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EXPERIMENTAL EFFECTS OF ACUTE MODERATE-INTENSITY EXERCISE ON PRIORITIZED MEMORY

AKUT ORTA-YOĞUNLUKTA EGZERSİZİN ÖNCÜLENMİŞ HAFIZA ÜZERİNE DENEYSEL ETKİLERİ

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Abstract

Emerging research demonstrates that acute exercise can improve neutral-based and emotional memory function. The present study extends this emerging line of inquiry by examining the effects of acute exercise on non-emotional prioritized information. A parallel-group, randomized controlled experiment was conducted. The experimental group exercised for 15 minutes, while the control group engaged in a seated, time-matched task. Afterward, participants completed a prioritized memory task, involving an immediate and delayed memory recall. There were no significant main effects for time ($F=2.10$, $p = 0.15$, $\eta^2p=0.05$), main effect for group ($F=0.46$, $p = 0.50$, $\eta^2p=0.01$), time by group interaction ($F=0.64$, $p = 0.42$, $\eta^2p=0.01$), content by group interaction ($F=2.07$, $p = 0.15$, $\eta^2p=0.05$), time by content interaction ($F=0.43$, $p = 0.43$, $\eta^2p=0.02$), or time by content by group interaction ($F=0.28$, $p = 0.59$, $\eta^2p=0.01$). However, there was a main effect for content ($F=4.48$, $p = 0.04$, $\eta^2p=0.11$). That is, collapsed across both the experimental and control conditions, as well as collapsed across immediate and delayed recall, the percent (SD) of content recalled for the highlighted and non-highlighted text, respectively, was 76.7 (15.7) and 69.4 (23.2) ($p = 0.04$). Our experimental findings demonstrate evidence of a prioritized memory effect. We, however, did not demonstrate any evidence of acute moderate-intensity exercise modulating prioritized memory.

Keywords: cognition; consolidation; emotion; encoding; episodic; physical activity.

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Öz

Araştırmalar, akut egzersizin nötral hafıza ve duygusal hafıza işlevini geliştirebileceğini göstermektedir. Bu çalışma, akut egzersizin duygusal olmayan biçimde öncülenmiş bilgiler üzerindeki etkilerini inceleyerek bu alanı genişletmeyi amaçlamaktadır. Paralel grup desenli randomize kontrollü bir araştırmada deney grubu 15 dakika boyunca egzersiz yaparken kontrol grubu aynı süreyle oturarak yaptıkları bir görev yürütmüşlerdir. Daha sonra, katılımcılar hızlı ve gecikmeli hatırlamaları içeren bir öncülenmiş hafıza görevi tamamlamışlardır. İki grup arasında süre ($F = 2.10$, $p = 0.15$, $\eta^2p = 0.05$), ana grup etkisi($F = 0.46$, $p = 0.50$, $p2p = 0.01$), grup etkileşimi süresi ($F = 0.64$, $p = 0.42$, $\eta^2p = 0.01$), grup etkileşimi içeriği ($F = 2.07$, $p = 0.15$, $\eta^2p = 0.05$), içerik etkileşimi süresi ($F = 0.43$, $p = 0.43$, $\eta^2p = 0.02$) veya gruba göre içerik etkileşimi ($F = 0.28$, $p = 0.59$, $\eta^2p = 0.01$) açısından anlamlı fark bulunmamıştır. Ancak, içerik için anlamlı bir farklılık saptanmıştır ($F = 4.48$, $p = 0.04$, $\eta 2p = 0.11$). Hem deney hem de kontrol gruplarında anlık ve gecikmeli hatırlamada bozulma olsa da gruplar arası fark istatistiksel olarak anlamlıdır, vurgulanan ve vurgulanmayan metin için hafızadan geri çağrılabilen içeriğin yüzdesi (SD) sırasıyla 76.7 (15.7) ve 69.4 (23.2) olarak bulunmuştur.) ($p = 0.04$). Bu deneyin bulguları öncülenen bir hafıza etkisinin varlığına işaret etmektedir. Bununla birlikte, akut orta şiddette egzersizin öncülenmiş hafıza üzerine etkisi gösterilememiştir.

Anahtar Kelimeler: *biliş; konsolidasyon; duygu; kodlama; epizodik; fiziksel aktivite.*

1. Introduction

Adequate memory function, unquestionably, is of critical importance for daily function. Among many other factors (e.g., using mnemonic techniques), prioritizing information can maintain the volume of information we learn at a manageable level. Further, prioritizing information may help to enhance the encoding of that information, as greater attentional resources may be used for the prioritized information (Loprinzi, Frith, Edwards, Sng, & Ashpole, 2018). Given that exercise may help to facilitate attentional arousal, it is conceivable that exercise may help to strengthen the effects of prioritized learning on memory retention (Loprinzi, Ponce, & Frith, 2018).

Emerging research demonstrates that acute exercise can influence neutral-based memory stimuli (Frith, Sng, & Loprinzi, 2017; Haynes Iv, Frith, Sng, & Loprinzi, 2018; Siddiqui & Loprinzi, 2018; Sng, Frith, & Loprinzi, 2018). We have previously discussed the mechanisms of this effect elsewhere (Loprinzi, Edwards, & Frith, 2017; Loprinzi & Frith, 2018; Loprinzi, Ponce, & Frith, 2018). However, no studies, to date, have examined whether acute exercise can increase the recall of memories that are encoded as prioritized information. Some memories, such as emotionally-charged memories, may be considered prioritized information. We have recently detailed the literature on the effects of acute exercise on emotional memory (Loprinzi, Frith, & Edwards, 2018). Findings are mixed, with some evidence suggesting a favorable effect (Loprinzi, Frith, & Edwards, 2018), whereas more recent work demonstrates a null relationship (Wade & Loprinzi, 2018). The present study extends this emerging line of inquiry by examining the effects of acute exercise on non-emotional prioritized information. Thus, the purpose of this study, written as a brief report, was to examine the potential augmented effects of acute exercise on prioritized memory.

2. Materials and Methods

2.1. Study Design

A two-arm, parallel-group, randomized controlled experiment was employed. Participants were randomized into one of two groups: an experimental group and a control group. The experimental group exercised for 15 minutes, while the control group engaged in a seated, time-matched task. This study was approved by the authors' institutional review board and participants provided written consent prior to study participation.

2.2 Participants

Each group included 20 participants (N=40). This is based from a power analysis indicating a sample size of 20 would be needed for sufficient power (d, 0.90; two-tailed α error probability, 0.05; 1-β error probability, 0.80; allocation ratio, 1). 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.

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

2.3. Exercise Protocol

The exercise bout involved exercising on a treadmill for 15 minutes. Participants exercise at approximately 70% of their estimated heart rate max (220-age), which is considered moderate-intensity exercise (Garber et al., 2011).

Immediately after the bout of exercise, participants rested in a seated position for 5 minutes. During this resting period, they played on-line game of Sudoku (described below) to prevent boredom. After this resting period, they commenced the memory assessment, as described below.

2.4. Control Protocol

Similar to other active control groups (McNerney & Radvansky, 2015), those randomized to the control group completed a medium-level, on-line administered, Sudoku puzzle for 20-minutes. The website for this puzzle is

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located here: https://www.websudoku.com/

2.5. Memory Assessment

Participants completed a prioritized learning task, shown in Appendix A. This task, which is identical to other work (Lo, Bennion, & Chee, 2016), involves reading a four sentence passage. Specifically, participants were instructed as follows, "You will be given 7 minutes to memorize the content of the following story. Your memory of the story will be tested later. Please pay particular attention to the content highlighted in yellow as those who remember the most of it will be entered into a raffle to win a $10 gift card." After the 7-minute learning period, participants completed arithmetic problems for 10 minutes. Following this 10-minute arithmetic session, an initial memory recall from the story occurred, which involved the participant writing down as much of the story as they could recall. After this initial memory recall, participants watched a 10-minute video clip from "Season 3 of The Office Bloopers". They were instructed to watch this video clip closely and write down 5 of the funniest things from the video clip (to keep them engaged on this distractor task). After this 10-minute video clip period, participants completed a second memory recall. For both memory recalls (10- and 20-minute post-learning assessment), the two outcome measures were the correct proportion of prioritized (highlighted text) and non-prioritized (non-highlighted text) words recalled.

2.6. Additional Assessments

Various demographic (e.g., BMI) and behavioral (e.g., habitual physical activity) assessments were completed to ensure that the groups were similar on these parameters. As a measure of habitual physical activity behavior, participants completed the Physical Activity Vital Signs Questionnaire to evaluate time spent per week in moderate-to-vigorous physical activity (MVPA) (Ball, Joy, Gren, & Shaw, 2016). Height/weight (BMI; kg/m2) were measured to provide anthropometric characteristics of the sample. Lastly, before and at the end of the exercise and control conditions, heart rate (chest-strapped Polar monitor, F1 model) was assessed.

2.6. Statistical Analysis

All statistical analyses were computed in Jasp (v. 0.9.2). A mixed-measures ANOVA was used to compare the memory score across the two groups and across the two time periods. One factor was time (immediate vs. delayed) and the other factor was content (prioritized vs. non-prioritized). Main effects for time, main effects for group, main effects for content, time by group interaction, content by group interaction, time by content interaction, and time by content by group interactions were evaluated. Statistical significance was set at an alpha of 0.05. Partial eta-square (η^2_p) was calculated as a measure of effect size.

3. Results

Table 1 displays the demographic and behavioral characteristics across the experimental and control groups. Participants, on average, were 21.1 (1.1) years of age, with the sample predominately female (95% female). Notably, there were no demographic or behavioral differences across the two groups (all P's>0.05).

Table 2 displays the physiological (heart rate) response to the exercise and control conditions. There was a significant main effect for time ($F=237.0$, $p<0.001$, $\eta^2_p=0.86$), main effect for group ($F=43.3$, $p<0.001$, $\eta^2_p=0.53$), and a time x group interaction effect ($F=252.8$, $p<0.001$, $\eta^2_p=0.87$). Over the 20-minute control period, heart rate remained steady (74.5-80.3 bpm), whereas in the exercise group, it increased from 73.6 bpm (rest) to 136.2 bpm (end of exercise).

Table 3 displays the results for the memory scores. In the following text, "time" refers to immediate and delayed memory, "group" refers to exercise or control, and "content" refers to prioritized vs. non-prioritized content. There were no significant differences in prioritized or non-prioritized memory recall across the two groups. There were no significant main effects for time ($F=2.10$, $p=0.15$, $\eta^2_p=0.05$), main effect for group ($F=0.46$, $p=0.50$, $\eta^2_p=0.01$), time by group interaction ($F=0.64$, $p=0.42$, $\eta^2_p=0.01$), content by group interaction ($F=2.07$, $p=0.15$, $\eta^2_p=0.05$), time by content interaction ($F=0.43$, $p=0.43$, $\eta^2_p=0.02$), or time by content by group interaction ($F=0.28$, $p=0.59$, $\eta^2_p=0.01$). However, there was a main effect for content ($F=4.48$, $p=0.04$, $\eta^2_p=0.11$). That is, collapsed across both the experimental and control conditions, as well as collapsed across immediate and delayed recall, the percent (SD) of content recalled for the highlighted and non-highlighted text, respectively, was 76.7 (15.7) and 69.4 (23.2) ($p=0.04$). This is also graphically shown in Figure 1.

4. Discussion

Acute exercise has been shown to enhance memory function of neutral stimuli (Frith, Sng, & Loprinzi, 2017; Haynes Iv, Frith, Sng, & Loprinzi, 2018; Siddiqui & Loprinzi, 2018; Sng, Frith, & Loprinzi, 2018) and emotional stimuli (Loprinzi, Frith, & Edwards, 2018). No studies, however, have examined whether acute exercise can enhance non-emotional prioritized information, which was the purpose of our experiment. Our main findings are as follows. We demonstrated evidence of the prioritized paradigm, as individuals recalled more prioritized text when compared to non-prioritized text. However, acute exercise did not enhance this prioritized effect.

Prioritized learning, which can be precipitated by reward, may be facilitated by many factors, including hippocampal activity. Following memory encoding, hippocampal neurons replay sequences of the event, which is thought to induce physiological strengthening of the engram. Notably, hippocampal neuronal replay often happens in reverse, starting with the most recent events and then playing back the trajectory from that point. For prioritized learning, there is an increased degree of reverse replay, ensuing engram stabilization (Ambrose, Pfeiffer, & Foster, 2016; Carr, Jadhav, & Frank, 2011; Singer & Frank, 2009). Within animal models, this paradigm has been evaluated in a movement context. Following maze navigation in rodents, hippocampal replay occurs concurrently with the firing of midbrain dopamine neurons (Gomperts, Kloosterman, & Wilson, 2015). This dopaminergic input may help to facilitate synaptic consolidation, and in turn, memory stabilization (Atherton, Dupret, & Mellor, 2015). We anticipated that acute exercise would enhance prioritized learning, similar to this reward paradigm, as acute exercise-induced dopaminergic release is thought to be a critical mediator of episodic memory function (Loprinzi, Ponce, & Frith, 2018).

Reward is thought to prioritize memory for events that are most proximal to the reward and is expected to depend on post-encoding processes (Gruber, Ritchey, Wang, Doss, & Ranganath, 2016). Our null findings regarding exercise and prioritized memory may be a result of our limited consolidation period (i.e., 10-minutes). Longer consolidation periods are thought to facilitate a greater degree of reward replay, and in turn, retroactively enhance prioritized memories (Braun, Wimmer, & Shohamy, 2018). Our null results may also be a result of the exercise intensity level. Higher intensity exercise will likely have a greater dopaminergic effect (Loprinzi, Ponce, & Frith, 2018), accompanied by enhanced memory function (Loprinzi, 2018). Thus, future work on this novel paradigm should consider addressing these study limitations.

In conclusion, our experimental findings demonstrate evidence of a prioritized memory effect. We, however, did not demonstrate any evidence of acute moderate-intensity exercise modulating prioritized memory. Given the novelty of this line of inquiry, there are lots of room for additional work on this topic. Such work should consider employing a higher intensity exercise protocol, extending the delayed assessment period, and consider altering the exercise temporality, such that the exercise occurs during the memory consolidation period.

Table 1. Characteristics of the sample.

Variable	Exercise	Control	p-Value
N	20	20	
Age, mean years	21.1 (1.3)	21.0 (0.75)	0.89
Gender, % Female	90.0	100.0	0.15
Race, % non-Hispanic white	80.0	95.0	0.15
BMI, mean kg/m2	24.2 (4.5)	24.4 (4.8)	0.90
MVPA, mean min/week	154.4 (89.7)	140.5 (83.3)	0.62

BMI, body mass index
MVPA, moderate-to-vigorous physical activity
Values in parentheses are standard deviations

Table 2. Heart rate responses across the conditions.

Variable	Exercise	Control	Test-Statistic
N			
Baseline heart rate, mean bpm	80.3 (15.6)	74.5 (17.6)	F(time)=237.0, p <0.001, η^2_p=0.86 F(group)=43.3, p <0.001, η^2_p=0.53
Endpoint heart rate, mean bpm	136.2 (19.1)	73.6 (16.8)	F(time x group)=252.8, p <0.001, η^2_p=0.87

Values in parentheses are standard deviations

Table 3. Memory scores across the experimental conditions.

Variable	Exercise	Control	Test-Statistic
Immediate Recall, mean %			
Prioritized Information	77.1 (15.1)	76.9 (17.0)	F(time)=2.10, p =0.15, η^2_p=0.05 F(group)=0.46, p =0.50, η^2_p=0.01
Non-Prioritized Information	66.1 (74.8)	74.8 (19.0)	F(time x group)=0.64, p =0.42, η^2_p=0.01 F(content)=4.48, p =0.04, η^2_p=0.11
Delayed Recall, mean %			F(content x group)=2.07, p =0.15, η^2_p=0.05
Prioritized Information	77.7 (14.9)	75.1 (17.7)	F(time x content)=0.43, p =0.43, η^2_p=0.02 F(time x content x group)=0.28, p =0.59, η^2_p=0.01
Non-Prioritized Information	64.2 (25.9)	72.5 (21.3)	

Values in parentheses are standard deviations

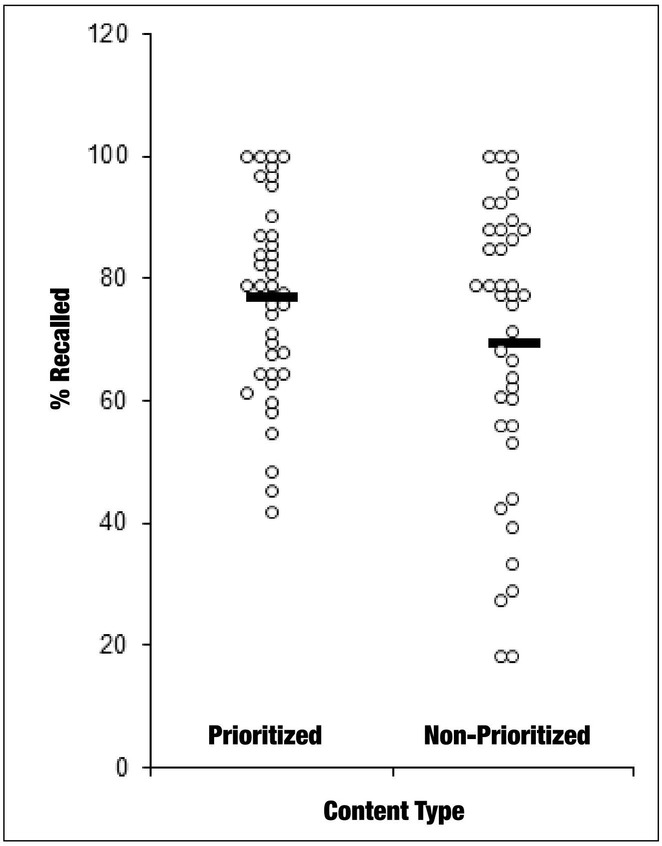

Figure 1. Percent of prioritized and non-prioritized recalled text. Open circles represent individual data, with solid black line representing the group average.

Appendix A.

Instructions: "You will be given 7 minutes to memorize the content of the following story. Your memory of the story will be tested later. Please pay particular attention to the content highlighted in yellow as those who remember the most of it will be entered into a raffle to win a $10 gift card."

Europe's clothing makers have a new problem. The shape of the European male has changed. According to

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the latest figures, European men now have slimmer waists and larger chests than they did in 1933 when the last measurements were taken. Manufacturers will alter their designs to make their clothes fit more comfortably and have promised to update their statistics more frequently in the future.

Patient informed consent: Informed consent was obtained.

Ethics committee approval: Ethics committee approval was obtained.

Conflict of interest: There is no conflicts of interest to declare.

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