Acute Exercise on Prospective Memory Function: Open vs. Closed Skilled Exercise

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ACUTE EXERCISE ON PROSPECTIVE MEMORY FUNCTION: OPEN VS. CLOSED SKILLED EXERCISE

by

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ABSTRACT

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(Under the direction of Dr. Paul Loprinzi)

Background: Accumulating research suggests that acute exercise may enhance memory function. Limited research, however, has evaluated whether the movement patterns of acute exercise may have a differential effect on memory. Such an effect is plausible, as research demonstrates that open-skilled exercise (e.g., racquetball) may have a greater effect on memory-related neurotrophins (e.g., brain - derived neurotrophic factors) when compared to closed-skilled exercise (e.g. treadmill exercise). A key distinction between open- and closed-skilled exercise is that open-skilled exercises are those that require an individual to react in a dynamic way to a changing, unpredictable environment. The purpose of this study was to evaluate whether prospective memory is differentially influenced from open and closed-skilled acute exercise. **Methods:** A within-subject design was employed. Participants (M age = 20.6 yrs; 69% female) completed two visits, in a counterbalanced order. The two experimental conditions included open-skilled acute exercise (racquetball) and closed-skilled acute exercise (treadmill exercise), each lasting 30-min at 60% of heart rate reserve. During both experimental conditions, participants completed short and long-term assessments of prospective memory function. **Results:** There were no significant effects for prospective memory. **Conclusion:** Prospective memory is not affected by exercise. Modality of exercise, open nor closed, does not play a notable role in the processes of prospective memory or its success.

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Background

Prospective memory is crucial to our day to day life. This is the type of memory that is used when "remembering to perform a delayed intention at the appropriate time" (Anderson 2017), such as remembering to get milk on the way home from work after finishing the gallon during breakfast that morning. Not only is prospective memory very common in our daily lives, but forgetting to achieve our prospective goal is almost as common. In many research protocols, prospective memory tasks can be seen to be forgotten by the participant just as in every day life. "Remembering to remember" without any cue can be difficult.

However, retrospective memory tasks have a higher success rate due to the explicit request or reminder to recall by the experimenter. Retrospective memory calls for subjects to be told to recall whatever it may have been that they memorized or learned. Alternatively, subjects must remember to remember on their own when participating in a protocol that calls for prospective memory tasks, which can often lead to forgetting or failure of completing the task.

Three theories have been developed about how people remember their tasks to accomplish them at the appropriate time. The preparatory attentional and memory processes (PAM) theory and the multiprocess theory have been researched extensively to understand how prospective memory is achieved. The third, delay theory, has more recently been established and challenges the others.

PAM theory is accurately named for one's cognitive abilities and attention being used to prepare to remember. Part of one's attention is devoted to scanning the environment for whatever cue may instigate memory retrieval and then lead to fulfilling the intended action of the prospective memory task. Similar to Anderson's example of the PAM theory at work, a person's prospective memory is being used because they want to tell a friend "happy birthday." So part of this person's attention is being used to scan the room for their cue, or target event, to say "happy birthday" to their friend. Once the person is cued by the target event - seeing their friend - they say "happy birthday," and thus fulfill their intended action with successful prospective memory.

Because part of one's attention is dedicated to preparing to fulfill a future intention, it can be said that the task at hand can suffer according to the preparatory attentional and memory processes theory. Alternatively, there have been research conclusions that point to prospective memory failure as a result of engaging in an ongoing task. An example of this would be remembering to go to the grocery store on the way home from work. If one's preparatory processes are not engaged while driving home, then prospective memory will fail and stopping at the store will not happen, but the flip side of that coin is that the preparatory processes take cognitive resources away from focusing on driving.

This conclusion is supported by Smith's 2003 study, "The cost of remembering to remember in event-based prospective memory: investigating the capacity of demands of delayed intention performance." In the study, participants that were more successful completing the prospective memory task were slower while doing the ongoing task. These findings depict that when cognitive abilities are dedicated to preparing to complete a prospective memory task, it is more likely to be achieved. Prospective memory failure is seen more when the ongoing task demands more attention. Other facets of prospective memory have been researched through multiple studies. According to research completed by Kliegal et al. and Uttl, prospective memory is shown to decline with old age, and that prospective memory success is linked to one's current working memory capacity, according to Brewer et al.

Preparatory attention process is considered to be a type of top-down monitoring process, where cognitive abilities are being used to monitor the environment and prepare to complete the intended action when the target event is spotted. However, bottom-up spontaneous retrieval processes are also considered to be a way to remember prospectively. This mode of retrieval falls under the multiprocess theory.

Multiprocess theory points out the shortcomings of the PAM theory and gives an alternative answer to the question of memory processes. It is inefficient for a person to constantly monitor their surroundings in order to successfully complete prospective memory tasks at the detriment to an ongoing task. This theory hypothesizes that intentions that have been set aside for later can be retrieved spontaneously with a cue. Compared to the previous example, someone may remember that it is their friend's birthday once they see the friend - instead of having to avidly prepare to remember when cued by the target event.

Controlling for spontaneous retrieval in research protocols is difficult. A way to avoid preparatory processes during lab testing is by using different types of cues - focal over nonfocal. Focal cues lend toward spontaneous memory retrieval, as these cues occur within the person's line of vision. An example of this in real life would be seeing the dry cleaner on the way home from work and then remembering that there is laundry to be dropped off. Alternatively, nonfocal cues require monitoring in order for prospective memory to succeed. In the same example, the dry cleaner is not on the road that is being driven, so it would not be seen. Therefore, the dry cleaner, now a nonfocal cue, would not cause spontaneous remembrance, and monitoring would have to be done in order to successfully complete the intended action of dropping off the dry cleaning.

Ways that focal cues have been shown to eliminate preparatory processes from laboratory testing are by withholding the cue until an ample amount of time has been spent in performing the ongoing task. In the study of Scullin et al., the focal cue was not shown until the 501st trial of the ongoing task, a lexical decisions control condition, which was 12 minutes into the task. The data showed that there was no time spent monitoring the words, referred to as "slowing" in this study, by the 500th trial which indicates spontaneous retrieval was possible after this point. The success rate of the prospective memory task during the spontaneous retrieval trials was nearly as high as the trials in which the participants monitored the words, indicated by the slowing during the ongoing task while preparing for the target event.

Another way to test for spontaneous retrieval success in prospective memory tasks while eliminating monitoring is by using intention-interference, or a suspended intention protocol. In this study design, participants are given focal cues for the prospective memory task during an ongoing task. Then at some point during the test, the participants are told that the prospective memory task is suspended or completed, but they are to continue doing the ongoing task. It was found that the participants showed signs of slowing at the target event, which points to spontaneous retrieval because they were not monitoring the ongoing task for the target event. In the study by Anderson and Einstein in which the prospective memory task was completed, it was found that 20% of the time, the participants thought about the prospective memory intention when the target event was seen - even after being told that the task was completed. These instances of retrieval show that the prospective memory task is being remembered residually after the task is suspended or completed.

The neuroscience of these different memory processes has been studied. It is easy to hypothesize that preparatory and monitoring processes would use the prefrontal cortex of the brain, as it is the region of planning and reasoning. This is exactly what was found by Mcdaniel et al. in 2013 - the prefrontal cortex was seen by fMRI to have continuous activation during an ongoing task and simultaneous prospective memory task with nonfocal cues. When preparatory processes were being used during the tasks, the areas of the brain associated with planning and attention were utilized. However, these areas of the prefrontal cortex were not found to be activated during tasks that utilized focal cues to engage spontaneous memory.

Beck et al. found that alternative areas of the brain are used during tests of spontaneous prospective memory retrieval, but the activation of these brain areas was not sustained throughout the entirety of the task. In 2014, the group saw that when a participant was exposed to a retired target event during a completed intention testing protocol, the ventral parietal cortex, the precuneus, and the posterior cingulate cortex were activated transiently. The data of other studies have supported the evidence that the preparatory attentional processes use the anterior prefrontal cortex while the spontaneous retrieval processes utilize the hippocampal regions of the brain.

Spontaneous memory retrieval occurs without the activation of many cognitive sources. Two researched mechanisms that explain the cognitive processes of spontaneous retrieval are reflexive associative retrieval and discrepancy plus search. Reflexive associative retrieval hypothesis describes the target event and the intended action as having a strong association from the encoding or planning stages. Thus, when one of these is retrieved, the other follows rapidly behind. Alternatively, the discrepancy plus search hypothesis is meant to account for the discrepancy between one’s expectations of their quality processing and the reality of their quality of processing. This discrepancy leads to retrospective remembrance of the prospective memory task, and then to fulfillment of the intended action.

Though much research has been conducted to examine the cognitive processes of spontaneous retrieval and the multiprocess theory, less has been conducted to understand prospective memory tasks that have costs. Costs that have been studied the most are due to cognitive resources being devoted to preparatory attention and monitoring of the surrounding environment in order to remember the intended task. Under the delay theory, decision boundaries are considered to be set for the decisions pertaining to the ongoing tasks. Further, decisions about the ongoing task and the prospective memory task are made simultaneously. In this case, the prospective memory task is only successful if the decision about it is made before semantic memory about the ongoing task takes over the decision boundary. The decision boundary is said to relax in order to allow the decision about the prospective memory to be formed. This change in the decision boundary is shown to give time to successfully complete both the ongoing memory task and the prospective memory task. This is supported by another study completed by Loft and Remington (2013) that shows when participants are forced to respond after a delay, nonfocal prospective memory tasks are almost equally as successful as focal tasks.

While many studies have been conducted to test the cognitive functions that occur during prospective remembering, few have been conducted to investigate the effects of physical exercise on prospective remembering. From the pool of studies that have investigated those effects, none have examined the possible effects of different kinds of exercise on prospective memory.

Introduction

Emerging research demonstrates that acute exercise is associated with enhanced memory performance, typically assessed from word-list paradigms.[1-7] Mechanisms of this potential effect are multifold, including, for example, exercise-induced neuronal excitability, transcription factor expression, and growth factor production.[8] Regarding the latter, a key growth factor that may mediate the effects of acute exercise on memory is brain-derived growth factor production (BDNF). This key protein plays a critical role in synaptic plasticity, as well as long-term potentiation, a key cellular correlate of memory function.[8] Notably, acute exercise can upregulate BDNF levels.[9] We have previously discussed the synthesis and regulation of BDNF, as well as the potential role through which BDNF may mediate the effects of acute exercise on memory.[10] Although it is conceivable, from a mechanistic perspective, that BDNF may mediate this effect,[10] actual experimental studies in humans have provided mixed findings regarding whether BDNF causally mediates the effects of acute exercise on memory.[11]

As recently suggested[4] and demonstrated,[1] the type of acute exercise, notably whether it is an open vs. closed skilled exercise, may have a differential role on cognitive function. "Open-skill" exercises are those that require an individual to react in a dynamic way to a changing, unpredictable environment (e.g., badminton, racquetball).[13] Exercises such as walking and running would be considered "closed-skill" exercises as the environment is relatively stable, predictable, and self-paced.[13] Recent research demonstrates that, at the same given intensity (60% of heart rate reserve), open-skilled acute exercise (30-min bout) was more effective in enhancing BDNF and executive function when compared to closed-skill acute exercise.[14] The present study extends this emerging line of inquiry by examining whether open vs. closed-skilled acute exercise has a differential effect on memory function, which, to date, has yet to be examined in the literature. For a comprehensive assessment of memory, herein we assess prospective memory (completion of a task to occur in the future). Notably, limited research has evaluated the effects of acute exercise on prospective memory[1,2,6,15,16] and no study has compared the potential differential effects of open vs. closed skilled exercises on prospective memory.

Methods

Study Design:

A within-subject design was employed. Participants completed two visits, in a counterbalanced order. The two experimental arms included open-skilled acute exercise (racquetball) and closed-skilled acute exercise (treadmill exercise). During both experimental conditions, participants completed short and long-term assessments of memory function.

Participants:

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 25 yrs. Additionally, participants were excluded if they: self-reported as a daily smoker,[17,18] self-reported being pregnant,[19] exercised within 5 hours of testing,[20] consumed caffeine within 3 hours of testing,[21] had a concussion or head trauma within the past 30 days,[22] took marijuana or other illegal drugs within the past 30 days,[23] or were considered a daily alcohol user (> 30/month for women; >60/month for men).[24]

Exercise Assessment:

In a counterbalanced order, on separate visits, participants were instructed to engage in either a 30-min bout of treadmill exercise or a 30-min bout of racquetball. Both bouts of exercise lasted for 30-minutes and occurred at 60% of their heart rate reserve (HRR). Heart rate was monitored continuously by Polar heart rate monitor and recorded every 5-minutes. Based on the achieved heart rate, participants were instructed to either increase or decrease the speed/intensity of the bout of exercise. Following the 30-minute bout of exercise at 60% of HRR, participants walked slowly (self-selected paced) for 5-minutes. Following this 5-minute cool-down period, participants rested (sitting) quietly for 5-minutes before commencing the memory assessment.

Prospective Memory Assessment:

To assess prospective memory, the RPA ProMem test (Royal Price Alfred Prospective Memory Test) was used.[16,26,27] Specifically, we used Form 2 of the RPA-ProMem. In brief, participants completed two laboratory and two naturalistic prospective memory tasks, including both time-based and event-based tasks. The first laboratory prospective memory task (short-term time-based) involved having the participant inform the researcher what their last meal was at a particular point in time during the lab visit (i.e., approximately 20 minutes after they finished exercising). The researcher gave these instructions approximately 5 minutes after the bout of exercise, and it was up to the participant to remember to complete this task. For the second laboratory prospective memory task (short-term event-based), the researcher indicated that they would like to borrow something from the participant (e.g. phone or wallet), and when an alarm (the researcher's computer alarm) goes off in the lab, the participant is to remind the researcher to give back the personal object.

One of the naturalistic prospective memory tasks (long-term event-based) included the participant texting the researcher on the phone when they got home or when eating dinner (whichever came first). The second naturalistic prospective memory task (long-term time-based) included the participant returning a piece of paper to the researcher during the 24-hour follow-up assessment, in which they were to write down the weather of that day (e.g., rainy, sunny, windy) or the high/low temperature that day (depending on the experimental condition).

For each of the 4 components (short-term time-based; short-term event-based; long-term time-based; and long-term event-based), participants were given a score between 0 and 3 (based on whether the task was completed correctly and on-time). For example, for the long-term time-based task, they received 3 points if they returned the envelope on the correct day with the correct information; 2 points if they returned the envelope on the incorrect day with the correct information; 2 points for the correct day but incorrect information; 1 point for the incorrect day and incorrect information; and 0 points if the envelope was not returned. Thus, the total points possible for the prospective memory task is 12, with a higher score indicating a better prospective memory performance.

Ongoing Memory Task:

Short-term and long-term memory (retrospective memory) was assessed using the standardized Rey Auditory Verbal Learning Test (RAVLT).[25] Participants were asked to view and immediately recall a list of 15 words (List A) five times in a row (Trials 1-5). Each word, one at a time, was presented on a computer screen for 3-seconds. Participants then were asked to listen to and immediately recall a list of 15 new words (List B). Immediately following the recall of List B, participants were asked to recall the words from List A (Trial 6). Following Trial 6, there was a 20-minute delay, involving watching a video (self-selected either The Office of Big Bang Theory). Following this 20-min delay, participants recalled as many words as possible from List A. Following this, participants returned to the laboratory for a 24-hr follow-up assessment of List A.

Protocol for Visits:

As stated, participants completed two main protocols, including 1) racquetball (open-skilled) exercise before the memory task, and 2) treadmill (closed-skilled) exercise before the memory task. These two main protocols occurred in a counterbalanced order. Details for these are as follows.

Racquetball Protocol (Open-Skilled Exercise)

Session 1

- 30-minutes of racquetball exercise at 60% of HRR
- 5-minutes of self-selected walking pace for cool-down
- 5-minute seated rest
- Commence ongoing memory task (RAVLT)
    - Short-term time-based prospective memory (last meal eaten?)
- Seated rest for 20 minutes
- Delayed recall of RAVLT
    - Short-term event-based prospective memory (alarm sounds)
- Long-term (time and event based) prospective memory task occurred between sessions 1 and 2.

Session 2

- Long-term (24-hr) recall of episodic memory (RAVLT)
- Long-term (24-hr) recall of prospective memory (weather conditions)

Treadmill Protocol (Closed-Skilled Exercise)

Session 1

- 30-minutes of treadmill exercise at 60% of HRR
- 5-minutes of self-selected walking pace for cool-down
- 5-minute seated rest
- Commence memory task (RAVLT)
    - Short-term time-based prospective memory (last meal eaten?)
- Seated rest for 20 minutes
- Delayed recall of RAVLT
    - Short-term event-based prospective memory (alarm sounds)
- Long-term (time and event - based) prospective memory task occurred between sessions 1 and 2.

Session 2

- Long-term (24-hr) recall of episodic memory (RAVLT)
- Long-term (24-hr) recall of prospective memory (weather conditions)

Statistical Analysis

All statistical analyses were computed in JASP (v. .10). A 2 (condition) x 8 (trials) repeated measures ANOVA was computed for the retrospective memory task. When violations to sphericity were violated, the Huynh-Feldt correction was applied. Paired samples t-tests were computed for the prospective memory task (short- and long-term memory and time- and event-based). Effect size estimates (eta - squared for ANOVA or Cohen's for t-tests) were calculated. Statistical significance was set at an alpha of 0.05.

Results

Table 1 displays the characteristics of the sample. The sample included 58 participants (M age = 20.6 yrs; 69% female).

Table 1. Sample characteristics.

Variable	**Point Estimate**	**SD**
Age, mean years	20.67	1.38
Gender, % Female	69.5	
Race-Ethnicity, % White	84.7	
BMI, mean kg/m^2	25.33	5.02
MVPA, mean min/week	178.81	171.1

BMI - Body mass index
MVPA - Moderate to vigorous physical activity (assessed from the Physical Activity Vital Signs survey)

Figure 1 displays the physiological (heart rate) response to the exercise stimuli. There was a significant main effect for time, F(5.07, 289.3) = 1261.6, p < .001, η 2 = .86, but no main effect for condition, F(1, 57) = 1.46, p = .23, η 2 = .0001, or time by condition interaction, F(4.63, 263.7) = 1.27, p = .28, η 2 = .001.

Figure 1. Heart rate responses across the 8 time periods (rest, 5-min, 10-min, etc.) for the two experimental conditions. Error bars (minimally visible) represent 95% CI.

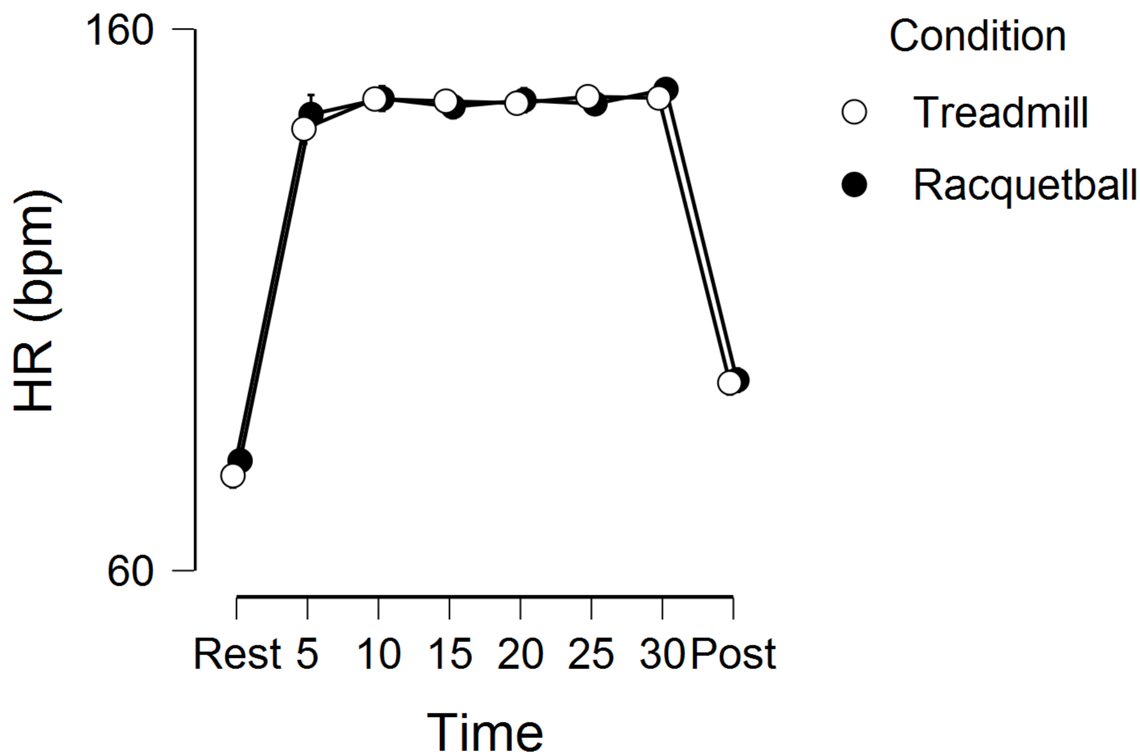

Table 2 displays prospective memory results. For all prospective memory outcomes, there were no statistically significant differences between the experimental conditions.

Table 2. Prospective memory results across the experimental conditions.

	Treadmill	**Racquetball**	**Test-Statistic**
Time-Based			
Short-Term	2.33 (1.1)	2.20 (1.2)	t(57) = .77, p = .44, d = .10
Long-Term	2.77 (1.5)	2.86 (1.1)	t(55) = .24, p = .80, d = .03
Event-Based			
Short-Term	2.41 (1.1)	2.41 (1.1)	t(57) = .001, p = .99, d = .001
Long-Term	2.15 (1.2)	1.85 (1.3)	t(56) = 1.58, p = .11, d = .21
Overall	9.67 (3.0)	9.32 (3.0)	t(55) = 1.17, p = .24, d = .16

Discussion

Recently, we have demonstrated that cognitive function may be influenced by the mode of exercise.[12] In a systematic review,[12] we demonstrated that open-skilled exercise was superior in enhancing cognitive function when compared to closed-skill exercise. This was observed for observational and intervention studies, as well as for several cognitive outcomes, including memory. Notably, however, few experimental acute exercise studies were conducted.[14] This served as the motivation for the present experiment, which was to evaluate whether acute open or closed-skill exercise has a differential effect on memory function.

The findings are as follows, there was no prospective memory difference between the two types of exercise. This observation aligns with our past five experiments on prospective memory (i.e., no effect of acute exercise on prospective memory).[1,2,6,15,16] We initially hypothesized that open-skilled exercise (racquetball) would be more effective in enhancing memory than closed-skilled exercise (treadmill). We anticipated that this would occur from greater cognitive demands as well as from potentially higher levels of neurotrophins that are likely to occur with open-skilled exercise.[12,14] However, our prospective memory results showed no differences.

The present experiment did not collect any mechanistic data, whether it be cognitive, affective or neurophysiological, that may help to explain our findings. It seemed, however, that most of the participants were new to racquetball. If this is true, then perhaps the racquetball session induced greater cognitive load/demand when compared to treadmill exercise, which involves an unchanging environment requiring minimal cognitive engagement. Speculatively, perhaps exercise that induces greater cognitive demands may be more suitable for executive cognitions, which may require the utilization of multiple cognitive processes, such as inhibition, planning and reasoning. In contrast, perhaps exercise that induces greater cognitive demands has a less favorable effect for cognitions which may require fewer cognitive processes. As such, it would be worthwhile for future work to evaluate whether open and closed-skilled acute exercise has a differential effect on distinct cognitive outcomes. Further, perhaps the affective response was different between the two conditions, which may have resulted in our findings. Although we do not know for certain, it seemed racquetball was new for most of the participants. Perhaps engaging in a new movement pattern, with poorer physical competency, altered their mood state, and in turn, influenced the degree to which the memory task was encoded. Of course, this is pure speculation, but the possibility for affect to mediate the effects of acute exercise on memory is worth further critical reflection.

A limitation of this experiment is not including a non-exercise control group. Similar to other related works on this topic,[14] we intentionally chose not to include a control group because the aim of this experiment was not to evaluate whether acute exercise influences memory, as this has already been evaluated in numerous studies. The central focus of this experiment was comparing open to closed-skilled exercise. However, we do acknowledge the benefit of including a non-exercise control group. Strengths of this study include the experimental design, study novelty, and relatively large sample for this type of experiment (see Figure 9 in Pontifex et al. 32).

In conclusion, the present experiment demonstrates that exercise modality did not have a differential effect on prospective memory. As shown in the previous studies,[1,2,6,15,16] closed-skill exercise does not affect prospective memory for better or worse. Open-skilled exercise also made no differences on the success of prospective memory.

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