

The Effects of Acute Exercise on Episodic Memory Subtypes: Free, Cued, Serial Recall and Recognition

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Abstract

The objective of this study was to comprehensively evaluate the experimental effects of acute moderate-intensity aerobic exercise on various episodic memory subtypes, including free, cued, serial recall and recognition. We employed a two-arm, between-subject randomized controlled experiment ($M_{age}=20$ y; $N=20$ per group), with participants engaging in a 15-minute moderate-intensity bout of aerobic exercise or engaged in a time-matched seated task. Free (including short-and long-term), cued, and recognition were assessed using the Buscheke Selective Reminding Task (BSRT), whereas serial recall was assessed using the Sentence Repetition Test (SRT). For immediate recall (5.95 vs. 6.00), total recall (11.68 vs. 11.57), number of trials to obtain 3 perfect trials from the BSRT (10.89 vs. 10.90), cued recall (9.16 vs. 10.05), recognition (12.0 vs. 12.0), delayed free recall (10.68 vs. 10.57) and serial recall (15.26 vs. 16.10), scores were not statistically significantly different (all P 's $> .05$) between the exercise and control groups. In this experiment we comprehensively evaluated the effects of acute moderate-intensity exercise on free, cued, serial recall and memory recognition. We did not observe any enhancement or detrimental effects of acute exercise on episodic memory function. Additional work is needed to disentangle the complex relationship between exercise and memory function, and in particular, evaluate potential moderators (e.g., sex, fitness level) of this paradigm.

Keywords: memory consolidation; physical activity; randomized controlled trial

Öz

Akut Egzersizin Epizodik Bellek Alt Tipleri Üzerine Etkileri: Serbest, İp uçlu, Seri Geri Çağırma ve Tanıma

Bu çalışmanın amacı, akut orta yoğunluklu aerobik egzersizin, serbest, ip uçlu, seri geri çağırma ve tanıma dahil olmak üzere çeşitli epizodik bellek alt tipleri üzerindeki deneysel etkilerini kapsamlı bir şekilde değerlendirmektir. Katılımcıları 15 dakikalık orta yoğunlukta aerobik egzersiz veya zaman eşleştirmeli oturmalı bir görev üzerinden iki ayaklı, denekler arası randomize kontrollü bir çalışma (Ort. yaş = 20; $N = 20$) kullanıldı. Serbest (kısa ve uzun dönem dahil), ip uçlu ve tanıma Buscheke Seçici Hatırlatma Görevi (BSRT) kullanılarak, seri geri çağırma ise Cümle Tekrar Testi (SRT) kullanılarak değerlendirildi. Hemen geri çağırma için (5.95 - 6.00), toplam hatırlama (11.68 - 11.57), BSRT'den 3 mükemmel deneme elde etmek için deneme sayısı (10.89 - 10.90), verilen geri çağırma (9.16 - 10.05), tanıma (12.0 vs 12.0), gecikmeli serbest geri çağırma (10.68 - 10.57) ve seri geri çağırma (15.26 - 16.10), puanları egzersiz ve kontrol grupları arasında istatistiksel olarak anlamlı derecede farklı değildi ($p > .05$). Bu deneyde akut orta yoğunlukta egzersizin serbest, işaretli, seri hatırlama ve bellek tanıma üzerindeki etkilerini kapsamlı bir şekilde değerlendirdik. Akut egzersizin epizodik hafıza fonksiyonu üzerinde herhangi bir gelişme veya zararlı etkisi gözlemlenmedi. Egzersiz ve hafıza fonksiyonu arasındaki karmaşık ilişkiyi çözmek ve özellikle bu paradigmanın potansiyel moderatörlerini (örneğin, cinsiyet, kondisyon düzeyi) değerlendirmek için ek çalışmalara ihtiyaç vardır.

Anahtar Kelimeler: Bellek konsolidasyonu; fiziksel aktivite; randomize kontrollü çalışma

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INTRODUCTION

Several main types of episodic memory recall include free recall (e.g., recalling a list of words), cued recall (e.g., using a cue to facilitate memory recall), serial recall (e.g., recalling items or events in the order in which they occurred) and recognition. Previous research demonstrates that acute exercise can facilitate episodic memory (Chang, Labban, Gapin, & Etnier, 2012; Crush & Loprinzi, 2017; Frith, Sng, & Loprinzi, 2017; Labban & Etnier, 2011; Loprinzi & Edwards, 2017; Loprinzi, Edwards, & Frith, 2017; Loprinzi & Kane, 2015; Sng, Frith, & Loprinzi, 2017). General mechanistic explanations for the effects of exercise on episodic memory have been described elsewhere (Loprinzi, Edwards, & Frith, 2017; Loprinzi & Frith, 2018a; McMorris, 2016; McMorris, Sproule, Turner, & Hale, 2011; McMorris, Turner, Hale, & Sproule, 2016; Roig, Nordbrandt, Geertsen, & Nielsen, 2013; Roig et al., 2016) and include, for example, alterations in neuronal excitability and neurotrophic growth factor production.

As shown in a recent systematic review (Loprinzi, Frith, Edwards, Sng, & Ashpole, 2017), studies evaluating the effects of acute exercise on memory function among young-to middle-age adults (population of the present study) have primarily focused on episodic memory and working memory. Regarding episodic memory, these prior studies (Loprinzi, Frith, Edwards, Sng, & Ashpole, 2017) employed mostly free recall episodic memory assessments. No single study, to date, has examined the effects of acute exercise on several types of episodic memory, including free, cued, serial recall and recognition, which was the purpose of the present study.

Previous work demonstrates that distinct mechanisms may influence free vs. cued memory recall (Caffarra et al., 2016; Papp et al., 2015; Popp & Serra, 2016; Volk, McDermott, Roediger, & Todd, 2006; Yamagishi, Sato, Sato, & Imamura, 2012), with unique effects also observed for serial recall (Grenfell-Essam, Ward, & Tan, 2017; Klein, Addis, & Kahana, 2005). For example, Popp & Serra (Popp & Serra, 2016) examined the effects of animacy (previously established for free-recall and recognition memory) on free-recall and cued-recall and demonstrated that animacy enhanced free-recall but typically impaired free-recall. This finding was speculated to occur, in part, from attributions associated with animacy, such as psychological attention and mental arousal, which may be influenced by acute exercise (Alves et al., 2014; Daffner et al., 2003; Dehaene, Kerszberg, & Changeux, 1998; Dietrich & Audiffren, 2011;

Enders et al., 2016; Fingelkurts & Fingelkurts, 2015; Geva, Zivan, Warsha, & Olchik, 2013; Iwamoto & Kaufman, 1987; Kinomura, Larsson, Gulyas, & Roland, 1996; McMorris et al., 2009; Rajab et al., 2014; Sarter, Gehring, & Kozak, 2006; Tsujii, Komatsu, & Sakatani, 2013; Wang et al., 2013). For a cued-recall task, enhanced attention on a particular animate word may impair the ability to form an intentional elaboration, mediator, or interactive image to pair the words together. This impairment effect, however, may be attenuated with inanimate stimuli. Exercise has been shown to enhance not only free-recall (Frith, Sng, & Loprinzi, 2017; Sng, Frith, & Loprinzi, 2017), but cued recall as well (Pontifex, Gwizdala, Parks, Pfeiffer, & Fenn, 2016; van Dongen, Kersten, Wagner, Morris, & Fernandez, 2016). Exercise may also help to enhance recognition (Bechara & Kelly, 2013) and rescue recognition impairment (Lafenetre et al., 2010). Various structures within the medial temporal lobe (e.g., hippocampal and parahippocampal structures) may subserve recognition (Squire, Wixted, & Clark, 2007), and exercise has been shown to increase memory-related biomarkers (e.g., brain-derived neurotrophic factor; (Loprinzi & Frith, 2018a)) in, for example, the hippocampal (Liu & Nusslock, 2018) and parahippocampal regions (Hopkins & Bucci, 2010).

Evaluating the effects of exercise on these memory types will help move the memorcise (Loprinzi & Frith, 2018b; Loprinzi, Frith, & Ponce, 2018; Loprinzi, Sng, & Frith, 2017) (memory influenced by exercise) field forward by identifying which memory recall type (s) may be more influenced by exercise, or alternatively, whether episodic memory type does not moderate the association between acute exercise and episodic memory function. Given that prior studies have provided suggestive evidence that exercise may subserve various episodic memory types, we hypothesized that acute exercise, when compared to a non-exercise control, would be associated with higher memory function from free, cued, serial and recognition.

METHODS

Study Design

A two-arm, parallel-group (between subject) randomized controlled experiment was employed. Through a computer-generated algorithm, participants were randomized into one of two groups, including an experimental group or a control group. The experimental group walked at a brisk intensity for 15 minutes; the control group engaged

in a time-matched seated activity (computer game). This study was approved by the authors' institutional review board. All participants provided written consent prior to participation.

Participants

Participants were recruited utilizing a convenience-based sampling approach at the authors' University. Each group included 20 participants (N=40), which aligns with our previous experimental work on this topic, demonstrating adequate statistical power with this sample size (Crush & Loprinzi, 2017; Frith, Sng, & Loprinzi, 2017; Sng, Frith, & Loprinzi, 2017). Participants included undergraduate or graduate students and were between the ages of 18 and 35 years.

Similar to prior studies (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 & Etnier, 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". This exercise duration was chosen as it aligns with other work demonstrating a beneficial effect on memory function (Frith, Sng, & Loprinzi, 2017; Sng, Frith, & Loprinzi, 2017). The minimum speed was set to 3.0 mph. Participants then increased the speed to a pace they perceived as brisk, meaning a pace they would walk as if they were late for catching the bus. After the brisk 15-minute walk, participants rested in a seated position for 5-minutes before commencing the memory tasks. This specific exercise protocol has previously shown to enhance episodic memory function (Sng, Frith, & Loprinzi, 2017).

Control Protocol

Participant randomized into the control group completed a medium-level, on-line administered, Sudoku puzzle. Participants completed this puzzle for 20-minutes prior to completing the memory task (described below). The website for this puzzle is available at: <https://www.web-sudoku.com/>

Memory Assessments

Four memory types were assessed, including free, cued, serial and recognition. Free, cued and recognition were assessed using the Buscheke Selective Reminding Task (BSRT), whereas serial recall was assessed using the Sentence Repetition Test (SRT). The BSRT assessment occurred first, followed by the SRT.

Various studies have demonstrated evidence of reliability and validity for the BSRT (Beatty et al., 1996; Hannay & Levin, 1985; Smith, Goode, la Marche, & Boll, 1995). The BSRT involves reading to the participant a list of 12 words (see Appendix A) and then having the participant recall as many of these words as possible. Each subsequent learning trial involves the selective presentation of only those items that were not recalled on the immediately preceding trial. This continues for 12 trials, or until the participant is able to recall the entire list on three consecutive trials. A cued-recall trial is presented after the 12th or last selective-reminding trial. The first two or three letters of each word are presented on an index card, and the participant is asked to recall the corresponding list word (see Appendix B). After the cued-recall trial, the researcher presents a multiple-choice recognition trial (Appendix C). The researcher presents a series of 12 index cards, each consisting of a list word, a synonym, a homonym, and an unrelated distractor word. Lastly, a delayed-recall is given without forewarning, 20-minutes after the multiple-choice recognition trial. After the multiple-choice recognition trial, the SRT was administered (see below, and located in Appendix D), and after the SRT, the delayed recall of the BSRT occurred.

The SRT assesses sentence memory, and specifically, immediate memory for sentences of increasing length. The SRT has demonstrated evidence of reliability and validity (Shewan & Kertesz, 1980). The SRT includes 22 sentences, increasing in length from 1 syllable ("Look") to 26 syllables. To allow for sufficient material at low and high levels of performance, the sentence length increases

Appendix A.
<i>Free Recall List</i>
Egg
Runway
Fort
Toothache
Drown
Baby
Lava
Damp
Pure
Vote
Strip
Truth

Appendix B.
<i>Cued-Recall List</i>
RU
FO
TO
DR
BA
LA
DA
PU
VO
ST
TR
-
Note, "egg" is not in the cued-recall because "egg" only has 3 letters.

Appendix C.				
1	Egg	Shell	Beg	Source
2	Airline	Runner	Darling	Runway
3	Fort	Castle	Sink	Fork
4	Boldness	Dentist	Toothache	Headache
5	Blown	Drown	Float	Rib
6	Body	Infant	Middle	Baby
7	Larva	Lava	Echo	Rock
8	Damp	Moist	Hook	Stamp
9	Purse	Clean	Pure	Bare
10	Ballot	Vote	Dish	Note
11	Chain	Peal	Strip	Slip
12	Trust	Rise	Fact	Truth

Appendix D.	
1	Look.
2	Come here.
3	Help yourself.
4	Bring the table.
5	Summer is coming.
6	The iron was quite hot.
7	The birds were singing all day.
8	The paper was under the chair.
9	The sun was shining throughout the day.
10	He entered about eight o'clock that night
11	The pretty house on the mountain seemed empty.
12	The lady followed the path down the hill toward home.
13	The island in the ocean was first noticed by the young boy.
14	The distance between these two cities is too far to travel by car.
15	A judge here knows the law better than those people who must appear before him.
16	There is a new method in making steel which is far better than that used before.
17	This nation has a good government which gives us many freedoms not known in times past.
18	The friendly man told us the directions to the modern building where we could find the cab.
19	The king knew how to rule his country so that his people would show respect for his government.
20	Yesterday he said he would be near the village station before it was time for the train to come.
21	His interest in the problem increased each time that he looked at the report which lay on the table.
22	Riding his black horse, the general came to the scene of the battle and began shouting at his brave men.

in one-syllable steps for the first 12 and the last 6 sentences; sentences 13 to 16 increase in two-syllable steps. See Appendix D for the SRT. One point is given for each sentence repeated correctly, with a maximum score of 22. The test is terminated after three consecutive failures. The oral instructions for this test are as follows: “*I will say some sentences. Listen carefully, and when I have finished a sentence, repeat the sentence back exactly as I have said it. Remember, do not begin until I have given you the whole sentence.*”

Additional Assessments

At the beginning of the visit, behavioral and anthropometric assessments were completed to ensure that the two groups were similar on these parameters. As a measure of habitual physical activity behavior (min/week in moderate-to-vigorous physical activity, MVPA), participants completed a two-item survey (Physical Activity Vital Signs Questionnaire) (Ball, Joy, Gren, & Shaw, 2016). Waist circumference and height/weight (BMI; kg/m²) was measured to provide anthropometric characteristics of the sample. Additionally, before, during and after the exercise and control conditions, heart rate (chest-strapped Polar monitor, F1 model) was assessed.

Statistical Analysis

All statistical analyses were computed in SPSS (v. 24). Independent sample t-tests were computed to evaluate group differences in free, cued, serial and recognition. Statistical significance was set at an alpha of 0.05.

Table 1: Characteristics of the study variables		
Variable	Exercise (N=20)	Control (N=20)
Age, mean years	20.32 (1.1)	19.67 (0.9)
% Female	90.0	85.0
% white	70.0	75.0
BMI, mean kg/m ²	25.55 (5.6)	24.67 (3.6)
Waist circumference, mean cm	80.36 (10.8)	79.52 (8.0)
MVPA, mean min/week	150.79 (127.9)	189.29 (116.1)
Heart Rate, mean bpm		
Resting	84.84 (8.6)	77.24 (11.5)
Mid-Exercise	138.32 (19.1)	75.95 (8.3)
End-of-Exercise	140.84 (21.9)	76.52 (9.4)
5-Min Post Exercise	95.05 (14.8)	76.38 (7.6)
Speed, mean mph	3.52 (0.3)	-
BMI: Body mass index, MVPA: Moderate to vigorous physical activity, Values in parentheses are SD estimates		

RESULTS

Table 1 displays the sample characteristics between the experimental and control groups. Participants, on average, were 20 years of age. Both groups were similar across all demographic, behavioral and anthropometric characteristics. In the control group, heart rate stayed in the mid-70's during the 20-minute control task. For the exercise group, heart rate increased from 84 bpm to 140 bpm during the exercise bout.

Table 2 displays the memory scores between the exercise and control groups. For immediate free recall (5.95 vs. 6.00), total free recall (11.68 vs. 11.57), number of trials to obtain 3 perfect trials from the BSRT (10.89 vs. 10.90), cued recall (9.16 vs. 10.05), recognition (12.0 vs. 12.0), delayed free recall (10.68 vs. 10.57) and serial recall (15.26 vs. 16.10), scores were not statistically significantly different (all P's >0.05) between the exercise and control groups.

Table 2: Memory scores (means/SD)

Variable	Exercise (N=20)	Control (N=20)	Test-Statistic
Trial 1 of BSRT (immediate recall), mean words recalled	5.95 (1.0)	6.00 (1.3)	t=0.13, p=0.85
Total Recall (highest word recall from any of the BSRT trials), mean words	11.68 (0.4)	11.57 (0.9)	t=0.47, p=0.63
Number of trials to obtain 3 perfect trials from BSRT	10.89 (2.2)	10.90 (1.5)	t=0.01, p=0.99
Cued Recall, mean words correct	9.16 (1.9)	10.05 (1.4)	t=1.65, p=0.10
Recognition, mean correct	12.0 (0.0)	12.0 (0.0)	t=0.00, p=1.00
Delayed (20-min) free recall, mean words	10.68 (1.4)	10.57 (1.5)	t=0.23, p=0.81
Sentence Repetition Test, mean sentences correct	15.26 (1.6)	16.10 (2.7)	t=1.19, p=0.25

DISCUSSION

The present experiment extends previous work in this field by evaluating the effects of acute moderate-intensity exercise on various domains of episodic memory, including free, cued, serial and recognition. Unlike other experiment work in this field, our findings do not demonstrate a memorial enhancement effect from an acute, moderate-intensity bout of exercise.

Our null effects between the exercise and control groups is challenging to elucidate. The non-creative potential explanation is to attribute our null findings to the relatively

small sample size, and thus, potential insufficient statistical power. This certainly is a possibility. However, other work employing a similar sample size on this topic has demonstrated adequate statistical power (Crush & Loprinzi, 2017; Frith, Sng, & Loprinzi, 2017; Sng, Frith, & Loprinzi, 2017). Additionally, the means and variance estimate between the two groups were similar, suggesting that even if a larger sample size was employed, it is unlikely that the results would have been different. Another potential explanation for our null findings is that our exercise stimulus may have been too low of an intensity to elicit differences in episodic memory function. This, however, is unlikely, as our protocol substantively elevated the participant's heart rate, and other research suggests that moderate-intensity acute exercise is sufficient to enhance memory function (Roig, Nordbrandt, Geertsen, & Nielsen, 2013; Sng, Frith, & Loprinzi, 2017). Another possible explanation is that our results may have been different if a greater proportion of male participants were recruited, as our sample was predominately female. Although we do not have a good understanding of whether sex moderates the effects of acute exercise on episodic memory function, the current evidence, among chronic training studies, suggests that sex may not have a meaningful effect on exercise-related alterations in memory function (Barha, Davis, Falck, Nagamatsu, & Liu-Ambrose, 2017).

Our memory assessments focused on verbal-based episodic memory and there is some evidence to suggest that acute exercise may benefit visuo-spatial memory to a greater extent than verbal-auditory memory (Roig, Nordbrandt, Geertsen, & Nielsen, 2013). However, this is not universal across all studies (Yanes & Loprinzi, 2018). Further, other recent work suggests that acute, moderate-intensity aerobic exercise is not associated with source memory function (Rigdon & Loprinzi, 2019). It is possible that the level of habitual engagement in physical activity may account for our null findings. Although fitness level does not appear to play a substantive role in moderating the effects of acute exercise on memory function, there is some evidence to suggest that individuals with an average fitness level may demonstrate greater memorial benefits from exercise (Roig, Nordbrandt, Geertsen, & Nielsen, 2013). Although we did not measure the cardiorespiratory fitness of our participants, our sample was fairly active, suggesting they had above average levels of fitness. Another potential explanation is the age of our participants (i. e., young adults). Although recent meta-analytic work (Loprinzi et al., 2019) suggests that young adults, compared to other age groups, are more

likely to have beneficial memory effects from acute exercise, future work should reconsider our evaluated paradigm in other age groups. Lastly, although our findings, from this comprehensive experimental investigation, are difficult to explain, it is important that we recognize the possibility that acute moderate-intensity exercise may not always demonstrate memorial benefits.

In conclusion, in this experiment we comprehensively evaluated the effects of acute moderate-intensity exercise on free, cued, serial and recognition. We did not observe any enhancement or detrimental effects of acute exercise on episodic memory function. Additional work is needed to disentangle the complex relationship between exercise and memory, and in particular, evaluate potential moderators (e.g., sex, fitness level) of this paradigm. Such work should also overcome some of the limitations of our study by employing a larger sample size and include long-term assessments of episodic memory function. Additionally, future work should also consider various control groups (e.g., non-exercise cognitive engagement, non-exercise with minimal cognitive engagement), as this may influence whether any potential enhancement effect of exercise on memory is observed.

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