The effects of different exercise modalities on visuospatial working memory in healthy young adults

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ABSTRACT

This study was to differentiate the acute effects of random motor skill practice and acute cardiovascular exercise on the task performance in visuospatial working memory (VSWM). 24 healthy adults with no golf experience were randomized into random motor skill practice (i.e., golf putting task) and acute cardiovascular exercise (i.e., 64% and 76 % of predicted maxi-mum heart rate) groups. Pre-test and post-test were administered for two VSWM tasks (i.e., memory matrix and rotation matrix). The performance of VSWM was improved immediately after the acute intervention. However, the improvement in retention effect was not maintained. In addition, no group differences were noted between random motor skill practice and acute cardiovascular exercise during post-test. The findings suggested the temporal effects of acute intervention. There is need to add a true control group for further research with larger sample size to examine the role of exercise modalities between acute intervention and executive function.

Keywords: Sport medicine, Sports health, Acute exercise, Executive function, Working memory, Motor learning.

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INTRODUCTION

Executive function has been considered a high-order system that controls and manages other cognitive processes to direct our behaviours to achieve a goal (Hillman et al., 2008). Inhibition, working memory, and cognitive flexibility are proposed as the primary aspects of executive function (Diamond, 2013). To date, much of the work has focused on executive function and its change in response to acute exercise. Evidence for enhanced executive function with acute exercise is rapidly growing (Chen et al., 2020; Chen and Ringenbach, 2016; Labban and Etnier, 2011; Li et al., 2014; Park and Etnier, 2019). In a meta-analytic finding of Chang et al. (2012), they observed a small yet positive effect size (overall effect size = 0.097) of acute physical activity across different aspects of executive function. Several mechanics models have been used to explain the changes in cognitive performance, including increased arousal levels (Lambourne and Thomporowski, 2010), increased neural activity (Basso et al., 2015; Li et al., 2014), and higher expressions of catecholamine (McMorris et al., 2008) or neurotrophic factors (Dinoff et al, 2017). Basso et al. (2015) noted that this increased neural effect seemed to persist for up to two hours in the prefrontal cortical region, a brain area known to be responsible for executive function. Despite this well-established relationship between acute exercise and executive function, past literature has been predominantly interested in changes in inhibition following the cessation of an acute bout of physical activity (Pontifex et al., 2019). Pontifex et al. (2019) reported that 41 percent of published studies to date focus on the effect of inhibition, but few studies focused on other components of executive function. Further, working memory is a cognitive capability to control attention to information and hold and manipulate it afterward, which plays an important role in daily tasks, such as grocery shopping and academic learning (Baddeley, 2007; Rzhanova and Alekseeva, 2020). Since Roig et al. (2012) reviewed the evidence and indicated cardiovascular exercise could improve memory with small to moderate effect sizes (effect size range from 0.12-0.32). Surprisingly, the concept of working memory has received less attention in the field of sport and exercise psychology. Therefore, the present study would extend the relevant research topic by examining the influence of an acute exercise on working memory performance.

Further, contextual interference (CI), which is experienced when practicing multiple skills, or variations of a skill, within a single practice session, has been recognized as an important variable for maximizing motor skill learning (Kaipa and Mariam Kaipa, 2018; Kim et al., 2018). Cross et al., (2007) indicated that the increasing level of CI (e.g., random sequencing practice), compared to low CI condition (e.g., blocked practice) throughout a training session could result in better motor performance on tests of retention since random practice could enhance more neural activity that was associated with motor preparation, sequencing, and response selection. Evidence to date also suggests that working memory capacity is related to motor skill learning and performance (Bo & Seidler, 2009, Unsworth & Engle, 2005). Thus, the increased involvement of cognitive processing could be expected during random practice (Li & Wright, 2000). Moreover, Motor skill learning is often implicit learning. Lee and Magill (1983) proposed the forgetting-reconstructive hypothesis to account for the CI effect on the process of working memory on every practice trial. Random motor skill practice might make the learners must continuously retrieve a motor pattern or reconstruct a new one when facing the changing visual and kinaesthetic information derived from the performance of the same action with different parameters (Rendell et al., 2009). Past literature concerning the CI effect and implicit motor learning has largely focused on gross motor skills in sports; however, few specifically investigate fine motor skills. Therefore, the golf putting task was adopted in the present study since it could be considered as it is a complex, fine motor sequence skill.

A recent study reported an association between golf putting performance and working memory capacity (Persson, 2021). Novice golfers initially need working memory for declarative knowledge and initial proceduralization. During the early stage of practice, they need to understand the rules and movement control of the degrees of freedom around the arm segment and simultaneously stabilize other body parts for putting performance. After random motor skill practice, novice golfers might create distinctive and strong memories compared to blocked practice (Fazeli et al., 2017). With the enhancement of working memory efficiency, novice golfers gradually developed procedural knowledge that led to motor improvement and skill acquisition. Therefore, it could stand to be the reason why athletes have superior working memory (Vaughan and Laborde, 2021). In other words, cognitive gains (i.e., increased working memory capacity) might be moderated by cognitive engagement during random skill practice. Therefore, in addition to the acute effect of exercise, it would be needed to investigate how cognitive abilities such as working memory could be impacted through random motor skill practice.

Taken together, the present study attempted to verify the role of random motor skill practice versus acute aerobic exercise in improving working memory. This study was restricted to novice golfers since they relied extensively on their cognitive abilities to acquire and execute skills (Baumeister et al., 2008). Given that working memory is related to long-term memory (Woltz and Was, 2006), 24-h retention test would be also conducted in the present study to observe the sustained improvements driven by acute interventions. The hypotheses of the present study were as follows: 1) working memory performance would be significantly improved immediately after acute interventions and maintained for 24 hours and, 2) group differences between random motor skill practice and acute aerobic exercise would be observed.

MATERIAL AND METHODS

Participants

Twenty-four healthy young adults participated in the present study (10 males and 14 females, 21.02 ± 0.70 years old). All participants were recruited from a southeastern university in the United States. Inclusion criteria for participants were listed as follows: (1) aged between 18-24 years old; (2) right-handed; (3) no golf experience; and (4) no physical, cognitive, emotional, and/or neurological disorder that would exacerbate physical performance or executive function. Before data collection, interested participants signed an informed consent form to be part of the study. Participants were randomized into two groups: random motor skill practice (n = 12, aged 21.08 ± 0.68 years) and acute aerobic exercise (n = 12, aged 20.97 ± 0.74 years) groups. Each group had similar age, body mass index (BMI), and numbers of females, as these variables might be associated with exercise and executive function performance (Baxi et al., 2018; Dinoff et al., 2017; Kaufman, 2007; Ludyga et al., 2016; Yang et al., 2018). The Human Subject Institutional Review Board in the university approved the study protocol.

Table1. Descriptive statistics of participants.

	Group		***p*-value**
	Random practice (n = 12)	Acute cardiovascular exercise (n = 12)	
Age (years)	21.08 ± 0.68	20.97 ± 0.74	.712
# of Females	7	7	1.00
BMI	27.20 ± 10.40	25.40 ± 2.87	.573

Note. BMI = Body Mass Index.

Procedure

Upon arrival, the demographic measures, including height, weight, age, golf experience, and handedness from the participants would be collected. Participants would visit the laboratory one at a time. Data collection for each participant was completed in two days, including pre-test, 30-min intervention, post-test, and 24-h retention test.

The pre-test consisted of two working memory tasks. Participants were asked to sit in a chair in front of a laptop to perform the working memory tasks that consisted of memory matrix and rotation matrix. The order of the two tasks was counterbalanced. A 30-min intervention was implemented after the pre-test time period. Participants were randomized into either random practice or acute aerobic exercise group. Then, there was a post-test immediately after the intervention. Lastly, participants were requested to visit the laboratory again 24 hours after interventions. The same working memory tasks were administered again to assess the intervention-induced effect.

Intervention

Acute aerobic exercise group

This group participated in a 30-min treadmill exercise, maintaining their exercise heart rates between 64% and 76 % of their predicted maximum heart rate (HR_{max}). The 64-76 % of HR_{max} could be considered as moderate intensity since it can be converted to about 40 to 60 % of VO_2max (Statton et al., 2015; Swain et al., 1994), which the American College of Sports Medicine (2018) suggested as moderate intensity. The present study employed the equation of age-predicted HR_{max} = 208 - (0.7 x age) to compute the target HR range for each participant (Tanaka et al., 2001). An HR monitor was worn (Polar H10, Finland) to monitor the intensity of exercise through a Bluetooth connection with a mobile device. The intervention session began with a warm-up phase which the treadmill speed was started at 1.0 mph and gradually increased until the participants' HR reached the target heart rate zone. The duration of the warm-up phase was up to 5 minutes. Participants started the exercise session once their exercise HRs reached the target range. The treadmill speed was manipulated as needed to maintain the participants' heart rates within the target range. The incline was set at 0% during the entire intervention period. After the 30-min exercise, participants were given another 5-min walking time at 1.0 mph for cool-down phase.

Random motor skill practice group

The random practice group practiced 3 blocks of 3 feet, 6 feet, and 9 feet golf putts. Each block had 10 trials of putting, so the total number of practice trials was 90. The distance of the putting was randomized, so the participants could not anticipate the upcoming putting distance. In addition, the attentional focus during practice was controlled and directed at an anticipated trajectory line, which was external focus of attention. An external focus of attention has been found to facilitate motor learning and outcome performance, specifically beneficial for novice golfers (Chen et al., 2021). The external proximal focus may promote cognitive engagement during practice since novice golfers were directed to compare the relationship between action planning and the surrounding environment. The total time in random motor skill practice was about 30 minutes.

Measurement

Working memory tasks

Two working memory tasks, memory matrix and rotation matrix, were administered via a web-based cognitive training program (i.e., lumosity.com). Memory matrix and rotation matrix tests have been widely used to assess VSWM function (Olfers and Band, 2018; Sternberg et al., 2103; Toril et al., 2016).

As noted in Figure 1, in the memory matrix task, the goal was to memorize a group of highlighted tiles on a grid. The highlighted tiles only revealed themselves momentarily and then flipped back over. Then, participants were requested to indicate the location of highlighted titles on a grid. Memory Matrix started with three tiles. If participants made no mistakes in one trial, then in the next trial, participants would get one more tile to remember. If participants missed one tile, then participants still got the same number of tiles in the next trial. If two or more tiles were missed, then participants would get one fewer tile in the following trial. The total of twelve trials of the memory matrix were administered. Participants could earn 250 points for every tile remembered correctly. Participants would also earn a bonus of 100 additional points per tile if they correctly selected all of the tiles on a grid.

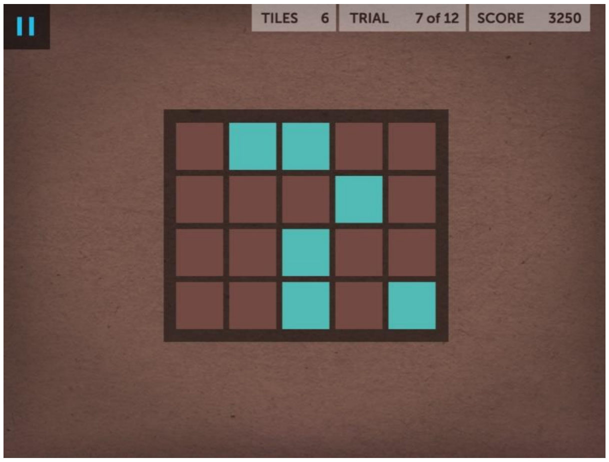


Figure 1. Example of memory matrix task.

As for the rotation matrix task, similarly, the goal was to remember the highlighted tiles. Participants needed to remember the location of the highlighted tiles before they were flipped back over after a few moments. Further, after the tiles flipped back over the entire game board would be rotated. Thus, participants had to not only remember where highlighted tiles were but also had to locate them in relation to the new board positioning. Twelve trials of the rotation matrix task were administered. The rule and scoring of the rotation matrix task were the same as the memory matrix task. The total score of both tasks was reported by the program to represent participants' VSWM performance.

Statistical analysis

Statistical analysis was carried out using the SPSS 27.0 program. First, the independent t-test and chi-square (χ^2) test were computed to confirm demographic features and pre-test performance between both groups. Data from the performance in VSWM was analysed by a 3 (time periods) x 2 (groups) ANOVA. If the main effect analysis violated the Mauchly test of sphericity, as indicated by a p-value of <.05, the corrected Greenhouse-Geisser F values for the main effect and the interactions between time periods and groups were reported.

The significant alpha level was set at .05 throughout the statistical analysis in the present study. Partial eta squared (η_p^2) was used in ANOVA to evaluate an effect size as follows: .01 to < .06 as small; .06 to < .14 as medium; and > .14 as a large effect size.

RESULTS

Demographic characteristics

An independent t-test was conducted to compare age and BMI factors between the groups. The Table 1 indicated Age: t (22) = -.373, p = .712, and BMI: t (22) = -.578, p = .573, were not significantly different. The chi-squared analysis indicated sex factor (i.e., the number of females) was not significantly different across the groups: χ^2 (1, N = 24) = .000, *p* = 1.00.

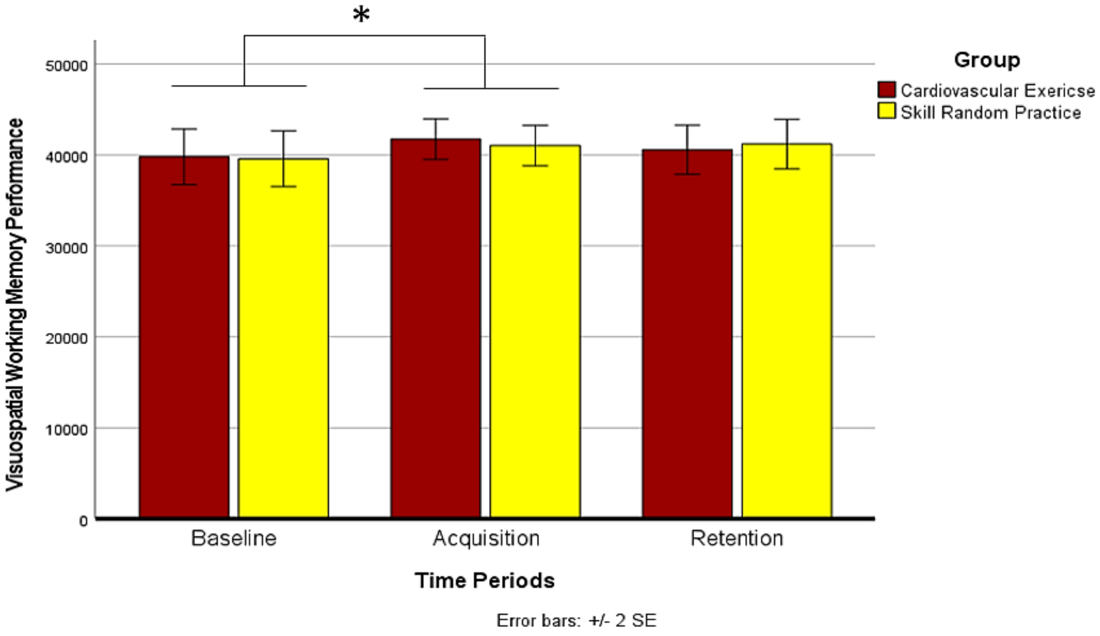
Exercise intensity

An average exercise HR in the acute cardiovascular group was 144.6 bpm, which was about 74.9 % of age predicted HR_{max}. Thus, participants performed treadmill running exercise with moderate intensity in the present study.

Visuospatial working memory performance

A two-way repeated measure ANOVA was conducted to compare the effect of skill random practice versus cardiovascular exercise training on the performance in VSWM tests. As noted in Figure 2, there was a significant effect of different time periods, *F* (2, 44) = 3.254, *p* = .048, η^2 = .129. Pairwise comparisons with an LSD correction were used to make post hoc comparisons between time periods. These indicated that there was a significant difference in acquisition period (*M* = 41393.75) and baseline period (*M* = 39687.50), *p* = .018.

Moreover, there was no interaction effect between different time periods and groups, *F* (2, 44) = .474, *p* = .626, η^2 = .021. There was also no significant main effect of groups, *F* (1, 22) = .004, *p* = .953, η^2 = .000.



Note. * *p* < .5.

Figure 2. Acute effect on visuospatial working memory performance.

DISCUSSION

The purpose of the present study was to investigate the effect of random motor skill practice versus acute aerobic exercise on VSWM. This is an important direction for future research because of our limited understanding of the time-dependent effect of random practice and acute aerobic exercise on cognitive processing. Consistent with the hypothesis and previous studies regarding acute exercise effect on working memory (Basso et al. 2015; Chang et al. 2012), the scores in VSWM tasks elicited a significant improvement after both acute interventions. Chang et al. (2012) had ever indicated the highest effect size in the executive function was within 1-15 minutes after exercise. Basso et al. (2015) suggested the exercise-induced neural activity in prefrontal cortex that was responsible for working memory performance, which could last up to 2 hours. These above-mentioned studies may explain why cognitive improvement was seen immediately after acute aerobic exercise.

However, inconsistent with our findings in a moderate-intensity exercise, the advantageous effect was not noted in some acute exercise studies (Ebisuzaki, 2020; Li et al. 2014). Li et al. (2014) found young adults did not improve behavioural performance in a working memory task, the N-back task a 20-min of moderate exercise intensity of 60% to 70% of age-predicted (220-age) HRmax, compared to control rest condition. Ebisuzaki et al. (2020) examined the effects of a bout of moderate exercise intensity of 60% to 70% of age-predicted (220-age) HRmax, versus rest condition on the performance in working memory test, List Sorting Working Memory Task, and indicated no effects of time, condition, nor an interactive effect on working memory. It was possible that the exercise intensity performed in the current study was closed to vigorous intensity. Jeon and Ha (2017) noted the change in the working memory significantly increased for the vigorous intensity exercise group compared to the low intensity aerobic group and moderate intensity exercise group.

Moreover, our findings showed that cognitive improvement was not sustained after 24 hours. The advantageous effect in 24-hour retention seemed to be noted in the high-intensity acute exercise studies (Frith et al., 2017; Winter et al. 2007). Winter et al. (2007) found that the participants could perform 20% faster in a novel vocabulary learning test after a short bout of intense exercise, compared to under moderate exercise and rest conditions. Frith et al. (2017) indicated that young adults improved their performance in memory assessment in the 24-hour retention test after a 15-min bout of progressive maximal exertion treadmill exercise. As such, future work is still needed to differentiate the mediation effect of intensity of exercise on the longevity of the memory system (working memory vs. long).

Interestingly, no interaction effect was evident in the current study. That meant there was no group differences between the effect of random motor skill practice and acute aerobic exercise on working memory. First, this type of physical practice might have increased the arousal level among participants, thereby promoting an immediate gain in working memory tests Secondly, although the intensity of exercise in golf putting practice might generated a smaller change in energy metabolism than cardiovascular exercise, participants spent much time practicing motor coordination, visual search, eye-hand coordination, balance, and spatial orientation while performing random practice in golf putting. These motor abilities demand higher level cognitive processes that were likely to be related to attention and managing visual and spatial information, thereby promoting an immediate gain in working memory tests. A review study conducted by Voelcker-Rehage and Neiman (2013) showed that exercise-metabolic exercise (i.e., cardiovascular and resistance) and coordinative (i.e., bimanual coordination) exercise affected the structural and functional brain changes differently. Random motor skill practice may affect cognitive processes differently compared to aerobic exercise. However, we did not assess other physiological data (e.g., HR, feelings) in golf putting practice that would allow investigating the underlying mechanisms in the current study. For this, the values and details of the training session should be recorded in the future.

Limitations

It is important to consider the possible limitations accompanied that need to be addressed in the future studies. To reveal significant differences in VSWM performance with Cohen's effect size f (f = .25), two groups using G*Power, were assigned. The groups underwent 2 tests, alpha of .05, and power of 80%, with the total of one hundred twenty-eight participants. Thus, our preliminary results need to be replicated with a larger sample and with randomized sampling to ensure the effectiveness of intervention. Although these results seemed to be promising, adding different duration of retention test, such as 10-min, 30-min, an hour after the intervention, would enable subsequent studies to investigate this area of interest more thoroughly. Further, the lack of a true control group. Hence, it is impossible to tell whether the performance changes following intervention was an intervention-induced effect or just a learning effect. Although an external focus instruction was provided during putting practice to promote cognitive engagement, participants' efforts was not truly verified by HR. In addition, the putting performance outcomes could be included in the future to investigate whether the improvement in golf putting may be associated with VSWM gains. Further, the age-estimated method may not be the appropriate method to determine the intensity of exercise that might moderate cognitive performance. Therefore, future work should expand these findings by utilizing maximal oxygen uptake (VO_2max) for a better understanding of the potential relationship between cognitive performance and exercise intensity in a more rigorous manner. Additionally, this study should consider other exercise modalities to comprehensively verify the association between acute intervention and executive function.

CONCLUSIONS

Taken together, the present study is one of the pioneering studies that has attempted to pair different exercise modalities and executive function. The evidence showed that the temporal effects on VSWM. Random motor skill practice and moderate exercise intensity seemed to result in an immediate increase in VSWM. There are numerous implications of these findings that could be applied to everyday settings, including the importance of daily physical activity or fine motor skill practice for facilitating better learning and memory for young students as well older adults.

AUTHOR CONTRIBUTIONS

Both Dr. Chen and Dr. Ryuh contributed to the design and implementation of the research, the analysis of the results, and the writing of the manuscript. Additionally, all authors participated in discussions about the results and contributed to the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

PUBLICATION ETHICS

Informed consent was obtained from all participants included in the study. All procedures in studies involving human participants were performed in accordance with the ethical standards of the institution's Human Research Ethics Committee.

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