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The Experimental Effects of Acute Exercise on Reducing the Amount of Re-Learning Needed to Enhance Memory Recall

Dylan DELANCEY, Paul D. LOPRİNZİ

Exercise & Memory Laboratory, Department of Health, Exercise Science and Recreation Management, The University of Mississippi University, MS 38677, USA

Abstract

Emerging research suggests that acute exercise may subserve episodic memory function, including both short- and long-term memory. What has yet to be investigated in the literature is whether acute exercise can increase "savings", that is, reduce the amount of re-learning needed to enhance recall, which was the purpose of this experiment. Participant were randomized into an experimental exercise group (15-minute moderate-intensity exercise) or a time-matched control group. The Open-Trial Selective Reminding Test (OT-SRT) was used to assess memory function, which was assessed at baseline and 4-hours later. The exercise group (vs. the control group) had slightly more favorable values. For the exercise and control groups, respectively, the number of words recalled after the first exposure to the word list (outcome 1) was 6.10 (1.6) and 5.95 (1.0). In these respective groups, it took the exercise group slightly fewer trials (outcome 2) to retrieve to criterion (5.95 (1.5) vs. 6.35 (1.8)). After the 20-minute delay (outcome 3), the exercise group recalled slightly more words (12.4 (1.6) vs. 12.15 (2.0)). Similarly, after the 4-hour delay (outcome 4), the exercise group recalled slightly more words (11.55 (2.4) vs. 11.25 (2.4). Lastly, for this 4-hour delayed assessment, it took the exercise group slightly fewer trials (outcome 5) to retrieve to criterion (3.00 (0.9) vs. 3.05 (0.7)). However, for the 2 (group) x 5 (outcomes) RM-ANOVA, there was no significant main effect for group ($F=0.07$, $P=.79$, $\eta 2p=.002$) or group by time interaction ($F=.25$, $P=.90$, $\eta 2p=.007$). In conclusion, acute exercise was not associated with better memory function or increased savings. Future work on this novel paradigm is warranted.

Keywords: Consolidation, encoding, episodic, physical activity

Öz

Akut Egzersizin Bellek Geri Çağrısını Geliştirmek İçin Gerekli Yeniden Öğrenme Miktarının Azaltılması Üzerine Deneysel Etkileri

Giderek artan miktarda araştırma, akut egzersizin hem kısa hem de uzun süreli bellek dahil olmak üzere epizodik bellek işlevine hizmet ettiğini göstermektedir. Literatürde henüz araştırılmamış olan, akut egzersizin "kaydedilenleri" arttırıp arttırmayacağı, yani bu deneyin amacı olan hatırlamayı geliştirmek için gereken yeniden öğrenme miktarını azaltıp azaltmadığıdır. Katılımcılar, egzersiz grubuna (15 dakikalık orta şiddette egzersiz) ve zaman uyumlu bir kontrol grubuna rastgele dağıltılmıştır. Açık Deneme Seçici Hatırlatma Testi (OT-SRT), başlangıçta ve 4 saat sonra değerlendirilen bellek fonksiyonunu değerlendirmek için kullanılmıştır. Egzersiz grubu (kontrol grubuna göre) biraz daha iyi değerlere sahipti. Egzersiz ve kontrol grupları için sırasıyla kelime listesine ilk maruz kaldıktan sonra hatırlanan kelime sayısı (sonuç 1) 6.10 (1.6) ve 5.95 (1.0) idi. Bu ilgili gruplarda, egzersiz grubuna kriterlere (5.95 (1.5) ve 6.35 (1.8)) ulaşmak için biraz daha az deneme (sonuç 2) uygulandı. 20 dakikalık gecikmeden sonra (sonuç 3), egzersiz grubu biraz daha fazla kelime hatırladı (12.4 (1.6) ve 12.15 (2.0)). Benzer şekilde, 4 saatlik bir gecikmeden sonra (sonuç 4), egzersiz grubu biraz daha fazla kelime hatırladı (11.55 (2.4) ve 11.25 (2.4). Son olarak, bu 4 saatlik gecikmeli değerlendirme için egzersiz grubu biraz daha az deneme aldı. (sonuç 5) kritere (3.00 (0.9) vs. 3.05 (0.7) karşılık) Ancak, 2 (grup) x 5 (sonuçlar) RM-ANOVA için zaman etkileşimi ile grup ($F = 0.07$, $P = .79$, $\eta 2p = .002$) veya grup için önemli bir ana etkiye sahip değildi. ($F = .25$, $P = .90$, $\eta 2p = .007$). Sonuç olarak, akut egzersiz daha iyi bellek fonksiyonu veya artan kayıt ile ilişkili değildi. Bu yeni paradigma üzerine gelecekteki çalışmalar önerilmektedir.

Anahtar Sözcükler: Konsolidasyon, kodlama, epizodik, fiziksel aktivite

Correspondence / *Yazışma:*
Paul D. LOPRINZI
Exercise & Memory Laboratory, Department of Health, Exercise Science and Recreation Management, The University of Mississippi University, MS 38677, USA
Tel: 662-915-5561
E-mail: pdloprin@olemiss.edu

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INTRODUCTION

Memory plays an important role in social functioning and quality of life (Kuiper et al., 2016; Sohrabi et al., 2009) as well as higher-level cognition (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). In terms of short- and long-term memory, episodic memory refers to the memory of an event or an “episode”. Working memory capacity and executive function share a common underlying executive attention that is strongly predictive of higher-level cognitive function, including episodic memory (McCabe et al., 2010).

An evaluation of the physical activity-cognition link across the life span provides modest support for the effect of physical activity on preserving and even enhancing cognitive vitality and the associated neural circuitry in older adults, with the majority of benefits seen for tasks that are supported by the prefrontal cortex and the hippocampus (Chang, Labban, Gapin, & Etnier, 2012; Prakash, Voss, Erickson, & Kramer, 2015). The literature on younger adults, however, is in need of well-designed randomized controlled trials (Engeroff, Ingmann, & Banzer, 2018; Loprinzi, Frith, Edwards, Sng, & Ashpole, 2017b; Prakash et al., 2015). Notably, far less research on exercise and memory function has been conducted among young adults (Etnier et al., 2016; Haynes IV, Frith, Sng, & Loprinzi, 2018; Loprinzi et al., 2017b). This population is important to study as memory may start to decline in the third and fourth decade of life (Salthouse, 2009). Thus, it is critical to identify behavioral strategies (e.g., exercise) that can attenuate this age-associated memory impairment.

With regard to the temporal effects of exercise on memory function (Haynes IV et al., 2018; Labban & Etnier, 2011; Pontifex, Gwizdala, Parks, Pfeiffer, & Fenn, 2016; Roig, Nordbrandt, Geertsen, & Nielsen, 2013; Roig et al., 2016; Siddiqui & Loprinzi, 2018), recent studies have shown that exercise before encoding a memory, as opposed to exercise after or during encoding a memory, may be more optimal in the retrieval of a memory (Frith, Sng, & Loprinzi, 2017; Roig et al., 2013; Siddiqui et al., 2018; Sng, Frith, & Loprinzi, 2017). Although speculative, this may be a result of exercise, prior to memory encoding, helping to facilitate cognitive attention (Muzzio, Kentros, & Kandel, 2009). Further, exercise prior to the memory encoding may help to facilitate CREB-1 levels (Chen & Russo-Neustadt, 2009) as well as neuronal excitability (Cunha, Brambilla, & Thomas, 2010; Zoladz & Pilc, 2010), thus helping to prime neuronal cells into encoding a particular memory (Loprinzi, Edwards, & Frith, 2017a; Rendeiro & Rhodes, 2018).

In addition to acute exercise potentially helping to facilitate short-term memory, albeit limited, there is evidence to suggest that exercise may also help to precipitate long-term memory (Frith et al., 2017; Labban et al., 2011). In part, this may be a function of exercise-induced modulation of proteins (e.g., BDNF) and receptors (e.g., NMDA) involved in the synaptic- and brain-systems level of memory consolidation (Cunha et al., 2010; Zoladz et al., 2010). If, however, the memory is not successfully encoded or consolidated, memory retrieval will be diminished.

What has been less investigated is the effects of exercise on minimizing forgetting. Recently, Hotting et al. demonstrated that high-intensity exercise was not associated with memory recall, but was associated with attenuating the loss of vocabulary 24-hours after learning (Hotting, Schickert, Kaiser, Roder, & Schmidt-Kassow, 2016). The classic Ebbinghaus forgetting curve from 1880 (“Ebbinghaus H (1880) Urmanuskript “Ueber das Gedächtniß”. Passau: Passavia Universitätsverlag,”) has been recently replicated (Murre & Dros, 2015), demonstrating a non-linear decline in memory recall as time progresses. The effect of exercise on this forgetting curve is unknown. Various moderators of the forgetting paradigm exist. Initial learning criterion refers to the number of times an item is tested and successfully recalled during the initial learning (Pyc & Rawson, 2009). Relatedly, successive re-learning refers to when retrieval success is achieved across multiple re-learning sessions (Bahrick, Bahrick, Bahrick, & Bahrick, 1993). Successful retrieval of previously forgotten information can help facilitate future retention, demonstrating that forgetting may be an enabler as opposed to a disabler (Storm, Bjork, & Bjork, 2008). Research demonstrates that a higher initial learning criterion may be advantageous for immediate memory retrieval, but this effect is attenuated with subsequent re-learning sessions. The beneficial effects of re-learning, or spaced learning, as opposed to massed training (high initial learning criterion) has received research interest regarding its biological etiology. After an initial learning session, the repressor CREB (cAMP Response Element Binding protein) isoform blocks the activator CREB isoform, and after a delay, the activator CREB isoform accumulates to a greater extent than the repressor CREB isoform, helping to facilitate memory consolidation (Smolen, Zhang, & Byrne, 2016).

Thus, at this point, there is evidence demonstrating that acute exercise may help to facilitate memory function (Frith et al., 2017; Loprinzi et al., 2017a; Roig et al., 2013) and that a re-learning session (or multiple spaced, re-learning sessions) can be advantageous in memory retrieval. Given the time-restraints of college students, it would be advantageous if the duration of the re-learning session was relatively short, yet still effective in enhancing subsequent memory retrieval. Thus, the purpose of this study was to evaluate if exercise can reduce the amount of time spent during the re-learning phase, but still be effective in enhancing subsequent memory retrieval. Importantly, the success and amount of re-learning is likely to be heavily influenced by the initial degree of memory encoding. Thus, and unlike nearly all exercise and memory-based studies, in this study we employ a technique (Open-Trial Selective Reminding Test (OT-SRT)) to ensure that memory encoding is the same between the exercise and control groups. This is crucial in order to be able to ensure that potential exercise-improvements in long-term memory and re-learning is really a result of exercise, as opposed to just a temporary enhancement in memory encoding.

We hypothesize the following: 1) that exercise (vs. control) prior to memory encoding will enhance immediate memory recall, 2) an initial re-learning session immediately after initial memory recall will result in similar short-term memory, and thus, memory encoding, in both groups (exercise and control), but 3) after a second re-learning session to occur 3-5 hours post-memory encoding, those in the exercise group will spend less time re-learning the material and will outperform the control group on the subsequent, delayed memory recall task.

METHODS

Study Design

The present experiment was a two-arm parallel group randomized controlled trial. One group was an exercise group and the other was a control group. This study was approved by the University of Mississippi's ethics committee and participants provided written consent prior to participation.

Participants

Each group included 20 participants (N=40), which aligns with other related experiment work on this topic demonstrating adequate statistical power (Crush & Loprinzi, 2017; Frith et al., 2017; Loprinzi & Kane, 2015). Recruitment occurred via a convenience-based, non-probability sampling approach (classroom announcement and word-of-mouth). Participants included undergraduate and graduate students between the ages of 18 and 35 yrs.

Similar to other work (Yanes & Loprinzi, 2018), participants were excluded if they:

Self-reported as a daily smoker (Jubelt et al., 2008; Klaming, Annese, Veltman, & Comijs, 2016)

Self-reported being pregnant (Henry & Rendell, 2007)

Exercised within 5 hours of testing (Labban et al., 2011)

Consumed caffeine within 3 hours of testing (Sherman, Buckley, Baena, & Ryan, 2016)

Had a concussion or head trauma within the past 30 days (Wammes, Good, & Fernandes, 2017)

Took marijuana or other illegal drugs within the past 30 days (Hindocha, Freeman, Xia, Shaban, & Curran, 2017)

Were considered a daily alcohol user (>30 drinks/month for women; >60 drinks/month for men) (Le Berre, Fama, & Sullivan, 2017)

Exercise Protocol

Those randomized to the exercise group walked on a treadmill for 15 minutes at a self-selected "brisk walk", with their pace being a pace as if they were late for class or to catch a bus, with a minimum speed of 3.0 mph. We have previously shown that this exact exercise stimulus is sufficient to enhance episodic memory (Sng et al., 2017). The bout of exercise occurred prior to the initial memory assessment. Immediately after the bout of exercise, participants rested in a seated position for 5 minutes. After this resting period, they commenced the initial memory assessment, as described below.

Control Protocol

Those randomized to the control group completed a medium-level, on-line administered, Sudoku puzzle for 20-minutes (time-matched to the exercise group). The website for this puzzle is located here: https://www.websudoku.com/

Memory Assessment

Verbal learning and memory was assessed using a slightly modified version of the Open-Trial Selective Reminding Test (OT-SRT) (Chiaravalloti, Balzano, Moore, & DeLuca, 2009). Specifically, instead of employing 10 words per trial, we employed 15 words per trial. This modification was made given our relatively healthy sample and the potential concern of a ceiling effect. Additionally, this number of words aligns with our previous experimental work on this topic (Frith et al., 2017).

Procedures

- After the 5-minute post-exercise rest period (or the 20-min control period), the memory assessment commenced.
- Participants listened to the list of 15 words from an audio recording where each word was said aloud every 1.5 seconds.
- After hearing this list via headphones, the participant repeated as many words back as possible (**outcome 1**).
- The researcher then informed the participant of the words they missed.
- The participant then re-listened to the list.
- The participant repeated as many words back as possible.
- The researcher then informed the participant of the words they missed. This process continued until the participant recalled at least 14/15 words on two consecutive trials (max attempts is 15 trials). The number of trials was recorded (**outcome 2**).
- The participant then watched a video for 20-minutes. This served as a distractor for the follow-up memory assessment.
- Then after the video, the participant recalled as many words as possible without listening to the list (**outcome 3**).
- The participant then left the laboratory and came back to the laboratory 4 hours later (range, 3-5 hrs). Participants were instructed not to exercise during this period.
- Then when they arrived back in the laboratory, the participant recalled as many words as possible without listening to the list (**outcome 4**).
- After this initial recall, they listened to the list and recalled as many words as possible. The researcher informed the participant of the words they missed. They then re-listened to the list. This process continued until the participant got at least 14/15 words on two consecutive trials. The number of trials was recorded (**outcome 5**).

Additional Assessments

At the beginning of the baseline assessment, various behavioral and psychological assessments were completed to ensure that the two groups were similar on these parameters. To assess mood status, participants completed the Positive and Negative Affect Schedule (PANAS) (Watson, Clark, & Tellegen, 1988). For this mood survey, participants rated 20 items (e.g., excited, upset, irritable, attentive) on a Likert scale (1, very slightly or not at all; to 5, extremely), with half of the items constituting a "positive" mood state, with the other half being a "negative" mood state. As a measure of habitual physical activity behavior, and reported as time spent per week in moderate-to-vigorous physical activity (MVPA), participants also completed a survey (Physical Activity Vital Signs Questionnaire) (Ball, Joy, Gren, & Shaw, 2016). Also, waist circumference was measured to provide anthropometric characteristics of the sample.

Statistical Analysis

All analyses were computed in SPSS (v. 22). A 2 (group) x 5 (time) repeated measures ANOVA (RM-ANOVA) was used. Group (exercise vs. control) served as the between subject variable and time served as the within subject variable. The five time points are the five outcomes noted above. Statistical significance was established as a nominal alpha of 0.05.

RESULTS

Table 1 displays the demographic and behavioral characteristics of the study groups. Both groups were similar regarding age, gender, race-ethnicity and all other characteristics (all P's>0.05). Table 2 displays the main outcome (memory scores) across the study groups. For each of the five outcome variables, the exercise group (vs. the control group) had slightly more favorable values. For the exercise and control groups, respectively, the number of words recalled after the first exposure to the word list (outcome 1) was 6.10 (1.6) and 5.95 (1.0). In these respective groups, it took the exercise group slightly fewer trials (outcome 2) to retrieve to criterion (5.95 (1.5) vs. 6.35 (1.8)). After the 20-minute delay (outcome 3), the exercise group recalled slightly more words (12.4 (1.6) vs. 12.15 (2.0)). Similarly, after the 4-hour delay (outcome 4), the exercise group recalled slightly more words (11.55 (2.4) vs. 11.25 (2.4). Lastly, for this 4-hour delayed assessment, it took the exercise group slightly fewer trials (outcome 5) to retrieve to criterion (3.00 (0.9) vs. 3.05 (0.7)). A visual schematic of these results is shown in Figure 1.

Although the exercise group (vs. control) had slightly more favorable results for each of the 5 outcomes, these differences were not statistically significant. For the 2 (group) x 5 (outcomes) RM-ANOVA, there was a significant main effect for time (F=146.7, P<.001, η^2_p=.94), but there was no significant main effect for group (F=0.07, P=.79, η^2_p=.002) or group x time interaction (F=.25, P=.90, η^2_p=.007).

Table 1: Characteristics of the study variables

Variable	*Exercise (N=20)*	*Control (N=20)*
Age, mean years	21.8 (2.3)	20.9 (1.2)
% Female	70.0	75.0
% white	70.0	65.0
Waist circumference, mean cm	80.3 (8.0)	85.4 (14.9)
% Taking medication to regulate mood	5.0	0.0
Affect, mean		
Positive	28.9 (6.2)	30.0 (7.6)
Negative	11.7 (3.0)	11.8 (2.0)
MVPA, mean min/week	216.7 (150.5)	145.0 (113.7)
Heart Rate, mean bpm		
Resting	74.6 (10.3)	78.7 (9.7)
Mid-Exercise	120.7 (18.9)	-
End-of-Exercise	123.4 (20.9)	-
5-Min Post Exercise	85.2 (14.6)	-

Values in parentheses are SD estimates, **CM:** centimeters, **MVPA:** Moderate to vigorous physical activity.

Table 2: Memory outcome scores (means/SD) between the exercise and control groups

Variable	*Exercise (N=20)*	*Control (N=20)*
Outcome 1 - # of words recalled from initial baseline assessment	6.10 (1.6)	5.95 (1.0)
Outcome 2 - # of trials it took to recall at least 14/15 words during the baseline assessment	5.95 (15)	6.35 (1.8)
Outcome 3 - # of words recalled after the 20-min delay period	12.40 (1.6)	12.15 (2.0)
Outcome 4 - # of words recalled after the 4-hour delay period	11.55 (2.4)	11.25 (2.4)
Outcome 5 - # of trials it took to recall at least 14/15 words during the 4-hour delay assessment	3.00 (0.9)	3.05 (0.8)

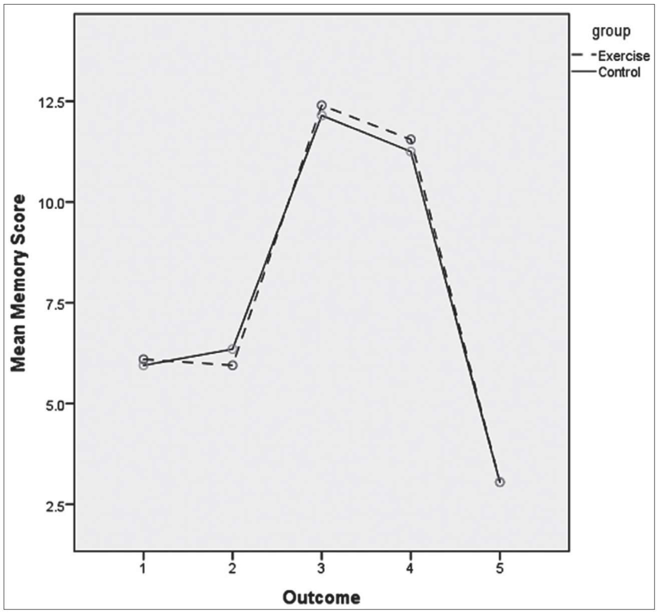

Figure 1. Memory scores for the experimental and control groups across the 5 outcome assessments.

Outcome 1 - # of words recalled from initial baseline assessment

Outcome 2 - # of trials it took to recall at least 14/15 words during the baseline assessment

Outcome 3 - # of words recalled after the 20-min delay period

Outcome 4 - # of words recalled after the 4-hour delay period

Outcome 5 - # of trials it took to recall at least 14/15 words during the 4-hour delay assessment

DISCUSSION

Previous experimental work demonstrates that acute exercise can enhance episodic memory function (Crush et al., 2017; Frith et al., 2017; Loprinzi et al., 2015). Such beneficial effects may depend on age (younger adults appear to have greater benefits) as well as the modality of exercise (walking appears optimal), intensity (low- to moderate-intensity appears optimal), duration (< 20 minutes appears optimal), and the timing of exercise (exercise prior to encoding appears optimal) (Roig et al., 2013). However, and similar to the present investigation, future work in this field should ensure that the experimental groups under investigation have similar levels of memory encoding, particularly if the outcome measure is long-term memory. Thus, our findings likely differ from other relevant studies given that we ensured that both groups had the same level of memory encoding. Another gap in the literature is whether acute exercise can increase "savings" or reduce the amount of time spent re-learning the memory stimuli, which was the objective of the present experiment. Our findings demonstrate that acute exercise was slightly superior in enhancing memory recall and memory savings; however, these results were not statistically significant. Thus, at the present moment, these findings do not provide strong evidence that acute exercise can reduce the amount of time spent re-learning material to criterion.

Given the novelty of this paradigm (exercise and memory savings), additional work on this topic is needed, particularly before any strong conclusions can be rendered. Although we stress the importance of encoding to criterion (via OT-SRT), it may be worth considering whether acute exercise can increase savings when this restriction is lifted. That is, perhaps acute exercise may influence savings by enhancing initial memory encoding, to a greater extent than a non-exercise stimulus. Further, we limited our delayed free recall and re-learning session to occur four hours post memory encoding. Given that other work has demonstrated long-term memory effects from exercise (Roig et al., 2013), perhaps a longer follow-up period would lend itself to observing a savings effect from acute exercise. Although not creative, it may also be worth evaluating whether various factors, such as age, exercise modality, intensity, and temporality, moderate the potential relationship between acute exercise and re-learning related savings.

In conclusion, the results of this experiment do not provide strong evidence that acute moderate-intensity exercise may enhance free recall and memory savings. Future work on this novel paradigm is warranted. Such work should consider this paradigm while employing a high-intensity bout of acute exercise, which appears to be superior than moderate-intensity exercise in enhancing episodic memory function (Crawford & Loprinzi, 2019; Loprinzi, 2018; Tillman & Loprinzi, 2019).

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