JOURNAL OF BEHAVIORAL HEALTH, 2019
VOL 8, NO. 2, PAGE 59–65
10.5455/jbh.20181203014456

SHORT COMMUNICATION

Open Access

Experimental effects of acute exercise on source memory recognition

Brandon Rigdon, Paul D. Loprinzi

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

ABSTRACT

Previous work suggests that acute exercise may enhance episodic memory function. However, no study has evaluated whether acute exercise can enhance source memory recognition, which was the purpose of this study. A two-arm, parallel-group randomized controlled intervention was employed. The experimental group walked briskly for 15 minutes with a 5-minute seated recovery task (Sudoku), while the control group engaged in a time-matched (20 minutes) seated task (Sudoku). Subsequently, participants completed a source episodic memory task. The experimental group recalled more words than the control group (M = 6.35, SD = 2.99 and M = 5.30, SD = 2.83, respectively; p = 0.26, d = 0.36). However, there were no differences in performance on the source memory recognition task (discrimination index, −0.20 *vs.* 1.50, t = 0.64, p = 0.52, d = 0.20). Our results provide some evidence of a non-statistically significant, small magnitude, exercise-induced enhancement effect on episodic memory, but our findings did not suggest a beneficial source memory effect from acute exercise.

ARTICLE HISTORY

Received December 03, 2018
Accepted March 28, 2019
Published April 07, 2019

KEYWORDS

Cognition; declarative memory; physical activity; source monitoring

Introduction

Memory is often categorized into declarative and non-declarative memory systems. Declarative memory, or explicit memory, includes the retrospective recall of information. This recall of information can be factual information (semantic memory) or bound to a particular context/event (episodic memory). Non-declarative memory, or implicit memory, is the memory that is not consciously encoded. Although not an exhaustive list, various brain structures play an important role in memory, such as the hippocampus, prefrontal cortex, basal ganglia, and cerebellum. Evaluating factors that influence memory function, even among young adults, is of critical importance, as memory has been shown to decline during the young adult years [1].

Emerging work demonstrates that acute exercise can enhance episodic memory [2–6]. For example, we have repeatedly demonstrated [2–6] that short-duration (e.g., 15 minutes) acute exercise, when occurring prior to the memory task, can enhance episodic memory, usually assessed via word-list trials. Other laboratories have also demonstrated similar effects of acute aerobic exercise on episodic memory [7,8]. We have also discussed the potential underlying mechanisms of this effect [9], which includes, for example, exercise-induced neuronal excitability [9–11], growth factor production [12], hormone secretion [13], and ensuing long-term potentiation (LTP) [9]. Regarding the latter, LTP is considered an underlying mechanism of episodic memory function, involving an enhanced functional connectivity among neurons, characteristically shown by sustained excitatory post-synaptic potentiation. Acute exercise is likely to enhance LTP via alterations in NMDA (N-methyl-D-aspartate) structure and function [14,15].

Episodic memory tasks, often including the encoding and retrieval of words from a list, is a common example of laboratory-based assessments of item memory. Source memory, however, involves remembering the context of an experience. For example, if local authorities publicized a photo of a suspected criminal, an individual would need to probe their memory to evaluate whether they have

Contact Paul D. Loprinzi pdloprin@olemiss.edu University of Mississippi, University, MS.

seen that individual before and identify the context of that experience. This would represent item memory and source memory, respectively. Context, or source-based memory, is a critical feature of episodic memory. Thus, identification of factors that may subserve source memory is of great importance. The purpose of the present study was to evaluate whether acute exercise may enhance source-based episodic memory.

To date, there are no studies specifically evaluating whether acute exercise can enhance source episodic memory recognition, or the ability to recognize which source the information comes from. The prefrontal cortex plays an important role in subserving source episodic memory [16,17]. For example, the dorsolateral prefrontal cortex is involved in the correct dissociation of source memory decisions [18]. This has also been extended to self-referenced materials among young adults. Specifically, in young and older adults, the dorsal medial prefrontal cortex supported source memory benefits for objects encoded self-referentially [19].

It is plausible that the acute exercise may enhance source memory via its influence on prefrontal cortex functioning. Acute moderate-intensity exercise has been shown to enhance prefrontal cortex function [20–22]. As we have thoroughly detailed elsewhere [23], acute exercise may activate intrafusal muscle spindle fibers, which send afferent signals, via peripheral nerves, to the brainstem. Brainstem activation may also arise from exercise-induced stimulation of the vagus nerve [23]. The prefrontal cortex receives input from brainstem arousal systems, and thus, its function is partially dependent on an individual's state of arousal [24]. Given these acute exercise-induced prefrontal cortex effects, coupled with the role of the prefrontal cortex on source memory, it is plausible that the acute exercise may enhance source episodic memory, which was the purpose of this experiment.

Methods

Study design

A two-arm, parallel-group randomized controlled intervention was employed. Participants were randomized into one of two groups, including an experimental group and a control group. The experimental group walked briskly for 15 minutes, while the control group engaged in a seated task. This study was approved by the ethics committee at the University of Mississippi and participants provided written voluntary consent prior to participation.

Participants

Each group included 20 participants (N = 40). 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 years.

Similar to other studies [2,25], participants were excluded if they:

- Self-reported as a daily smoker [26,27]
- Self-reported being pregnant [28]
- Exercised within 5 hours of testing [7]
- Consumed caffeine within 3 hours of testing [29]
- Had a concussion or head trauma within the past 30 days [30]
- Took marijuana or other illegal drugs within the past 30 days [31]
- Were considered a daily alcohol user (>30 drinks/month for women; >60 drinks/month for men) [32]

Exercise protocol

The acute exercise bout involved exercising on a treadmill for 15 minutes. Participants exercised at approximately 70% of their estimated heart rate max (220-age), which corresponds with moderate-intensity exercise [33]. This intensity and duration has previously been shown to enhance memory function [5].

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

Control protocol

Similar to other studies [34], those randomized to the control group completed a medium-level, on-line administered, Sudoku puzzle for 20 minutes. The website for this puzzle is located here: https://www.websudoku.com/

Memory assessment

As an assessment of source recognition, participants viewed 30 randomly selected words from the Toronto word pool. Words were displayed on a computer, with each word presented one at a time, for 2 seconds each. Similar to other related experiments [35], half of the words, in random order, were presented in red text, with the other half in green text. Participants viewed two cycles of the 30 words. Afterward, they watched a 10-minute video clip of "The Office—Bloopers" as a distractor. After this 10-minute distraction period, participants:

- Recalled as many words as they could—they wrote the words down on a paper (episodic memory).
- Then for the source recognition task (source memory), they viewed a list of 60 words (30 of which they previously saw). For each of these 60 words, they indicated if the word was displayed in red font, green font, don't know, or was not exposed to the word.

The outcome measure was the number of correctly recalled words (episodic memory) and the number of correctly recalled red and green words (source memory recognition). A discrimination index (for both red and green words) was calculated as the hit rate minus the false positive. An average discrimination index was calculated for the two sources (i.e., average discrimination index for the red and green words). Prior to the memory task, we provided instructions of the task, but we did not have them complete a practice task, as we did not want to induce a potential memory interference effect (i.e., proactive memory interference).

Additional measurements

As a measure of habitual physical activity behavior, participants completed the Physical Activity Vital Signs Questionnaire, which reported time spent per week in moderate-to-vigorous physical activity (MVPA) [36]. Height/weight (body mass index; kg/m^2) were measured to provide anthropometric characteristics of the sample. Furthermore, 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 Stata (v. 12). An independent samples *t*-test was used to compare the memory scores across the two groups. For the heart rate data, a RM-ANOVA (repeated measures analysis of variance) was computed. We also considered ANCOVA (analysis of covariance) results, controlling for various parameters (e.g., gender); however, these results were similar to the unadjusted models, and thus, the latter models are

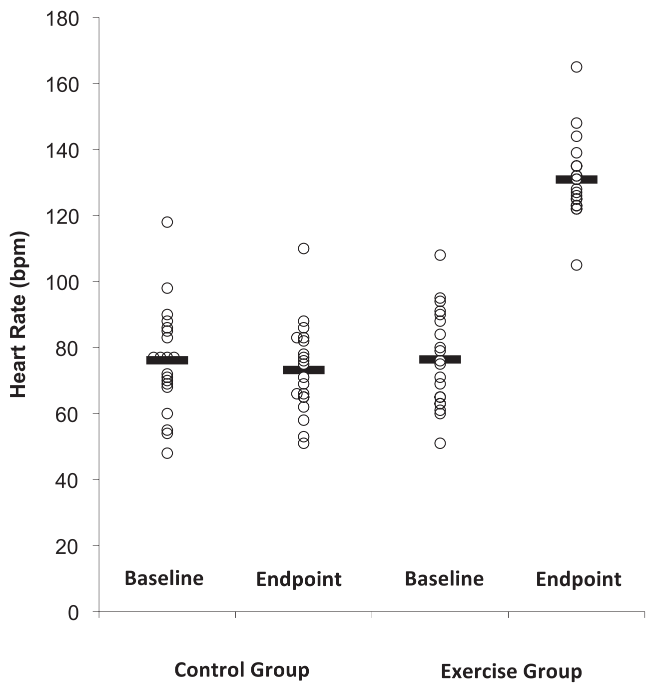

Figure 1. Heart rate responses (baseline and endpoint) between the control and exercise groups. Group × time interaction *p*-value < 0.001. Circles represent the individual data points, whereas the solid lines represent the average.

Table 1. Sample characteristics.

Variable	Exercise (*n* = 20)	Control (*n* = 20)	*p*-Value†
Age, mean years	20.50 (1.1)	20.30 (1.0)	0.90
Gender, % female	60.00	85.00	0.08
Race, % white	70.00	95.00	0.09
Body mass index, mean kg/m^2	28.00 (5.4)	25.53 (4.4)	0.12
MVPA, mean min/week	215.20 (177.4)	209.75 (208.8)	0.92

†Independent samples *t*-test was used for continuous variables (e.g., body mass index), whereas a chi-square test was used for categorical variables (e.g., gender).

reported herein. Statistical significance was set at an alpha of 0.05.

Results

Table 1 displays the demographic and behavioral characteristics of the sample. Participants, on average, were 20 years of age. Figure 1 displays the heart rate responses to the acute exercise and control protocols. At resting and endpoint, respectively, heart rate was stable for the control group [76.11 bpm (16.1) *vs.* 73.24 bpm (13.7)]. For both respective groups, this corresponded to 38% of their relative heart rate max (220-age). In the acute exercise group, heart rate increased (resting to endpoint) from 76.44 bpm (14.7) to 130.95 bpm (12.1), corresponding to 65.5% (6.1) of their relative heart rate max. For heart rate, we observed a significant group by time interaction effect in a RM-ANOVA model ($F = 195.5$, $p < 0.001$, $\eta^2_p = 0.84$).

Figure 2 displays the memory performance across the acute exercise and control groups. For episodic memory, the acute exercise group recalled more words than the control group ($M = 6.35$, SD = 2.99 and $M = 5.30$, SD = 2.83, respectively). However, this did not reach statistical significance ($t = 1.14$, $p = 0.26$, $d = 0.36$).

The source memory recognition scores are displayed in Table 2. For hit rates, false positives, and discrimination indexes, there were no significant differences across the groups. The average discrimination index, across the acute exercise and control groups, is graphically displayed in Figure 3.

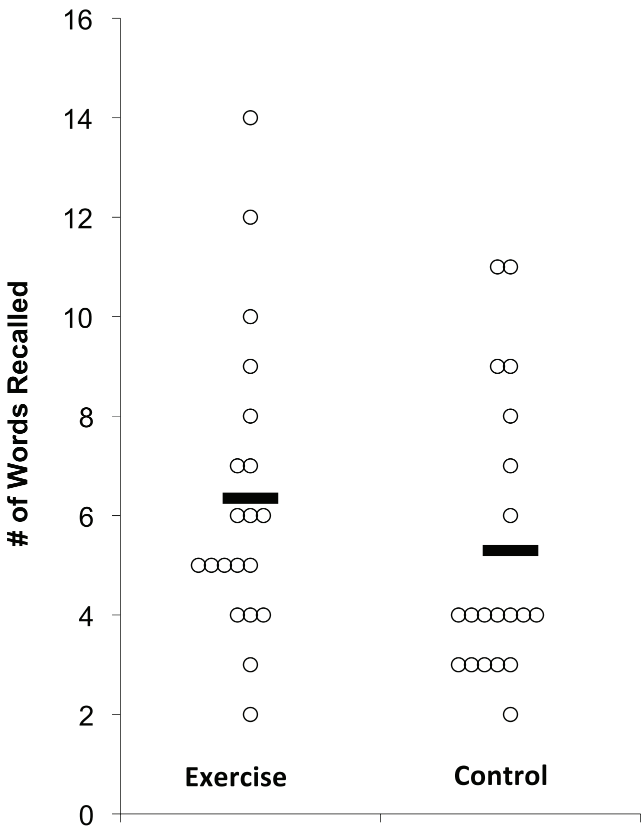

Figure 2. Memory recall between the exercise and control groups ($t = 1.14$, $p = 0.26$, $d = 0.36$). Circles represent the individual data points, whereas the solid lines represent the average.

Discussion

Emerging work demonstrates that acute exercise may enhance episodic memory function. The prefrontal cortex, in particular, appears to play an integral role in source recognition of episodic memory [16,17]. Despite previous work demonstrating that acute exercise can enhance episodic memory and increase neuronal activity in the prefrontal cortex, no previous work has evaluated whether acute exercise can specifically enhance source episodic memory function. To bridge this gap in the literature, the present study evaluated this possibility. The main findings of our study include the slight non-statistically enhancement effect of acute exercise on episodic memory, with a relatively small effect size ($d = 0.36$); however, acute exercise did not facilitate source episodic memory recognition.

As detailed elsewhere [37], there are several brain structures that subserve source episodic

Table 2. Source memory performance scores [mean (SD)].

Variable	Exercise ($n = 20$)	Control ($n = 20$)	Test-statistic
# of Correctly Recalled Red Words—Hit Rate	8.70 (3.6)	8.50 (2.0)	t =0.21, p = 0.83, d = 0.06
# of Correctly Recalled Green Words—Hit Rate	8.10 (3.5)	8.70 (2.9)	t = 0.58, p = 0.56, d = 0.18
Overall False Positive Rate	8.60 (8.3)	7.10 (7.5)	t =0.59, p = 0.55, d = 0.18
Discrimination Index (Hit Rate—False Positive Rate)			
Red Words	0.10 (8.5)	1.40 (7.4)	t = 0.51, p = 0.61, d = 0.16
Green Words	−0.50 (8.2)	1.60 (9.2)	t = 0.75, p = 0.45, d = 0.24
Average	−0.20 (8.2)	1.50 (8.2)	t = 0.64, p = 0.52, d = 0.20

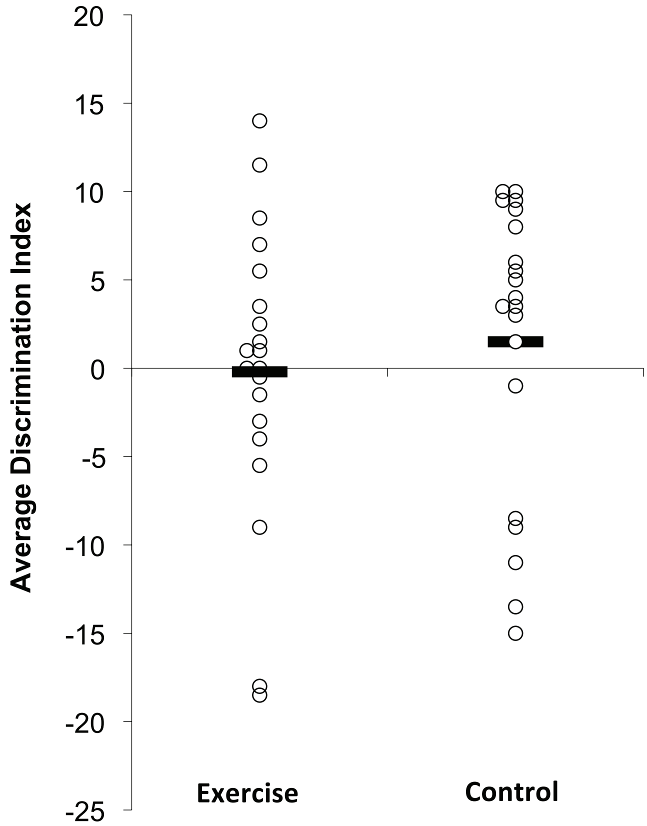

Figure 3. Source memory recognition performance between the exercise and control groups ($t = 0.64$, $p = 0.52$, $d = 0.20$). Circles represent the individual data points, whereas the solid lines represent the average.

memory, including the medial temporal lobe, parietal lobe, and prefrontal cortex. Notably, exercise has been shown to increase neuronal activity in each of these brain regions [20–22,38], which makes it conceivable that acute exercise could enhance source episodic memory. Our results, however, did not provide evidence of an acute exercise-induced enhancement effect on source episodic memory. Although speculative, these findings may be a result of several factors, such as the intensity of acute exercise or the type of source memory task that we employed. Notably, our employed acute exercise intensity was on the lower end of moderate-intensity exercise. Future work may wish to consider if a higher-intensity bout of exercise has a greater effect on source episodic memory [39] and whether a more complex and comprehensive evaluation of source episodic memory will aid in an acute exercise-induced effect. With regard to exercise intensity, we recently demonstrated that higher-intensity acute exercise may be more advantageous in enhancing episodic memory function [39], via its superior effect in enhancing synaptic plasticity. Synaptic plasticity has previously been shown to play a critical role in memory recognition [40]. Despite the notable strengths of our study, including the study novelty and experimental approach, future work should consider overcoming some of the limitations of our study, including the relatively small sample among a homogeneous population. Furthermore, to control for potential group differences, future work on this topic should employ a within-subject design.

In conclusion, our study evaluated the effects of acute moderate-intensity exercise on episodic memory and source memory recognition. We provided some evidence of a small magnitude of effect for an exercise-induced enhancement of episodic memory (albeit not statistically significant), but our findings did not suggest a beneficial source memory effect from acute exercise.

Funding Source

No funding was used to prepare this manuscript.

Conflict of Interest

The authors declare that they have no conflicts of interest.

References

[1] Salthouse TA. When does age-related cognitive decline begin? Neurobiol Aging 2009; 30:507–14; doi:10.1016/j.neurobiolaging.2008.09.023
[2] Siddiqui A, Loprinzi PD. Experimental investigation of the time course effects of acute exercise on false episodic memory. J Clin Med 2018; 7; doi:10.3390/jcm7070157
[3] Haynes Iv JT, Frith E, Sng E, Loprinzi PD. Experimental effects of acute exercise on episodic memory function: considerations for the timing of exercise. Psychol Rep 2018; 33294118786688; doi:10.1177/0033294118786688
[4] Frith E, Sng E, Loprinzi PD. Randomized controlled trial evaluating the temporal effects of high-intensity exercise on learning, short-term and long-term memory, and prospective memory. Eur J Neurosci 2017; 46:2557–64; doi:10.1111/ejn.13719
[5] Sng E, Frith E, Loprinzi PD. Temporal effects of acute walking exercise on learning and memory function. Am J Health Promot 2018; 32:1518–25; doi:10.1177/0890117117749476
[6] Sng E, Frith E, Loprinzi PD. Experimental effects of acute exercise on episodic memory acquisition: decomposition of multi-trial gains and losses. Physiol Behav 2018; 186:82–4; doi:10.1016/j.physbeh.2018.01.014

[7] Labban JD, Etnier JL. Effects of acute exercise on long-term memory. Res Q Exerc Sport 2011; 82:712–21; doi:10.1080/02701367.2011.10599808

[8] Labban JD, Etnier JL. The effect of acute exercise on encoding and consolidation of long-term memory. J Sport Exerc Psychol 2018; 40:336–42; doi:10.1123/jsep.2018-0072

[9] Loprinzi PD, Edwards MK, Frith E. Potential avenues for exercise to activate episodic memory-related pathways: a narrative review. Eur J Neurosci 2017; 46:2067–77; doi:10.1111/ejn.13644

[10] Loprinzi PD, Ponce P, Frith E. Hypothesized mechanisms through which acute exercise influences episodic memory. Physiol Int. 2018; 105(4):285–97.

[11] Frith E, Loprinzi PD. Physical activity and individual cognitive funcion parameters: unique exercise-induced mechansims. J Cogn Behav Psychother Res 2018; 7:92–106.

[12] Loprinzi PD, Frith E. A brief primer on the mediational role of BDNF in the exercise-memory link. Clin Physiol Funct Imaging 2019; 39(1):9–14; doi:10.1111/cpf.12522

[13] Loprinzi PD. IGF-1 in exercise-induced enhancement of episodic memory. Acta Physiol 2018; e13154; doi:10.1111/apha.13154

[14] Molteni R, Ying Z, Gomez-Pinilla F. Differential effects of acute and chronic exercise on plasticity-related genes in the rat hippocampus revealed by microarray. Eur J Neurosci 2002; 16:1107–16.

[15] Dietrich MO, Mantese CE, Porciuncula LO, et al. Exercise affects glutamate receptors in postsynaptic densities from cortical mice brain. Brain Res 2005; 1065:20–5; doi:10.1016/j.brainres.2005.09.038

[16] Rajan V, Cuevas K, Bell MA. The contribution of executive function to source memory development in early childhood. J Cogn Dev 2014; 15:304–24; doi:10.1080/15248372.2013.763809

[17] Cycowicz YM, Friedman D, Snodgrass JG, Duff M. Recognition and source memory for pictures in children and adults. Neuropsychologia 2001; 39:255–67.

[18] Gallo DA, McDonough IM, Scimeca J. Dissociating source memory decisions in the prefrontal cortex: fMRI of diagnostic and disqualifying monitoring. J Cogn Neurosci 2010; 22:955–69; doi:10.1162/jocn.2009.21263

[19] Leshikar ED, Duarte A. Medial prefrontal cortex supports source memory for self-referenced materials in young and older adults. Cogn Affect Behav Neurosci 2014; 14:236–52; doi:10.3758/s13415-013-0198-y

[20] Erickson KI, Leckie RL, Weinstein AM. Physical activity, fitness, and gray matter volume. Neurobiol Aging 2014; 35(Suppl 2):S20–8; doi:10.1016/j.neurobiolaging.2014.03.034

[21] Hung CL, Tseng JW, Chao HH, Hung TM, Wang HS. Effect of acute exercise mode on serum brain-derived neurotrophic factor (BDNF) and task switching performance. J Clin Med 2018; 7; doi:10.3390/jcm7100301

[22] Tsujii T, Komatsu K, Sakatani K. Acute effects of physical exercise on prefrontal cortex activity in older adults: a functional near-infrared spectroscopy study. Adv Exp Med Biol 2013; 765:293–8; doi:10.1007/978-1-4614-4989-8_41

[23] Loprinzi PD, Ponce P, Frith E. Hypothesized mechanisms through which acute exercise influences episodic memory. Physiol Int 2018; 105:285–97; doi:10.1556/2060.105.2018.4.28

[24] Arnsten AF, Paspalas CD, Gamo NJ, Yang Y, Wang M. Dynamic network connectivity: a new form of neuroplasticity. Trends Cogn Sci 2010; 14:365–75; doi:10.1016/j.tics.2010.05.003

[25] Yanes D, Loprinzi PD. Experimental effects of acute exercise on iconic memory, short-term episodic, and long-term episodic memory. J Clin Med 2018; 7; doi:10.3390/jcm7060146

[26] Jubelt LE, Barr RS, Goff DC, Logvinenko T, Weiss AP, Evins AE. Effects of transdermal nicotine on episodic memory in non-smokers with and without schizophrenia. Psychopharmacology (Berl) 2008; 199:89–98; doi:10.1007/s00213-008-1133-8

[27] Klaming R, Annese J, Veltman DJ, Comijs HC. Episodic memory function is affected by lifestyle factors: a 14-year follow-up study in an elderly population. Neuropsychol Dev Cogn B Aging Neuropsychol Cogn 2017; 24(5):528–42; doi:10.1080/13825585.2016.1226746

[28] Henry JD, Rendell PG. A review of the impact of pregnancy on memory function. J Clin Exp Neuropsychol 2007; 29:793–803; doi:10.1080/13803390701612209

[29] Sherman SM, Buckley TP, Baena E, Ryan L. Caffeine enhances memory performance in young adults during their non-optimal time of day. Front Psychol 2016; 7:1764; doi:10.3389/fpsyg.2016.01764

[30] Wammes JD, Good TJ, Fernandes MA. Autobiographical and episodic memory deficits in mild traumatic brain injury. Brain Cogn 2017; 111:112–26; doi:10.1016/j.bandc.2016.11.004

[31] Hindocha C, Freeman TP, Xia JX, Shaban NDC, Curran HV. Acute memory and psychotomimetic effects of cannabis and tobacco both ‘joint’ and individually: a placebo-controlled trial. Psychol Med 2017; 47(15):2708–19; doi:10.1017/S0033291717001222

[32] Le Berre AP, Fama R, Sullivan EV. Executive functions, memory, and social cognitive deficits and recovery in chronic alcoholism: a critical review to inform future research. Alcohol Clin Exp Res 2017; 41(8):1432–43; doi:10.1111/acer.13431

[33] Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining

cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc 2011; 43:1334–59; doi:10.1249/MSS.0b013e318213fefb
[34] McNerney MW, Radvansky GA. Mind racing: the influence of exercise on long-term memory consolidation. Memory 2015; 23:1140–51; doi:10.1080/09658211.2014.962545
[35] Kensinger EA, Corkin S. Memory enhancement for emotional words: are emotional words more vividly remembered than neutral words? Memory Cogn 2003; 31:1169–80.
[36] Ball TJ, Joy EA, Gren LH, Shaw JM. Concurrent validity of a self-reported physical activity "vital sign" questionnaire with adult primary care patients. Prev Chron Dis 2016; 13:E16; doi:10.5888/pcd13.150228
[37] Mitchell KJ, Johnson MK. Source monitoring 15 years later: what have we learned from fMRI about the neural mechanisms of source memory? Psychol Bull 2009; 135:638–77; doi:10.1037/a0015849
[38] Robertson AD, Marzolini S, Middleton LE, Basile VS, Oh PI, MacIntosh BJ. Exercise training increases parietal lobe cerebral blood flow in chronic stroke: an observational study. Front Aging Neurosci 2017; 9:318; doi:10.3389/fnagi.2017.00318
[39] Loprinzi PD. Intensity-specific effects of acute exercise on human memory function: considerations for the timing of exercise and the type of memory. Health Promot Perspect 2018; 8:255–62; doi:10.15171/hpp.2018.36
[40] Banks PJ, Warburton EC, Brown MW, Bashir ZI. Mechanisms of synaptic plasticity and recognition memory in the perirhinal cortex. Prog Mol Biol Transl Sci 2014; 122:193–209; doi:10.1016/B978-0-12-420170-5.00007-6