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Open vs. Closed Skill Acute Exercise on Emotional Memory

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OPEN VS. CLOSED SKILL ACUTE EXERCISE ON EMOTIONAL MEMORY

by

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ABSTRACT

ASHLEY LOVORN: Acute Open vs. Closed Skill Exercise on Emotional Memory

(Under the direction of Dr. Paul D. Loprinzi)

Accumulating research suggests that acute exercise may influence emotional memory. However, there is limited research on this topic evaluating which modality of exercise elicits the greatest effects on emotional memory. The purpose of this thesis experiment was to evaluate if treadmill exercise (closed-skill) has a differential impact on emotional memory relative to racquetball exercise (open-skill). One-hundred and ninety-three participants were recruited and divided into three groups: closed-skill (N=65), open-skill (N=65) and control (N=64). Prior to exercise, each of the groups watched a 10 minute car crash video. After the video, the three groups exercised (or stretched; control condition) for 30 minutes at a moderate intensity. Following exercise, the participants completed a Cued Recall Test in order to test their memory of the car crash video; for each item on the test, participants also rendered confidence ratings. Following this assessment, participants completed a memory intrusions assessment, evaluating the extent to which they thought about the emotional details during their bout of exercise. Our findings are as follows: (1) central details were remembered more frequently than peripheral details, (2) acute exercise did not impact central or peripheral emotional details directly, but (3) acute exercise increased intrusion memories, as well as the relationship between perceptions of memory confidence and memory accuracy. In conclusion, although the modality of exercise did not have a reliable differential effect on emotional memory, acute exercise may influence aspects (e.g., intrusion memories, association between perceptions of confidence and memory accuracy) of emotional memory.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES……………………………….... 1

BACKGROUND……………………………………………………. 2

INTRODUCTION…………………………….………………….. 7

METHODS……………………………………………….....…... 11

RESULTS…………………………………………………….….... 20

DISCUSSION………………………………………………….….. 29

REFERENCES……………………………………………..…....33

LIST OF TABLES AND FIGURES

Table 1 Overview of study protocol……………………………………………….……. 11

Table 2 Participant characteristics across the experiment groups………………. 20

Figure 1 Physiological responses across time & between experimental groups…. 21

Figure 2 Affect/Arousal scores before and after watching the emotional video…. 22

Figure 3 Impact of Event Survey results…………………………………………. 24

Figure 4 Emotional memory accuracy results……………………………………. 25

Figure 5 Emotional memory confidence results………………………………….. 26

Figure 6a The relationship between confidence in peripheral items and accuracy of peripheral events. ………………………………......................... 27

Figure 6b The relationship between confidence in central items & accuracy of central events. ……………………………….............................. 27

BACKGROUND

Long term memory is the last stage in the multi-store memory model that was proposed by Atkinson-Shiffrin (1968). Based on this model, memory is not just a single store of information, but a division of other stores that can be combined together to create complete memories. One sub-type of long-term memory is explicit memory, which is our declarative memory. More specifically, our explicit memory is the memory that we can consciously recall, such as certain memories or facts. The second sub-type of long-term memory is implicit memory, which is our non-declarative memory. Implicit memory is defined as "*experiences (that) remain concealed from consciousness and yet produce an effect which is significant, and which authenticates their previous experience*" (Ebbinghaus, 1885/1964, pp. 2). The idea of implicit memory is more challenging to grasp, in the sense that it is not a declaration we can make, we just know something or remember it, even if we did not consciously retrieve the memory.

With each of these sub-types of long-term memory, explicit and implicit, we can further divide them into sub-categories. The explicit memory subcategories are episodic and semantic memory. Episodic memory is one's ability to recall experienced events, such as events that have happened in the past. An example of this would be remembering one's wedding or their first day of college. In contrast, semantic memory is responsible for storing facts and information about the world we live in. This would include general knowledge, like knowing Paris is in France, as well as knowing that the sky is blue, even if you are inside on a cloudy day. The implicit memory subcategories are procedural and emotional conditioning. Procedural memory is responsible for our ability to know how to do things, such as riding a bike or driving a car. One may explain procedural memory as being our ‘motor memory’, since it does not involve conscious thought in order to perform a certain skill. Emotional conditioning, as defined by the American Psychological Association, is “*any negative emotional response, typically fear or anxiety, that becomes associated with a neutral stimulus as a result of classical conditioning*” (Vanden-Bos, 2015) With this knowledge of each sub-category of long-term memory, the narrative that follows will discuss, in greater detail, components and mechanisms within the emotional memory system.

The idea of flashbulb memories was first proposed in 1977 by psychologists Roger Brown and James Kulik (Law, 2011). Flashbulb memories were first explained as memories that are so important to us that they leave a vivid image in our minds that are as accurate as a photograph. However, this is thought to be a misconception. Data suggests that such memories as these are not as accurate as we think and may be reconstructed and distorted over time. Take September 11, 2001, for example. When talking to survivors and those who witnessed the event, some of them may say that they will never forget what occurred that day, and some can specifically indicate where they were when they heard the news. However, if we ask individuals this same question every five years, their story may deviate with the passing of time (Law, 2011). We see this same phenomenon occurring in Daniel B. Wright’s paper, where he discusses the idea of flashbulb memories in reference to the Hillsborough football disaster. During the 1989 Football Associate Cup semi-final between Liver-pool and Nottingham forest, a traumatic incident occurred. The incident occurred at Hillsborough stadium as people were running inside to the game; the Liverpool terraces were being filled to capacity, but individuals kept pushing their way in. Due to this, 95 people were crushed to death on the terraces of Hillsborough stadium (Wright, 1993). From Wright's paper, what was discovered between the 247 subjects was that individuals were able to explain and verbally discuss personal information in reference to the event, rather than the event itself. However, this study also illustrates that 5 months after the incident, memories were "*altered as to cohere with (their) symbolic status*" (Wright, 1993, pp. 137). By this, Neisser explains how tragedies can change individuals outlook on their lives and bring families closer together. These traumatic events leave an impact on us and we reconstruct the details of these events so that we think we will never forget them, yet that may not be the case.

When we encode a certain memory, it may not always be as accurate as we assume it to be. Memories are not known facts that we can easily prove. During the encoding of memories, sometimes bits and pieces of details can be left out, leaving us without the whole picture of what truly occurred in that moment or on a certain day. Although memories may not always be perfectly retrieved, emotion plays an important role in retaining aspects of memories. With this idea of flashbulb memories and trying to connect the idea of emotion and what impact it has on memory, John Yuille and Judith Cutshall conducted an experiment.

The goal of Yuille and Cutshall's experiment was to try and assess how emotions elicited from violence and deviant acts can influence one's memory. To investigate this, they interviewed patrons, at multiple time points, who witnessed the death of a business owner during a robbery. They demonstrated that accuracy of this event, as compared to video evidence, was over 80% accurate according to the patrons who witnessed it. Based on these findings, it seems that acts or events that elicit stronger emotions tend to be remembered with greater accuracy (Yuille and Cutshall, 1986). However, as stated previously, this accuracy may wane over time.

There is also evidence from other studies that emotions can enhance one's long-term memory for words that are learned in a laboratory setting. One of the first studies that investigated this was conducted by Lewis Kleinsmith and Stephen Kaplan. To investigate this idea, Kleinsmith and Kaplan had participants come into their laboratory and study word pairs that were to be later recalled. A few of the words were "*kiss, rape*, and *swim*", as some of these words elicit a high arousal (e.g., kiss) and negative valence (e.g., rape), whereas others may be more neutral in arousal and valence (e.g., swim). When they had participants come back one week later, they noticed that the memory retention rates for the emotional words was greater than the neutral ones (Kleinsmith and Kaplan, 1963).

These observations that emotional stimuli are more likely to be remembered than non-emotional stimuli sparked an interest in investigating the underlying mechanisms of this effect. One critical brain region thought to play a critical role in emotional memory is the amygdala. The amygdala is a "*collection of nuclei located in the medical temporal lobe that mediate(s) stress hormones that influence memory consolidation"* (McGaugh, 2013, pp. 10403). For effective retention of emotional memory, activation of the amygdala may be needed. This was discovered by Cahill et al. (1996) in their study that used PET imaging; they demonstrated that when the amygdala was activated when watching emotionally arousing films, emotional memory retention was enhanced. As discussed in the next chapter, we are interested in evaluating whether acute exercise can enhance emotional memory. This is plausible as acute exercise has been shown to improve non-emotional memory (Loprinzi, Blough, Crawford, Ryu, Zou, Li, 2019) and also may increase norepinephrine (Skriver et a., 2014), for example, which plays an important role in the consolidation of emotional memories (Van Stegeren, 2008).

INTRODUCTION

Memory is a complex cognition involving several memory systems, most notably explicit and implicit systems. Of interest to this thesis is explicit memory function. Types of explicit memory include episodic and semantic memory. Episodic memory refers to the retrospective recall of information from a spatial-temporal context. Examples of episodic memory include remembering your high school graduation day, your first date, or wedding day. Semantic memory involves the retrospective recall of non-context-based information. Examples of semantic memory include knowing that the sky is blue, Mississippi is a state, and knowing the basic names of colors.

As stated, episodic memory involves the retrieval of context-based memories. A type of episodic memory that has been extensively investigated is emotional episodic memory, which involves an emotional or highly arousing context to the retrospective event. Although the underlying mechanisms of emotional memory are complex, and likely moderated by the context in which it is studied, the field of neurophysiology has made considerable progress in understanding the etiology of emotional memory. For details on this topic, the reader is referred to the excellent reviews by others (LaBar, 2007; Mather & Sutherland, 2011; Talmi, 2013). In brief, potential mechanisms include arousal-biased competition, which suggests that arousal modulates the competing strengths of mental representations. Specifically, arousal biases competition in favor of goal-relevant stimuli (Mather & Sutherland, 2011). Further, as outlined by Talmi (2013), emotional stimuli may facilitate the encoding and consolidation of memory via norepinephrine-related modulation of synaptic plasticity in the amygdala.

Accumulating research has begun to investigate the effects of acute exercise on emotional memory. In a systematic review, Loprinzi et al. (2018) evaluated the effects of exercise on emotional memory. In this review, they identified six studies evaluating this topic. In brief, their main findings highlight several points. Due to the limited selection of relevant articles, they determined that there were too few studies to render strong conclusions; however, it was suggested that exercise may enhance emotional memory through various hormonal, psychological and neural mechanisms. This 2018 review by Loprinzi et al. highlighted the need for additional research evaluating the effects of acute exercise on emotional memory.

There is mechanistic evidence to suggest that acute exercise may enhance emotional memory. This has been fully discussed in a recent review (Keyan and Bryant, 2019). In brief, Keyan and Bryant (2019) suggest that the likely mechanisms through which acute exercise may enhance emotional memory include various factors (e.g., BDNF, norepinephrine, and glucocorticoid production) that may facilitate synaptic plasticity of the amygdala and hippocampus. This was supported by a recent experiment suggesting that acute exercise, during the consolidation phase of emotional memory, may enhance emotional memory via noradrenergic-glucocorticoid interactions (Jentsch and Wolf, 2020).

As indicated by the most recent systematic review on this topic (Loprinzi et al., 2018), relatively few (N=6) studies have evaluated the effects of acute exercise on emotional memory. Recently, Wade and Loprinzi (2018) experimentally evaluated whether acute, moderate-intensity exercise could enhance emotional memory. The bout of exercise (duration = 15 minutes) occurred prior to memory encoding, with emotional memory assessed using emotional images from the International Affective Picture System (IAPS). Their main finding was that, over a 14-day follow-up period, the recognition of emotional memory declined for both valence and arousal stimuli. The control and the exercise groups did not illustrate significant differences in the rate of decline and therefore, this study did not demonstrate evidence supporting a beneficial effect of acute, moderate-intensity exercise on emotional memory.

As a follow-up to the Wade and Loprinzi (2018) experiment, Loprinzi, Wages, and Ferguson (currently unpublished) conducted an experiment that made two notable changes from their previous experiment. In their follow-up experiment, instead of implementing a moderate-intensity bout of exercise, they used a high-intensity bout of acute exercise. The motivation for this came from a recent systematic review (Loprinzi, 2018) and meta-analysis (Loprinzi, Blough, Crawford, Ryu, Zou, Li, 2019) demonstrating that high-intensity acute exercise more favorably influences episodic memory when compared to lower-intensity acute exercise. The second modification involved altering the temporal period in which the exercise bout occurred. Instead of implementing the acute bout of exercise prior to memory encoding (Wade and Loprinzi, 2018), Loprinzi, Wages, and Ferguson (currently unpublished) placed the bout of exercise after memory encoding. The motivation for this came from a recent meta-analysis demonstrating that the greatest effect of acute exercise on episodic memory occurs when the acute bout of exercise occurs during the early consolidation period (Loprinzi, Blough, Crawford, Ryu, Zou, Li, 2019). However, despite these two modifications, and similar to the Wade and Loprinzi (2018) study, their follow-up experiment also did not demonstrate an effect of acute exercise on emotional memory (Loprinzi, Wages, and Ferguson, currently unpublished).

The present experiment extends the Wade and Loprinzi (2018) and Loprinzi, Wages, and Ferguson (currently unpublished) experiments in several ways. To augment the strength of the exercise stimulus, the present experiment extends the exercise duration from 15 minutes to 30 minutes. Further, the type of exercise was manipulated to include both open- and closed-skilled exercises. Open-skilled exercise (e.g., racquetball) involves unpredictable movement patterns when compared to closed-skilled exercise (e.g., treadmill exercise). This exercise modality modification was in response to recent research demonstrating that the type of exercise (open- vs. closed-skilled) may have a unique effect on both synaptic plasticity (Hung, Tseng, Chao, Hung and Wang, 2018) and memory function (Cantrelle, Burnett, Loprinzi, 2020; Gu, Zou, Loprinzi, Quan, Huang, 2019). Lastly, rather than utilizing images (IAPS) to induce emotional memory (Wade and Loprinzi, 2018; Wages, Ferguson and Loprinzi, currently unpublished), the present experiment implements a more dynamic, emotional stimuli (video), in an effort to augment the perceived emotional response.

METHODS

Study Design

A three-arm, randomized controlled experiment was employed. Participants were randomized into one of three groups, including a closed-skill exercise group, open-skill exercise group, and a control group. Randomization was performed using a computerized algorithm. Allocation concealment was maintained by having the researcher and participant not know which group the participant was randomized into until after arriving in the laboratory.

Both the closed- and open-skill exercise groups exercised at a moderate-intensity for 30 minutes. The closed-skill group exercised on a treadmill, the open-skill group played racquetball, and the active control group engaged in a series of light stretches. See Table 1 below for a schematic of the study design, including the temporal periods of assessments.

Table 1. Overview of study protocol.

Condition	**Start**						**Finish**
Open-Skill Exercise	Pre-Assessments of Valence and Arousal	Watch 10 min Car Crash Video	Post-Assessments of Valence and Arousal	30 min of moderate-intensity racquetball	7 min rest †	Cued Emotional Memory Recall	Surveys (e.g., Impact of Event)
Closed-Skill Exercise	Pre-Assessments of Valence and Arousal	Watch 10 min Car Crash Video	Post-Assessments of Valence and Arousal	30 min of moderate-intensity treadmill exercise	7 min rest †	Cued Emotional Memory Recall	Surveys (e.g., Impact of Event)
Control	Pre-Assessments of Valence and Arousal	Watch 10 min Car Crash Video	Post-Assessments of Valence and Arousal	30 min of stretching	7 min rest	Cued Emotional Memory Recall	Surveys (e.g., Impact of Event)

† Involved a 2 minute recovery walk followed by 5 minutes of seated rest.

Participants

The total sample size included 193 participants, including 65, 65, and 64 participants, respectively, in the closed-skill, open-skill, and control groups. This sample size was based on an a-priori power analysis using data from previous experiments that used the same emotional video employed in the present study. Partial eta-squared estimates (derived from their ANOVA f-values, df, and using a 95% CI)[1] were as follows for these previous experiments: Keyan and Bryant (η_p^2 = 0.1379; from f(2,51) = 4.08), Devilly et al. (η_p^2 = 0.1412; from f(2,58) = 4.77), and Gittins et al. (η_p^2 = 0.0614; from f(1,75) = 4.91). Based on these estimates, we utilized the lower (more conservative) η_p^2 of 0.0614 (Gittens et al.). Using G*Power (v.3.1.9.2), and assuming 3 groups, alpha level of 0.05, power level of 0.85, and an effect size f of 0.2557 (calculated from η_p^2 of 0.0614), a total sample size of 171 individuals was needed. We intentionally oversampled given the following reasons: (1) to account for potential missing data (e.g., non-compliance, technical errors, etc.) and (2) although these prior experiments employed the same emotional video as used in the present experiment, notably, they were not answering the same research question as the present study. Given the latter point, and like most a-priori power analyses, the estimated effect size is a rough guess, and as such, we employed a conservative a-priori power analysis. Notably, our sample size (N = 193) is considerably higher than previous studies (Keyan and Bryant, N = 54; Devilly et al., N = 61; Gittins et al., N = 85).

[1] This website was used to calculate partial eta-squared estimates: https://effect-size-calculator.herokuapp.com/

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 28.

In an effort to minimize confounding effects on emotional memory function, participants were excluded if they:

-Self-reported as a daily smoker

-Self-reported as being pregnant

-Exercised within 5 hours of testing

-Consumed caffeine within 3 hours of testing

-Had a previous concussion of head trauma

-Took marijuana or other illegal drugs within the past 30 days

-Were considered a daily alcohol user (>30 drinks/month for women; >60 drinks/month for men; or consumed alcohol within the past 24-hours)

-Were color blind. Color blind status was assessed objectively by showing individuals (on a computer screen) rectangular shapes in a several different colors (all the colors present the emotional memory video) and asking them to identify the color. Participants incorrectly responding to any of the colors were excluded from the study.

Experimental Conditions

Participants were randomized into one of three experimental conditions, including closed-skill exercise (treadmill), open-skill exercise (racquetball) or control (stretching). Among the 193 participants, 165 completed the exercise bout with a mask on, due to concerns with the COVID-19 pandemic.

The exercise visits involved participants exercising (either jogging on treadmill or engaging in racquetball) for 30 minutes at 60% of their heart rate reserve (HRR). Heart rate was assessed every 5 minutes throughout the exercise bout. The treadmill speed and incline were manipulated to keep the participant's heart rate within 5 beats per minute of their estimated 60% of HRR. The same applied for the racquetball participants, as they were asked to play harder or reduce effort in order to keep their heart rate within 5 beats per minute of their estimated 60% of HRR. Racquetball was played as a two-person game (researcher and participant).

The HRR equation used is:

$HRR = [(HR_{max} - HR_{rest}) * \% \text{ intensity}] + HR_{rest}$

To calculate HR_{rest}, at the beginning of the visit, participants sat quietly for 5 minutes, and HR was recorded from a Polar HR monitor. HR_{max} was estimated from the average of the following 5 equations: (a) Fox et al. (1971): 220-age; (b) Astrand et al. (1952): 216.6 – (0.84*age); (c) Tanaka, Monahan, & Seals (2001): 208 – (0.7*age); (d) Gellish et al. (2007): 207 – (0.7*age); and (e) Gulati et al. (2010): 206 – (0.88*age). Notably, 60% of HRR represents moderate-intensity exercise (Garber et al., 2011).

The stretching visit was modeled after previous work (Edwards, Rhodes, & Loprinzi, 2017). That is, for 30 minutes, participants engaged in light stretches that were guided by the researcher. This involved a series of upper and lower body stretches that were held for an approximate 15 second period, with an emphasis on light stretching (not to the point of discomfort). The stretching condition included two, 12.5 minute bouts. Participants engaged in guided stretches for 12.5 minutes, rested for 5 minutes (gentle conversation with the researcher), and then re-completed the stretches for an additional 12.5 minutes (i.e., 30 minutes in total).

Emotional Memory Induction

Participants were asked to watch a 10 minute video that depicts the scene of a car crash. The following intentional instructions were given to the participants before they viewed the video. "*Please closely watch this 10 minute video. Please be as attentive as possible during this video, as later I will be asking you to recall specific information from the video*."

The video was watched in an enclosed, isolated unit, with audio played via headphones (self-selected volume). This video has been used in other studies evaluating emotional memory (Devilly, Varker, Hansen, Gist 2007; Gittens, Paterson, Sharpe, 2015; Keyan and Bryant, 2017a). In these prior studies, this video has demonstrated evidence of construct validity, as noted by increased distress scores following the video viewing (Gittens, Paterson, Sharpe, 2015).

Emotional Response Assessment

Immediately prior to and after viewing the video, participants completed two single-item assessments to evaluate perceived valence and arousal. The Feeling Scale was used to evaluate the valence response to the video, which includes the statement, "*Please circle the most appropriate number to represent how you feel right now, in this very moment*." The response options ranged from -5 (very bad) to 5 (very good). The Felt Arousal Scale was used to evaluate the physiological arousal from the video. This scale includes the statement, "*Estimate here how aroused you actually feel. Do this by circling the appropriate number. By "arousal" we mean how "worked-up" you feel. You might* *experience high arousal in one of a variety of ways, for example, as excitement or anxiety or anger. You might also experience low arousal in a number of different ways, for example, as relaxation or boredom or calmness."* The response options ranged from 1 (low arousal) to 6 (high arousal).

Participants were also asked to complete an Impact of Event Survey (Horowitz, Wilner, Alvarez, 1979), which assesses three difficulties that people sometimes have after stressful life events. It was used in the present study to assess intrusion memories, or how distressing each difficulty was during the 35 minute memory consolidation period (i.e., during the bout of exercise/stretching). The three items included the statements, "*I thought about it when I didn't mean to; Pictures about it popped into my mind; I had waves of strong feelings about it."* For each of these three items, a 5-point Likert scale was used (0 = not at all; 1 = a little bit; 2 = moderately; 3 = quite a bit; 4 = extremely). In the present sample, internal consistency (Cronbach's alpha) for these three items was 0.85.

Emotional Memory Assessment

For the emotional memory assessment and pilot procedure used to develop this instrument, see Appendix A. In alignment with other studies (Devilly, Varker, Hansen, Gist, 2007; Gittens, Paterson, Sharpe, 2015; Keyan and Bryant, 2017a), a 25-item survey was used to evaluate the participant's emotional memory. This 25-item assessment included 12 peripheral and 13 central questions (see Appendix A), involving questions related to the three constituents of episodic memory (i.e., *"what", "where*" and "*when"* questions). Similar to other studies (Devilly et al., 2007), after each item, participants rated their confidence in their response, ranging from 1 (not at all confident) to 5 (extremely confident). Two composite confidence metrics were calculated, including a peripheral confidence and central confidence scores, involving their average confidence responses across the peripheral and central items.

A series of steps (Kyriazos and Stalikas, 2018; Flake and Fried, 2020), in alignment with the Delphi-method, were followed in developing our emotional memory assessment. First, among the 25 items, 3 items (#1, #2, #3) were identical to previous studies (Devilly, Varker, Hansen, Gist 2007) utilizing this same emotional video. For the remaining 22 items that we created, we took a four-step approach (fully detailed in Appendix A) in developing these items. As fully detailed in Appendix A, our pilot study demonstrated evidence: (1) that our peripheral and central questions were, indeed, measuring peripheral and central aspects of the video, (2) that the video elicited the desired emotional response (decreased valence and increased arousal), and (3) that floor/ceiling memory effects were not present.

Additional Assessments

Based on the potential to influence the relationship between acute exercise and emotional memory, participants completed a series of surveys (and had measurements taken; e.g., body mass index) at the end of the experiment. Evaluated parameters included (1) age (years), (2) gender (male/female), (3) measured body mass index, (4) self-reported weekly moderate-to-vigorous physical activity, (5) estimated cardiorespiratory fitness, (6) experience playing racquetball, (7) time of day in which the assessment took place, (8) chronotype, and (9) emotional reactivity.

Age and gender were self-reported. Body mass index (kg/m^2) was directly measured from height and weight assessments using standard procedures. Self-reported weekly moderate-to-vigorous physical activity was assessed from the validated Physical Activity Vital Signs questionnaire (Ball et al., 2016). Estimated cardiorespiratory fitness was determined from a validated prediction equation published elsewhere (Jackson et al., 1990). Racquetball experience was assessed from the following question, "*What is your racquetball experience*?" Response options included: (1) never played previously, (2) previously played but not regularly anymore, (3) currently play about every other week, (4) currently play once a week, and (5) currently play at least twice a week. The time of day in which the laboratory visit took place was recorded by the researcher. Chronotype was assessed from a validated instrument using a single question (Loureiro et al., 2015), "*One hears about "morning-types" and "evening-types". Which one of these types do you consider yourself to be*: (a) definitely a morning-type, (b) rather more a morning-type than an evening-type, (c) rather more an evening-type than a morning-type, or (d) definitely an evening-type. Lastly, emotional reactivity was assessed from an 18-item Perth Emotional Reactivity Scale – Short Form (Preece et al., 2019). From this assessment, two composite subscales were evaluated, including negative reactivity (8 items) and positive reactivity (8 items). An example item of negative reactivity is, "*When I'm upset, it takes me quite a while to snap out of it*." An example item for positive reactivity is, "*When I am joyful, I tend to feel it very deeply*." All items were evaluated on a 5-point scale, ranging from 1 (very unlike me) to 5 (very like me). For these two respective composite measures (negative and positive reactivity), internal consistency (Cronbach's alpha) in the present sample was 0.87 and 0.86.

Analyses

Frequentist and Bayesian repeated measures ANOVAs (RM-ANOVA) were conducted. These analyses included the following factors: *Condition* (three levels: Closed-Skill Exercise, Open-Skill Exercise, Control), *Memory Detail* (two levels: Peripheral, Central), *Memory Confidence* (two levels: Peripheral Confidence, Central Confidence), *Arousal/Valence* (two levels: Pre-Video, Post-Video), *Impact of Event Survey Item Type* (three levels, Item 1, 2, 3), and *Exercise/Control Heart Rate Response* (eight levels: Pre, 5 min, 10 min, 15 min, 20 min, 25 min, 30 min, Post). Condition was a between-subject factor, whereas all other factors were within-subject factors. Violations of sphericity were corrected with Huynh-Feldt corrections. All Frequentist post-hoc testing used Holm-corrected post-hoc comparisons.

To supplement the Frequentist analyses, Bayesian analyses were utilized to test the robustness of the examined effects. Unlike frequentist analyses, Bayesian analyses allow for the ability to obtain evidence in favor of the null hypothesis and discriminate between "*absence of evidence*" and "*evidence of absence*". The inclusion Bayes factor (BFi) is reported, which represents the change from prior to posterior inclusion odds, in a ratio reflecting support for the effect being included versus support for the effect being excluded. We follow the convention that a BF > 3 indicates moderate evidence in favor of the alternative hypothesis, whereas a BF< 1/3 indicates moderate evidence in favor of the null hypothesis.

RESULTS

Participant Characteristics. Table 2 displays the characteristics of the sample. There were no differences for any of the parameters across the three experimental conditions.

Table 2. Participant characteristics across the experiment groups.

Variable	**Closed-Skill Exercise (n = 65)**	**Open-Skill Exercise (n = 64)**	**Control (n = 64)**	P-Value	BF
Demographics					
Age, mean years	20.75 (1.5)	20.48 (1.1)	20.82 (1.6)	.37	.128
Gender, % Female	66.2	73.4	59.4	.24	.149
Race, % White	78.5	92.2	81.3	.41	5.25e-6
BMI, mean kg/m^2	25.37 (5.3)	25.83 (4.8)	26.21 (5.8)	.65	.078
Medication/Diagnosis					
Taking mood medication, %	1.5	3.1	4.7	.59	.008
ADHD diagnosis, %	7.7	3.1	7.8	.46	.022
Behavioral					
MVPA, mean min/week	219.7 (175.5)	193.0 (175.1)	205.6 (175.8)	.69	.074
Cardiorespiratory fitness, mean mL/kg/min	41.23 (7.6)	40.06 (7.6)	41.29 (8.4)	.59	.084
Racquetball experience, %				.88	.076
Never played	83.3	80.6	76.5		
Previously played	16.7	19.4	23.5		
Other					
Chronotype, %				.19	.037
Definitely morning-type	11.3	12.7	19.0		
Rather more morning- than evening-type	27.4	12.7	25.4		
Rather more evening- than morning-type	32.3	47.6	28.6		
Definitely evening-type	29.0	27.0	27.0		
Time of assessment (military time), mean	1457.5 (276.0)	1397.5 (256.8)	1379.4 (247.4)	.22	.207
Emotional reactivity, mean					
Negative reactivity	25.62 (8.7)	23.61 (7.2)	25.48 (7.1)	.26	.17
Positive reactivity	35.86 (6.1)	37.45 (5.9)	35.47 (5.5)	.13	.32

ADHD, attention deficient hyperactive disorder; BF, Bayes factor (inclusion); BMI, body mass index; MVPA, moderate-to-vigorous physical activity; ANOVA was used to calculate p-values for continuous variables, whereas a chi-square analysis was employed for categorical variables.

Manipulation Checks

Physiological Response

Figure 1 displays the physiological (heart rate) response to the exercise/control conditions. In a 3 (Condition: Closed-Skill, Open-Skill, Control) × 8 (Time: Pre, 5, 10, 15, 20, 25, 30, Post) RM-ANOVA, there was a main effect for Condition, $F(2, 190) = 358.4$, $p < .001$, $\eta^2 = .44$, BF > 1000, and Time, $F(4.96, 943.9) = 682.6$, $p < .001$, $\eta^2 = .28$, BF > 1000, which was qualified by a Condition x Time interaction, $F(9.94, 943.9) = 112.2$, $p < .001$, $\eta^2 = .09$, BF > 1000. Post-hoc tests demonstrated that heart rate was not different at any time point between the two exercise conditions, all *p*s > .05. These results demonstrate that the two exercise manipulations were equally effective in increasing heart rate.

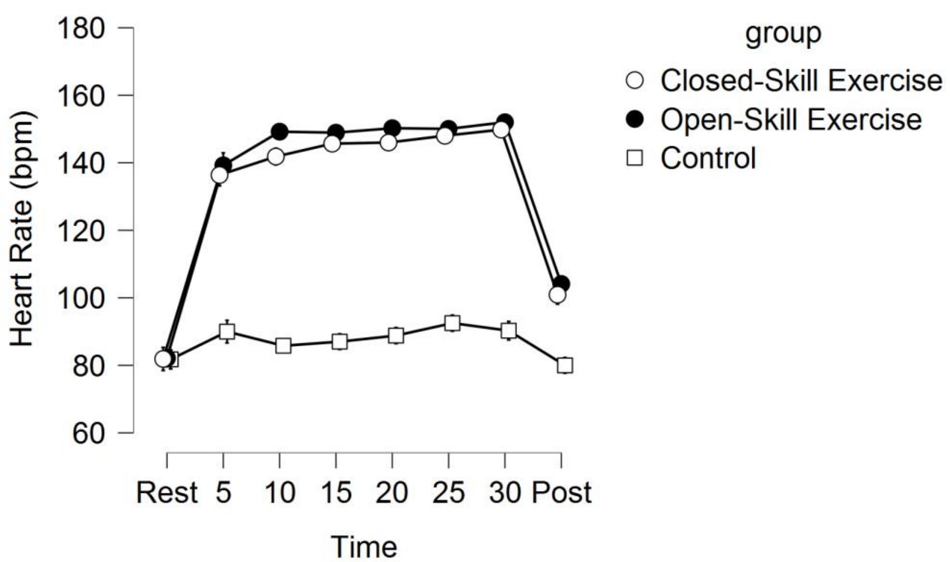

Figure 1. Physiological (heart rate) responses across time (min) and between experimental groups. Error bars (minimally present) represent 95% confidence intervals.

Valence and Arousal Response

Figure 2 displays the valence and arousal scores immediately before and after watching the emotional video. In a 3 (Condition: Open, Closed, Control) × 2 (Time: Pre, Post) RM-ANOVA on valence, there was a main effect for Time, $F(1, 190) = 299.7$, $p < .001$, $\eta^2 = .39$, BF = 5.291e+44, but no main effect for Condition, $F(2, 190) = 2.76$, $p = .07$, $\eta^2 = .01$, BF = .426, or Time × Condition interaction, $F(2, 190) = 2.29$, $p = .10$, $\eta^2 = .006$, BF = .461.

Similarly, for arousal, there was a main effect for Time, $F(1, 190) = 307.0$, $p < .001$, $\eta^2 = .31$, BF = 3.266e+39, but no main effect for Condition, $F(2, 190) = 1.31$, $p = .27$, $\eta^2 = .01$, BF = .20, or Time × Condition interaction, $F(2, 190) = 2.77$, $p = .07$, $\eta^2 = .006$, BF = .545. These results demonstrate that the emotional video was effective, in all three experimental conditions, in increasing arousal and reducing valence.

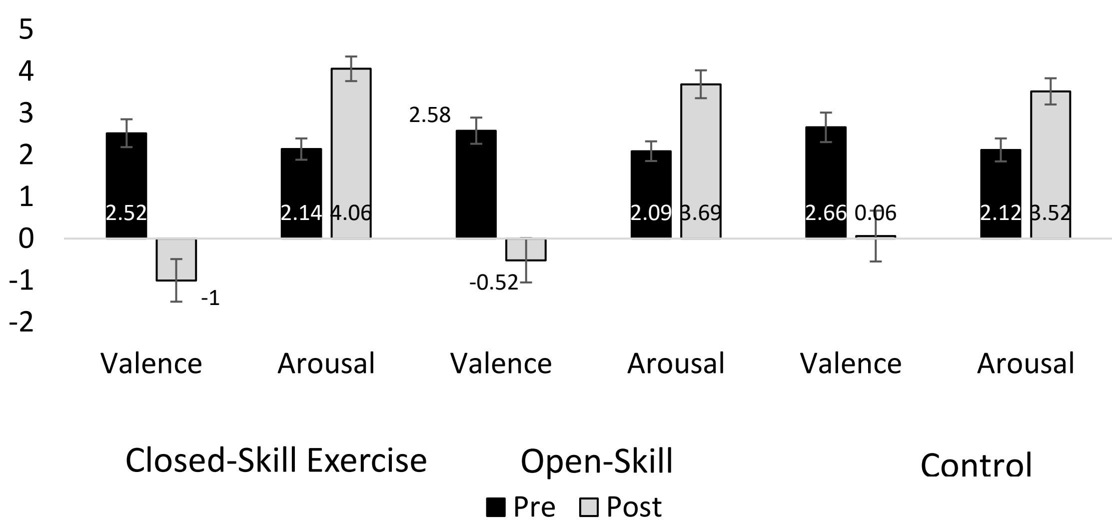

Figure 2. Valence and arousal scores immediately before (pre) and after (post) watching the emotional video. Error bars represent 95% confidence intervals. For valence, the response scale ranged from -5 (very bad) to +5 (very good). For arousal, the response scale ranged from 1 (low arousal) to 6 (high arousal).

Memory Results

Intrusion Memories

Figure 3 displays the results of the Impact of Event Survey. At the end of the experiment, participants completed three questions assessing difficulties that people sometimes have after stressful life events. These questions were specifically tailored toward the emotional video. These included, "*I thought about it when I didn't mean to; Pictures about it popped into my mind; I had waves of strong feelings about it."* For these questions, response options ranged from 0 to 4 (0 = not at all; 1 = a little bit; 2 = moderately; 3 = quite a bit; 4 = extremely). As shown in Figure 3, across all conditions, and for each of the three items, mean responses were between 1 (a little bit) and 2 (moderately), suggesting that during the exercise/stretching sessions, participants thought about the video *a little bit* to *moderately*.

In a 3 (Condition: Open, Closed, Control) × 3 (Item: 1, 2, 3) RM-ANOVA, there was a main effect for Item, $F(1.95, 370.6) = 9.39$, $p < .001$, $\eta^2 = .01$, BF = 120.1, main effect for Condition, $F(2, 190) = 3.24$, $p = .04$, $\eta^2 = .03$, BF = 1.27, but no Item × Condition interaction, $F(3.90, 370.6) = 1.24$, $p = .29$, $\eta^2 = .003$, BF = .05. Holm-corrected post-hoc tests demonstrated that Item 2 was higher than Item 1, $M_{diff} = .20$, $t = 2.71$, $p = .01$, d = .20, BF = 6.2, and Item 3, $M_{diff} = .31$, $t = 4.28$, $p < .001$, d = .30, BF = 209.0, but Item 1 and 3 did not differ, $p = .12$, BF = 24. Regarding the main effect for Condition, Closed-Skill Exercise was higher than Open-Skill Exercise, $M_{diff} = .46$, $t = 2.49$, $p = .04$, d = .18, BF = 145.6, but Control did not differ from Open-Skill, $p = .19$, BF = 3.20, or from Closed-Skill, $p = .43$, BF = .21. These results suggest that aspects of the emotional video (intrusion memories) were more likely to have come to mind during the Closed-Skill Exercise.

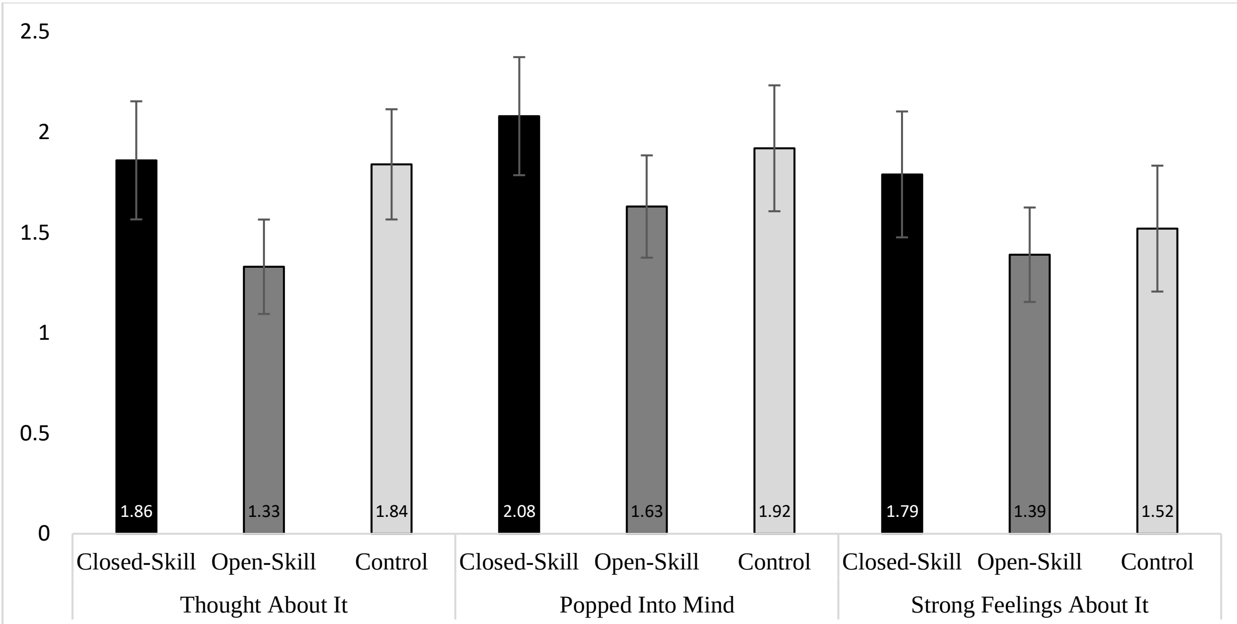

Figure 3. Impact of Event Survey (intrusion memory) results. Error bars represent 95% confidence intervals. Response options ranged from 0 (not at all) to 4 (extremely).

Emotional Memory Accuracy

Figure 4 displays the emotional memory accuracy results. In a 3 (Condition: Closed, Open, Control) × 2 (Memory Detail: Peripheral, Central) RM-ANOVA, there was a main effect for Memory Detail, $F(1, 190) = 9.38$, $p = .003$, $\eta^2 = .02$, BF = 13.45, but not a main effect for Condition, $F(2, 190) = 1.29$, $p = .27$, $\eta^2 = .007$, BF = .11, or Memory Detail x Condition interaction, $F(2, 190) = 1.44$, $p = .23$, $\eta^2 = .007$, BF = .21. Regarding the main effect for Memory Detail, post-hoc testing showed greater accuracy for Central details compared to Peripheral details, $M_{diff} = .04$, $t = 3.06$, $p = .003$, d = .22, BF = 7.18. These findings suggest that memory accuracy was greater for Central than

Peripheral details, but this did not vary as a function of acute exercise occurring during the memory consolidation period.

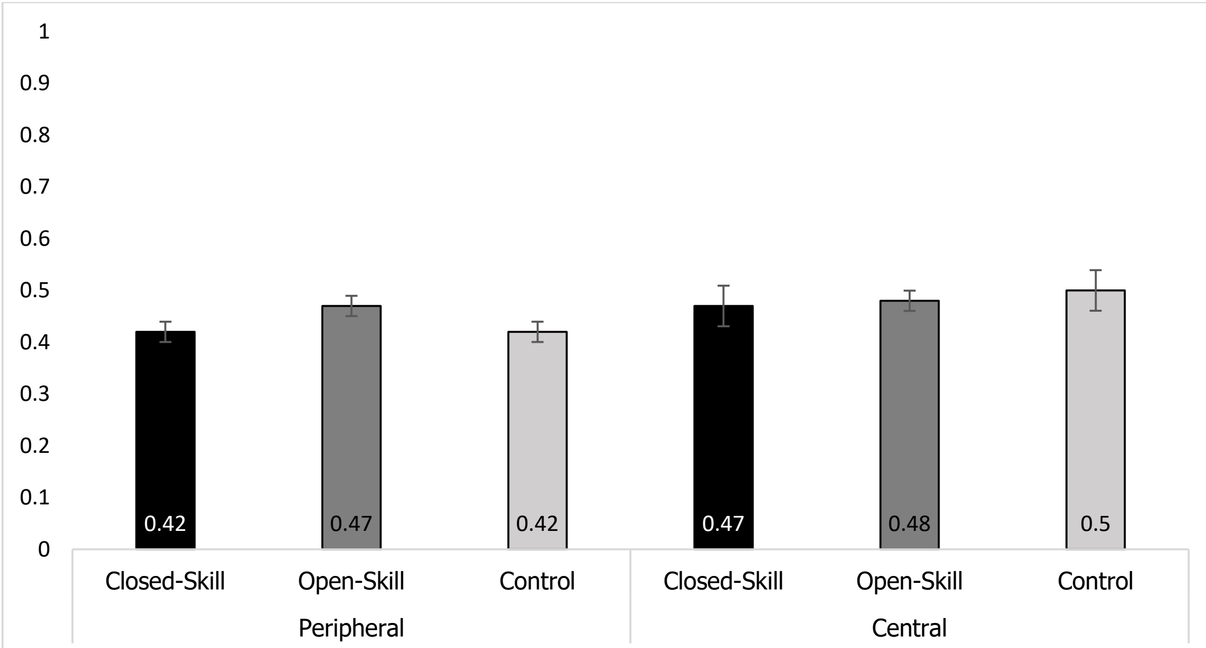

Figure 4. Emotional memory accuracy results. Estimates are proportions, with error bars representing 95% confidence intervals.

Emotional Memory Confidence

Figure 5 displays the memory confidence results. In a 3 (Condition: Closed, Open, Control) × 2 (Memory Confidence: Peripheral, Central) RM-ANOVA, there was a main effect for Memory Confidence, $F(1, 190) = 25.3$, $p < .001$, $\eta^2 = .025$, BF > 1000, and main effect for Condition, $F(2, 190) = 4.71$, $p = .01$, $\eta^2 = .04$, BF = 4.27, but not a Memory Confidence x Condition interaction, $F(2, 190) = .36$, $p = .70$, $\eta^2 = .0001$, BF = .07. Holm-corrected post-hoc tests demonstrated that participants were more confident in remembering Central details compared to Peripheral details, $M_{diff} = .20$, $t = 5.03$, $p < .001$, d = .36, BF > 1000. Regarding the main effect for Condition, those in the Closed-Skill condition had lower memory confidence when compared to those in the Control condition, $M_{diff} = -.29$, $t = 3.04$, $p = .008$, d = .22, BF = 107.8. Open-Skill Exercise did not differ from Closed-Skill Exercise, $p = .25$, BF = .39, or from Control, $p = .12$, BF = 1.66. These findings suggest that, similar to the greater memory accuracy of central events (see Figure 4), participants had greater memory confidence for central events. However, acute exercise was not reliably associated with memory confidence.

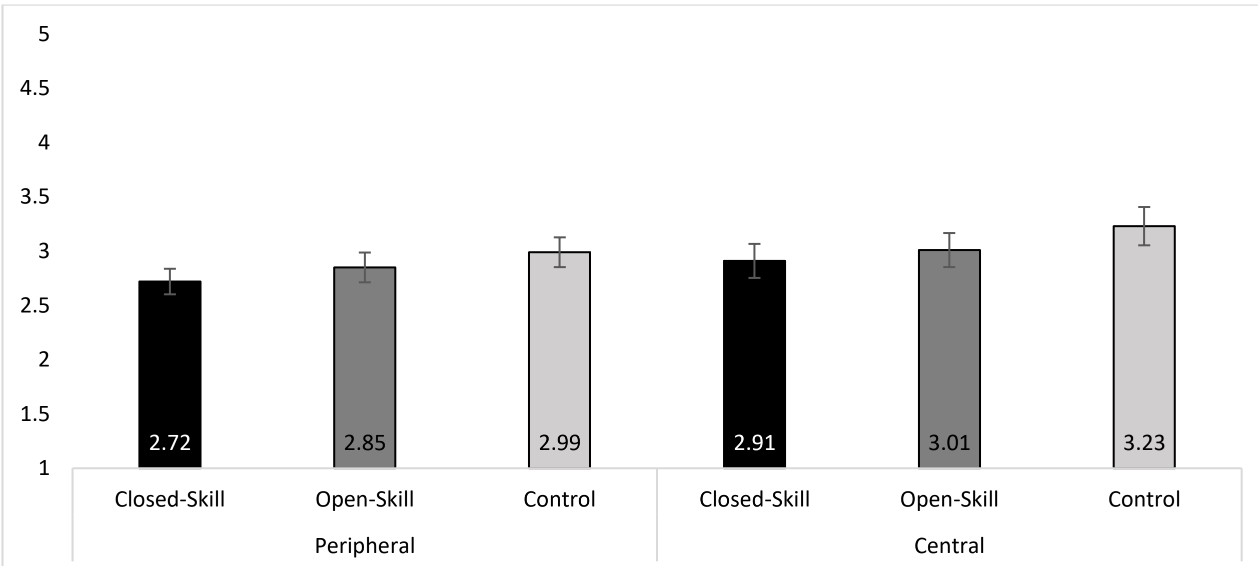

Figure 5. Emotional memory confidence results. Error bars represent 95% confidence intervals. Response options ranged from 1 (not at all confident) to 5 (extremely confident).

Memory Confidence on Memory Accuracy

Figure 6a illustrates the relationship between confidence in peripheral items and memory accuracy of peripheral events, $r = .205$, $p = .004$, BF = 5.19. Figure 6b illustrates the relationship between confidence in central items and memory accuracy of central events, $r = .37$, $p < .001$, BF > 1000. These results demonstrate higher perceptions of confidence were associated with higher memory accuracy.

Notably, however, the magnitude of the correlation varied by group. The relationship between confidence in peripheral items and memory accuracy of peripheral items, for closed-skill, open-skill, and control, respectively, were $r = .29$ ($p = .01$), $r = .33$ ($p = .008$), and $r = .01$ ($p = .92$). The correlation between closed-skill and open-skill was not different (p = .40); closed-skill vs. control approached significance, $p = .05$; and open-skill vs. control was significant, $p = .03$.

The relationship between confidence in central items and memory accuracy of central items, for closed-skill, open-skill, and control, respectively, were $r = .49$ ($p < .001$), $r = .39$ ($p = .001$), and $r = .23$ ($p = .07$). The correlation between closed-skill and open-skill was not different (p = .24); closed-skill vs. control was significant, $p = .04$; and open-skill vs. control was not different, $p = .16$.

Collectively, these findings suggest that higher perceptions of confidence were associated with greater memory accuracy, and this association was more pronounced among those who exercised.

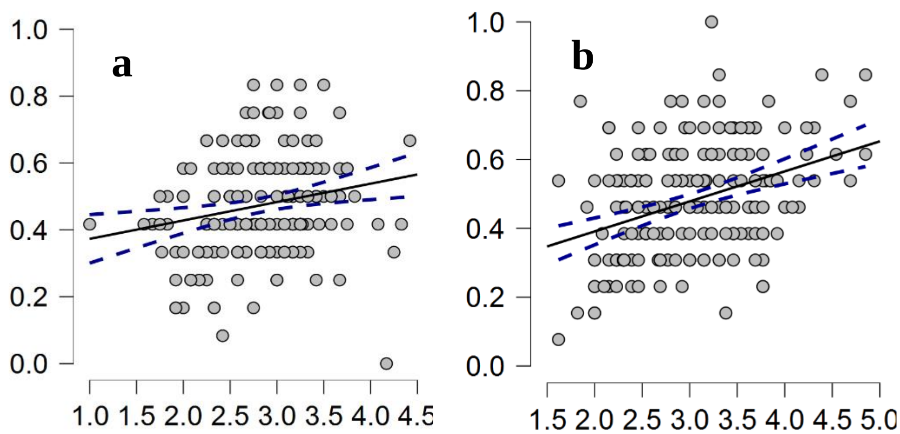

Figure 6. The relationship between confidence in (a) peripheral items and accuracy of peripheral events, and (b) central items and accuracy of central events. Ordinate (y-axis) represents memory accuracy (proportion) and abscissa (x-axis) represents confidence scores. Dashed lines represent 95% confidence interval. For memory confidence, response options ranged from 1 (not at all confident) to 5 (extremely confident).

Sensitivity Results

A series of RM-ANOVA analyses were computed to evaluate the interaction effects of the categorical study characteristic parameters (Table 1) with Condition (three levels: Closed, Open, Control) on memory accuracy (2 levels: Peripheral, Central). Results showed that Gender, $p = .23$, Mood Medication, $p = .19$, and Chronotype, $p = .28$, did not interact with Condition to influence memory accuracy.

A series of 3 (Condition) × 2 (Memory Detail) RM-ANCOVA analyses were computed to evaluate the independent effects of the continuous study characteristics on memory accuracy. There was no main effect of age, $p = .37$, body mass index, $p = .22$, self-reported moderate-to-vigorous physical activity, $p = .43$, estimated cardiorespiratory fitness, $p = .64$, time of day of the laboratory session, $p = .52$, negative emotional reactivity, $p = .24$, or positive emotional reactivity, $p = .13$.

DISCUSSION

Research has demonstrated that exercise may enhance emotional memory through various hormonal, psychological and neural mechanisms (Loprinzi et al., 2018). However, due to the limitations of available research of this topic, Loprinzi et al. (2018) called for more research on this subject to determine the effects of different exercise modalities on emotional memory. As an expansion of the research from Wade and Loprinzi (2018) and Loprinzi, Wages, Ferguson (currently unpublished), this project was designed to investigate different exercise modalities, as well as evaluate this relationship while considering a more robust emotional memory stimuli. The main finding of this experiment was that memory accuracy was greater for central than peripheral details. Further, although exercise did not consistently improve emotional memory, we observed a few interesting results: (1) closed-skilled exercise had a greater effect on intrusion memories when compared to open-skilled exercise, and (2) the relationship between perceptions of confidence and emotional memory accuracy was stronger among those who exercised, relative to the control condition.

Our null results align with other studies. In the Loprinzi, Wages, and Ferguson (currently unpublished) study, they found that acute exercise did not enhance emotional memory recognition. These same findings were observed in the Wade and Loprinzi (2018) study, where they showed that acute, moderate intensity walking did not have an effect on long-term emotional memory recognition. In speculating why there was no observable reliable evidence regarding acute exercise improving emotional memory, it is possible that there is no true causal link between acute exercise and emotional memory.

Another reason for finding no reliable evidence could be due to the exercise intensity that was implemented in our study (i.e., 60% of HRR). Segal et al. (2012) observed a post exercise memory increase and their experiment implemented only six minutes of exercise on a cycle ergometer at 70% of the participants VO_{2max}. Relatedly, Keyan and Bryant (2017a) showed that when the exercise group engaged in ten minutes of stepping exercises at 50 – 85% of their HR max, there was no main effect for the condition. Based on these results, it is possible that exercise needs to be at a higher intensity in order to demonstrate a link between acute exercise and emotional memory. In support of this, Keyan and Bryant (2017b) conducted a study where participants were asked to engage in intense stepping exercises for ten minutes at 60 – 85% of their HR max. Their results demonstrated a main effect for condition, in that compared to the walking group that exercise for 10 minutes at a slow, undisclosed speed, the intense exercise group recalled more emotional images.

In regard to our memory intrusion results, we observed that the emotional video (intrusion memories) was more likely to have come to mind during Closed-Skill Exercise. This partially aligns with work by Keyan and Bryant (2017c) as they studied this by having participants watch a film depicting a highway car crash, which is the same film used in our study. After watching the video, participants came back two days later, and engaged in various exercise and memory reactivation groups. After each group completed their exercise/reactivation, or lack thereof, they were given memory questionaries that related to declarative and intrusive memory recall two days after their memory reactivation session. Their findings demonstrated that intense exercise during memory reactivation enhanced emotional traumatic memory. They also found that, although acute exercise did not robustly influence emotional memory, exercise increased intrusion memories. We also showed that, during the Closed-Skilled Exercise condition, intrusion memories were greater when compared to Open-Skilled Exercise. This makes sense, in that, by running on a treadmill, one's mind is more free to wander when compared to playing racquetball, which may require more cognition operations.

In regard to our confidence-memory results, we observed an interesting relationship. We observed that the relationship between perceptions of confidence and emotional memory accuracy was stronger in those who exercised, compared to the control group. Although speculative, exercising before a memory test may improve prefrontal memory monitoring processes (Davis et al., 2011, Kujach et al. 2018), such that participants are better judges of how accurate they are in their answers.

Our results also demonstrated that central details are more likely to be remembered than peripheral details. Reasons for this is that encoding of central details, versus peripheral ones, are less prone to cognitive overload (Yegiyan and Lang, 2010); cognitive overload is the amount of working memory resources used. This makes sense, in that central details are ones that are specific to an event or object itself, whereas the peripheral details are not always consciously encoded. It was, for example, easier for an individual to remember how many victims there were in a car crash that they watched, than it is for them to remember if there was a house in the background of that scene.

In reference to this study, strengths include using an experimental design, comprehensively evaluating different aspects of emotional memory, and recruiting a relatively large sample size compared to other studies on this topic. However, limitations for this study include the issue that the majority of the participants were undergraduate students, and the mean age was around 20 years of age. This limits this current study from being able to generalize to other age groups, such as those 40-50 years of age, or even 65+ years of age. This study was also limited in regard to the demographics of individuals, as over 78% of the participants identified to be Caucasian and over 66% identified as female. This reduces the ability to generalize to other races and ethnicities, which may react to the emotional video differently due to cultural experiences (Lim, 2016). In future studies, we recommended that a broader participant pool be recruited.

In conclusion, we observed that, for emotional memory, people tend to remember details that are central to the incident itself more so than peripheral details. Although exercise did not directly influence emotional memory performance, we demonstrated that the type of exercise (open- vs. closed-skilled) may uniquely influence emotional memory intrusions as well the relationship between perceptions of confidence and emotional memory accuracy.

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