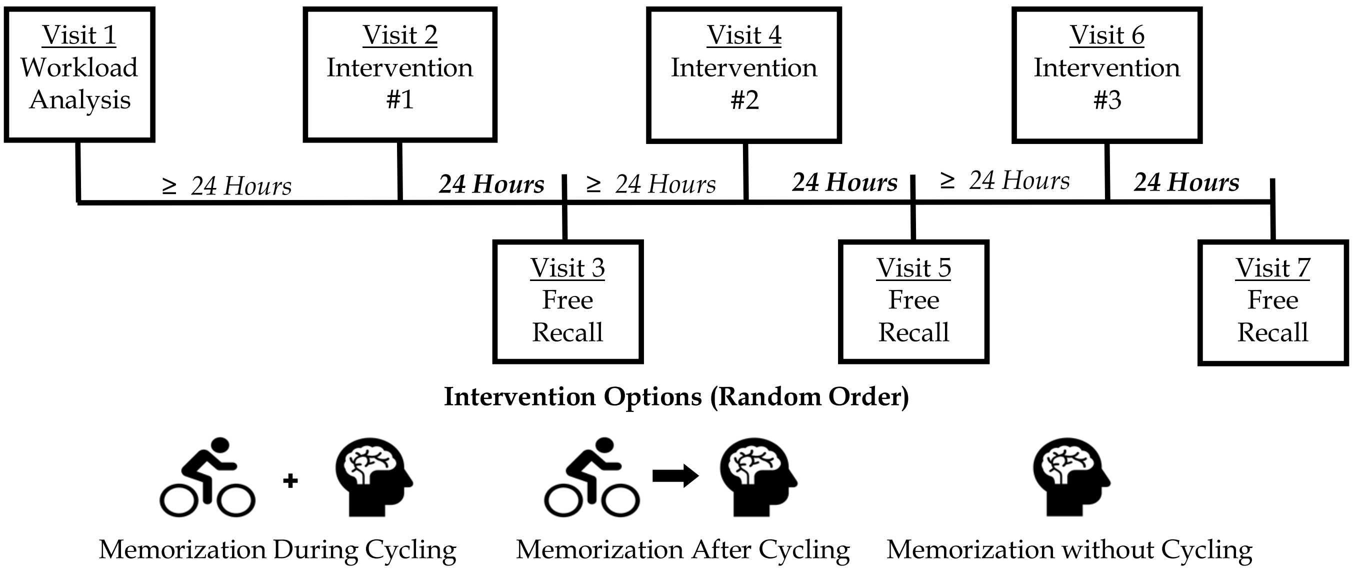

Figure 1. Explanation of study design.

During the first visit, participants were guided through a workload analysis in which researchers determined the revolutions per min (rpm, 60-70 rpm) and resistance that elicited the participant's target rating of perceived exertion (RPE) and HR. RPE was used because researchers anticipated that subjective perception of intensity would influence participant's ability to concentrate. The target RPE for all participants was a 13-15 rating, or somewhat hard to hard (3). The target absolute intensity was no more than 65% of the participant's HRR. In the three intervention visits, participants completed different combinations of study and exercise in a cross-over, randomized, counter-balanced fashion. The possible interventions were: memorization while cycling for 30 min; memorization for 30 min after 30 min of cycling, and 30 min of memorization without exercise. The 30 min of cycling did not include a prescribed warm-up or cool-down though participants were permitted to perform a brief self-directed warm-up or cool-down if they desired. When studying did not occur on the cycle ergometer, participants sat at a desk in a quiet, climate-controlled examination room. Participants were asked to avoid exercise in the 24 hrs preceding or following the intervention visits. Participants returned to the laboratory 24 hrs after each intervention visit to perform a free recall test of the material they memorized the day prior. Each participant waited a minimum of 24 hrs after a recall test before reporting for the next assigned condition.

The memorization material was a list of 100 nouns and participants were instructed to memorize as many as possible. The method of word list creation was replicated from the work of Coles and Tomporowski (8). The word lists were compiled and randomized using the findings of Paivio et al. who assessed 925 nouns for concreteness, imagery, and meaningfulness (20). Researchers selected 300 nouns from this analysis that exhibited high levels of imagery and concreteness (imagery score ≥ 6, concreteness score ≥ 5.7) without regard for meaningfulness.

Researchers divided the 300 nouns into three master lists, each with 100 unique words. Every participant used each list once in random order.

During assessment of recall, each participant was given a sheet of paper, numbered to 100, and were instructed to write as many words as possible, regardless of order, from the list they studied 24 hrs earlier. Participants were given unlimited time for recall, but few exceeded 20 min. This testing scheme was designed to function as an extended free-recall test.

Statistical Analysis
An *a priori* power analysis (G*Power 3.1, Dusseldorf, Germany) was conducted to determine sample size using $\alpha = 0.05$, power = 0.80, and effect size = 0.4. The effect size value was selected based upon data reported by Lambourne et al. (15) who found improved cognition when exercise lasted at least 20 min with an effect size of 0.39. The estimated total sample size for this effect was 64. A total of 21 participants completed the three conditions in a randomized counterbalanced crossover design, creating a total of 63 data points. Data were analyzed in SAS 9.4 (SAS Institute, Cary, NC) and all data are reported as mean ± standard deviation (SD). The number of words correctly recalled, with no regard for order, was the outcome measure. The outcome measure was first assessed for normality visually and using the Shapiro Wilk test. A 3 x 6 nested mixed-measures ANOVA was conducted using main effects for exercise intervention, visit number, order of intervention, and participant nested within order. This research necessitated a participant (or individual) effect because every participant did not experience every order. Because this analysis utilized order (i.e., the interaction of visit number and intervention) as a covariate, interactions were not assessed in the model. Cohen's *d* was calculated as a measure of effect size. *A priori,* researchers planned to construct contrasts using the conservative Scheffé correction method, which maximally controls error rate, to analyze combinations of groups. A significance level of $\alpha = 0.05$ was used.

RESULTS

The number of words correctly recalled was assessed for each intervention and is presented in Table 2. The order in which the interventions were encountered did not affect the ability to recall words ($F_{5,15} = 1.11$, $p = 0.396$). The visit number when a participant encountered the intervention was also not significant ($F_{2,38} = 1.53$, $p = 0.230$), indicating a negligible learning effect. The effect of participant nested within order was revealed to be statistically significant ($F_{15,38} = 9.53$, $p = < 0.001$), suggesting that individual memorization ability significantly impacted results. The effect of exercise intervention was not significant ($F_{2,38} = 2.24$, $p = 0.121$). Researchers performed specific hypothesis testing following means analysis using Scheffé-corrected contrasts which demonstrated that when comparing memorization while exercising to the other two interventions, memorization during exercise resulted in significantly better word recall 24 hrs later ($F_{1,38} = 4.40$, $p = 0.043$) (see Table 2). Another contrast revealed that there was no difference between the control intervention and the combined effect of both exercise interventions ($F_{1,38}= 0.64$, $p = 0.4294$).

Table 2. Summary of 24 hrs recall ability.

Variables	Average Word Recall (95% CI)	Cohen's d
Study While Exercising	51.5 ± 19.8* (42.5, 60.5)	0.27
Study After Exercising	45.1 ± 20.6 (35.7, 54.5)	-0.03
Study Without Exercise	45.7 ± 23.3 (35.1, 56.3)	--

Note: CI = confidence interval. Data is presented as mean ± SD. Cohen's *d* calculated with Study Without Exercise as the control group. * $p = 0.043$, significantly different from combined average of other interventions using Scheffé Contrasts

DISCUSSION

The results of this research suggest that the proximity of a single exercise bout to studying does not inhibit the ability to recall information 24 hrs after exposure to the information, even if studying and exercise are pursued simultaneously. Further, based on the results, the authors suggest that the effect of studying during exercise is beneficial compared to the combined effect of studying after or without exercise. These results imply that individuals who choose to participate in self-directed learning or studying during a moderate intensity cycling workout will not be limited cognitively.

By accounting for the visit number and the various orders, it was determined that there was not a significant learning effect, meaning that participants did not become significantly better at the recall task with repeated task performance. As expected, the analysis demonstrated that the recall capacity after the memorization task was participant-dependent. Some participants found memorization to be an easy task, recalling nearly 90 words on each recall test, while others struggled to recall many words. This large variability in participants led to a range of 87 in the number of words correctly recalled. The individual nature of memorization documented in this research is likely due to factors modifying memorization capacity (e.g., motivation, environment, previous exposure and experience, etc.) as well as memorization techniques. Participants who previously had more need to memorize material outside of this research had likely developed useful skills (i.e., imagery or creation of pneumonic devices) that aided their performance in this protocol. Less experienced memorizers may have relied primarily on rote memorization. This discrepancy in memorization techniques and abilities, coupled with the sample size, could limit the statistical power of this investigation.

Based upon prior research, it was expected that (1) exercise timing would not inhibit recall and (2) that one or both exercise conditions would result in higher recall than memorization without exercise. These hypotheses were built upon the work of other researchers who revealed exercise in proximity to cognitive testing or memory tasks led to better performance (6, 13, 26). While the effect of memorization during exercise was small and did not necessarily indicate improvement, exercise did not hinder recall ability, as there was no statistical difference between any of the conditions. This finding, in and of itself, is promising, as it suggests that multi-tasking may not be detrimental at this exercise intensity and mode. However, further hypothesis testing demonstrated that simultaneous exercise and study resulted in a positive increase in recall ability compared to the combined effects of the other two conditions, suggesting that the attentional demands and physiological arousal caused by this work bout created a promising setting for memorization. This discovery is similar to that of Schmidt-Kassow et al. (24) who noted that light-moderate exercise during memorization of aurally presented novel vocabulary words resulted in better recall capacity 48 hrs later. However, the present study uses a higher intensity suggesting that moderately-intense cycling may also create a beneficial environment for encoding of memories. This result strengthens the implications for students who desire to multitask by reviewing course materials during a workout. Also, the present research provides evidence that the encoding of facts from visual information (e.g., the word list) without aural presentation of information is not inhibited during exercise. This aspect of this study is important, as students may only have access to visual study aides as opposed to audio recordings.

This study produces evidence that would support the concept of an "active classroom" in which students would cycle on an ergometer during educational encounters. Based on the results of this study, we would expect to see courses utilizing the "active classroom" model to score as well or better than a standard classroom. Several researchers have found that active workstations (50 min of low-intensity treadmill walking) do not detrimentally affect cognitive ability and concentration, while simultaneously combatting sedentary behavior (2, 10). Children have been shown to have increased scores in several subjects when they participate in 20-30 min of moderate-vigorous intensity physical activity during instructional periods (18, 19). Concentration has also been shown to be improved in children who perform 15 min of moderate-vigorous physical activity during school lessons (11). Given the propensity toward sedentariness in our culture, active classrooms may be a good way to introduce greater physical activity into student lives, without compromising the purposes of the classroom. The present study supports the use of moderate-intensity exercise during learning periods, which may result in greater aerobic fitness and preserved education.

Our investigation is not without limitations. First, the study is likely moderately underpowered and would have been strengthened with a larger sample, as the noted effect size is not as large as was anticipated during sample size planning. Second, it is likely that the relationship between cognitive capacity and exercise is influenced by aerobic fitness and this study could have been strengthened by assessing maximal aerobic capacity or utilizing more restrictive physical activity requirements. Individuals with lower aerobic fitness likely experienced higher heart rates, respiration rates, and attentional demands than those who were more fit. This would have potentially conflicted with both the attentional and arousal theories of exercise and cognition. Third, it would have been beneficial to assess long-term memory using a standardized and validated test at the beginning of the study, to allow research to account for individual memorization capacity. Because memorization can be influenced by a multitude of factors (i.e., motivation, concentration, previous experience with the task, etc.), beginning the study with a validated assessment of memory would have enabled researchers to present a better picture of the relative influence of the exercise intervention, as opposed to the absolute effect of exercise. Fourth, participants did not complete a standardized warm-up, which while more similar to what each individual would do outside of the research, adds an element of variability. Future studies should utilize a brief but standardized warm up and cool down protocol as opposed to those which are self-guided.

While this research attempted to quantify the effect of exercise on studying, it would be interesting to know the effect of studying on exercise quality. Future researchers may aim to understand if multi-tasking leads to diminished workout quality, intensity, or duration. While a variety of procedures have been employed to assess the impact of multi-tasking on learning with contradictory results (7), no identified research has investigated the effect on exercise output when participants perform an additional unrelated task during an exercise bout. Additionally, future research may want to evaluate if other modes of exercise, for instance ellipticals or graded treadmill walking, have a similar relationship with regard to memory and recall. It would likewise be worthwhile to research the influence of the presence of music and musical selection on recall when exercise and study occur concurrently.

This is the first study of its kind to provide a visual memorization task during moderate-intensity exercise and to test for delayed recall after a night of sleep. Despite the previously mentioned limitations, it is important to note that this research indicates that studying may safely be combined with moderate intensity cycling exercise without any compromise in ability to recall memorized information. Future research should test higher levels of cognitive learning such as comprehension, application, or analysis (1) using a traditional college course. In addition to further exploration into the active classroom design, research should also focus on the efficacy of studying during exercise when higher-order cognitive processes are requisite for success.

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REFERENCES

1. Adams NE. Bloom's taxonomy of cognitive learning objectives. J Med Libr Assoc 103(3): 152-153, 2015.

2. Alderman BL, Olson RL, Mattina DM. Cognitive function during low-intensity walking: A test of the treadmill workstation. J Phys Act Health 11(4): 752-758, 2014.

3. Borg Gav. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14(5): 377-381, 1982.

4. Budde H, Voelcker-Rehage C, Pietrabyk-Kendziorra S, Ribeiro P, Tidow G. Acute coordinative exercise improves attentional performance in adolescents. Neurosci Lett 441(2): 219-223, 2008.

5. Chang YK, Chu CH, Wang CC, Wang YC, Song TF, Tsai CL, Etnier JL. Dose-response relation between exercise duration and cognition. Med Sci Sports Exerc 47(1): 159-165, 2015.

6. Chang YK, Labban JD, Gapin JI, Etnier JL. The effects of acute exercise on cognitive performance: A meta-analysis. Brain Res 1453(2012): 87-101, 2012.

7. Clarebout G, Coens J, Elen J. The use of ipods in education: The case of multi-tasking. In. *Beyond knowledge: The legacy of competence (ch 7)*: Springer; 2008.

8. Coles K, Tomporowski PD. Effects of acute exercise on executive processing, short-term and long-term memory. J Sports Sci 26(3): 333-344, 2008.

9. Dietrich A. Functional neuroanatomy of altered states of consciousness: The transient hypofrontality hypothesis. Conscious Cogn 12(2): 231-256, 2003.

10. Ehmann PJ, Brush CJ, Olson RL, Bhatt SN, Banu AH, Alderman BL. Active workstations do not impair executive function in young and middle-age adults. Med Sci Sports Exerc 49(5): 965-974, 2017.

11. Grieco LA, Jowers EM, Errisuriz VL, Bartholomew JB. Physically active vs. sedentary academic lessons: A dose response study for elementary student time on task. Prev Med 89(2016): 98-103, 2016.

12. Hillman CH, Pontifex MB, Castelli DM, Khan NA, Raine LB, Scudder MR, Drollette ES, Moore RD, Wu CT, Kamijo K. Effects of the fitkids randomized controlled trial on executive control and brain function. Pediatrics 134(4): e1063-1071, 2014.

13. Hopkins ME, Davis FC, Vantieghem MR, Whalen PJ, Bucci DJ. Differential effects of acute and regular physical exercise on cognition and affect. Neuroscience 215(2012): 59-68, 2012.

14. Karvonen MJ, Kentala E, Mustala O. The effects of training on heart rate; a longitudinal study. Ann Med Exp Biol Fenn 35(3): 307-315, 1957.

15. Lambourne K, Tomporowski P. The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. Brain Res 1341(2010): 12-24, 2010.

16. Loprinzi PD, Kane CJ. Exercise and cognitive function: A randomized controlled trial examining acute exercise and free-living physical activity and sedentary effects. Mayo Clin Proc 90(4): 450-460, 2015.

17. Mekari S, Fraser S, Bosquet L, Bonnery C, Labelle V, Pouliot P, Lesage F, Bherer L. The relationship between exercise intensity, cerebral oxygenation and cognitive performance in young adults. Eur J Appl Physiol 115(10): 2189-2197, 2015.

18. Mullender-Wijnsma MJ, Hartman E, de Greeff JW, Bosker RJ, Doolaard S, Visscher C. Improving academic performance of school-age children by physical activity in the classroom: 1-year program evaluation. J Sch Health 85(6): 365-371, 2015.

19. Mullender-Wijnsma MJ, Hartman E, de Greeff JW, Doolaard S, Bosker RJ, Visscher C. Physically active math and language lessons improve academic achievement: A cluster randomized controlled trial. Pediatrics 137(3): e20152743, 2016.

20. Paivio A, Yuille JC, Madigan SA. Concreteness, imagery, and meaningfulness values for 925 nouns. J Exp Psychol 76(1): Suppl:1-25, 1968.

21. Potter D, Keeling D. Effects of moderate exercise and circadian rhythms on human memory. J Sport Exerc Psychol 27(1): 117-125, 2005.

22. Quelhas Martins A, Kavussanu M, Willoughby A, Ring C. Moderate intensity exercise facilitates working memory. Psychol Sport Exerc 14(3): 323-328, 2013.

23. Roig M, Skriver K, Lundbye-Jensen J, Kiens B, Nielsen JB. A single bout of exercise improves motor memory. PLoS One 7(9): e44594, 2012.

24. Schmidt-Kassow M, Deusser M, Thiel C, Otterbein S, Montag C, Reuter M, Banzer W, Kaiser J. Physical exercise during encoding improves vocabulary learning in young female adults: A neuroendocrinological study. PLoS One 8(5): e64172, 2013.

25. Venckunas T, Snieckus A, Trinkunas E, Baranauskiene N, Solianik R, Juodsnukis A, Streckis V, Kamandulis S. Interval running training improves cognitive flexibility and aerobic power of young healthy adults. J Strength Cond Res 30(8): 2114-2121, 2016.

26. Winter B, Breitenstein C, Mooren FC, Voelker K, Fobker M, Lechtermann A, Krueger K, Fromme A, Korsukewitz C, Floel A, Knecht S. High impact running improves learning. Neurobiol Learn Mem 87(4): 597-609, 2007.