Effects of an Acute Bout of Exercise on Memory in 6th Grade Children

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Abstract:

Research supports the positive effects of exercise on cognitive performance by children. However, a limited number of studies have explored the effects specifically on memory. The purpose of this study was to compare the effects of an acute bout of exercise on learning, short-term memory, and long-term memory in a sample of children. Children were randomly assigned to an exercise condition or to a no-treatment control condition and then performed repeated trials on an auditory verbal learning task. In the exercise condition, participants performed the PACER task, an aerobic fitness assessment, in their physical education class before performing the memory task. In the control condition, participants performed the memory task at the beginning of their physical education class. Results showed that participants in the exercise condition demonstrated significantly better learning of the word lists and significantly better recall of the words after a brief delay. There were not significant differences in recognition of the words after an approximately 24-hr delay. These results provide evidence in a school setting that an acute bout of exercise provides benefits for verbal learning and long-term memory. Future research should be designed to identify the extent to which these findings translate to academic measures.

Keywords: Exercise | Memory | Children | PACER task

Article:

The body of literature in which the effects of acute exercise on cognition has been tested is substantial. Authors of both narrative (3,13,23,24) and meta-analytic reviews (4,6,8,21) of this literature have consistently concluded that a single bout of exercise generally exerts a small-to-moderate beneficial effect on subsequent cognitive performance. Any effects of acute exercise on cognitive performance are generally thought to be transient, with the potential for observation arising sometime during the exercise bout, and only lasting a brief time following exercise cessation (4). Research exploring the effects of acute exercise on cognitive performance by children is relatively limited, but results suggest that the effects are beneficial. Tomporowski

(23) narratively reviewed the literature on acute exercise and cognitive performance in children and concluded that a single session of exercise has a transient positive effect on cognitive performance.

Recently, researchers have become interested in specifically exploring the effects of acute exercise on memory. Memory is unique among most cognitive outcomes in that changes brought about through acute exercise may be assessed and observed at a point long after the exercise session has ended (8). Several studies have been conducted to explore the potential benefits of acute exercise for memory performance with results from a recent meta-analytic review suggesting that the average effect size for studies assessing memory is not significantly different from zero (4). Memory is not a singular construct though, and the distinctiveness between different types of memory stores suggests that it may be misleading to average effects from all studies that include memory outcomes. The three types of memory most commonly studied in the exercise literature are short-term memory (STM), working memory (WM), and long-term memory (LTM). STM and WM are related in that both require continual active attention to the target information (typically in the form of mental rehearsal) until such time as the demand for that information has been met. WM is unique from STM because it also involves an element of information updating and manipulation to meet higher order demands such as problem solving or decision making (2). The relatively rote cognitive processes involved with STM are such that STM may fit more appropriately under an information processing categorization; whereas, the higher-order processes involved in WM have led to it being categorized under the umbrella of executive function. Therefore, although measures of WM may also assess elements of STM to some degree, measures of STM do not necessarily also assess elements of WM. In contrast to the transient nature of STM and WM, LTM involves the stabilization of information into LTM stores that are available for retrieval at such time when demand arises. The stabilization, consolidation, and retrieval processes point to more permanent cognitive changes that make LTM unique from STM and WM. The importance of the distinction between STM/WM and LTM was recently underscored by the results of a meta-analysis by Roig et al. (19) in which the authors focused exclusively on memory and reported heterogeneity of exercise effects by memory type. When studies testing for effects of STM/WM or LTM were analyzed together, the authors reported a small but statistically significant overall effect of acute exercise (standardized mean difference, SMD = 0.22). However, when studies testing STM/WM and LTM were examined separately, the authors reported that acute exercise had a moderate-to-large effect on LTM (SMD = 0.52), but a statistically nonsignificant effect on STM/WM (SMD = 0.11). Therefore, the evidence suggests that acute exercise may exert a generally positive effect on LTM processes, but there is little evidence to support a consistent effect of acute exercise on STM or WM.

To our knowledge, only two studies have tested the effects of acute exercise on memory in children (5,15). Craft et al. used the digit span and coding B subtests from the Wechsler Intelligence Scale for children—Revised and the visual sequential memory subtest from the Illinois Test of Psycholinguistic Abilities to measure STM and WM performance by children (7–10 yrs old) immediately following vigorous intensity exercise performed for 1, 5, or 10 min. Consistent with the nonsignificant effect on STM/WM reported by Roig et al. (19), Craft reported that there was no difference in memory performance on any of the tests as a function of exercise. Recently, Pesce, Crova, Cereatti, Casella, and Bellucci (15) tested the effects of two different modes of exercise on STM and LTM. Children (11–12 years) performed a word-list memory task after completing a circuit training session, team games for 60 min, or after doing no physical activity. Word-list retention was assessed following delays of 100 s ("immediate free recall") and 12 min ("delayed free recall"). Because participants had the opportunity to mentally rehearse word-list items during the 100-s delay, cognitive performance was likely a product of both LTM processes and STM strategies. Classroom discussion was used as a distractor that did not allow for mental rehearsal during the time between the "immediate free recall" assessment and the "delayed free recall" assessment, and so the "delayed free recall" assessment relied more heavily on LTM processes. Although no significant differences in total recall at either time point were observed, significant effects were observed when analyses were limited to primacy (first 5 words) and recency (last 5 words) items from the word-list. In particular, for "immediate free recall", the team game resulted in significantly better recall of both primacy and recency items than did the no-exercise condition. For "delayed free recall", both the team game and the circuit training resulted in better performance, but only for the recency items, as compared with the no-exercise condition. These findings of differential effects for total recall as compared with the primacy and recency portions of the word list were interpreted by Pesce et al. as indicating that exercise specifically affects memory storage processes important for these particular portions of the list.

In sum, the results of studies testing the effects of acute exercise on cognitive performance by children support a transient beneficial effect, however the research testing the effects on memory, and particularly STM and LTM, are limited. As previously described, there is evidence from one recent empirical study (15) that an acute bout of exercise benefits STM and LTM for children. However, this study is limited by the relatively short delay following the exercise after which memory was assessed. Hence, we do not have a clear understanding of how durable the effects of an acute exercise session are on LTM. Further, there is little guidance from the extant literature with children with regards to the intensity and duration of the exercise that might be necessary to observe longer-lasting LTM effects.

One recently published study with younger adults may provide such guidance. Winter et al. (26) reported effects of acute exercise on LTM in a memory paradigm in which participants were given repeated exposure to the target stimuli. Briefly, Winter and colleagues examined the effects of two different intensities and durations of running on short-term and long-term verbal memory in healthy adults (age = 19–27 years). Exploratory analyses indicated that retention at 1-week, as measured by cued recall, was significantly better following a 6-min intense running condition than a 40-min moderate running condition but not different from a sedentary condition. No differences in free recall were observed between conditions. In general, the authors concluded that a single session of short-duration high intensity exercise can facilitate both learning and retention of novel material.

Although Winter et al.'s finding was exploratory, it is suggestive of the possibility that a high intensity exercise session can beneficially affect memory performance after a longer delay than has been previously observed. This finding is consistent with Lambourne and Tomporowski's (8) expectation that effects on LTM could be observed at longer postexercise latencies than have been previously used (e.g., 24 hr versus ≤ 1 hr). Such an effect could have important implications for educational and study paradigms that require memorization through repeated practice.

The purpose of this study was to further our understanding of the effects of acute exercise on the performance of a memory task by children. Participants completed a memory task either after performing an exercise session or after a no-treatment control condition. The memory task consisted of repeated trials of a word list, rather than a single presentation as used by Pesce et al.

(15), to provide insight as to which memory processes may be sensitive to the effects of acute exercise and as to the time course of those effects. Analyses were performed to assess performance on learning, STM, and LTM. It was hypothesized that participants in the exercise condition would perform better than those in the control condition on all measures. Analyses also included tests for effects on learning and memory as a function of the serial position of word-list items. Testing for effects by serial position allowed for a further exploration of how exercise might affect learning and retention of particular portions of a word list and allowed for comparisons with the study by Pesce et al.

Methods

Participants

Participants were 43 male (n = 15) and female (n = 28) sixth grade students (11–12 yrs of age) recruited from an independent school in North Carolina. Informed assent from the children and informed consent from the children's parent or guardian was obtained before collecting any data, as per the regulations of the Institutional Review Board of the University of North Carolina at Greensboro. Students were randomly assigned to either a no-treatment control condition (n = 24) or an exercise condition (n = 19). Unequal sample sizes were the result of students not being present in class on their originally assigned testing day. When possible, students who were not present on the original testing day were assessed at a subsequent session. In their physical education curriculum, students had previously performed the mile run test in which they were asked to cover the distance of a mile as quickly as they could by walking or running. Mile run time data are presented for descriptive purposes and were examined to assess whether the exercise and control groups were equivalent in terms of fitness.

Memory Test

The AB version of the Rey Auditory Verbal Learning Test (RAVLT) was used to assess verbal learning and memory (20). For all trials, word lists were read according to the manual directions (20) and were prerecorded so that all participants heard the lists of words read in exactly the same fashion. Before playing the word lists, the volume was adjusted until all participants reported that they could clearly hear the recording. The RAVLT includes a primary word list that consists of 15 words. The participants were told that this list was called "List A". After hearing the word list, participants were given a sheet of paper with their identification number on it and were asked to write down as many of the words as they could remember. It was made clear that the spelling and order of their responses did not matter. The sheet of paper containing the words was removed when the participants informed the researcher that they had written down all of the words they could remember, or after a maximum of 2 minutes. This process of list exposure and immediate recall was repeated five times (Trials 1–5). While the first of these trials was considered purely a measure of immediate recall (STM), gains in recall accrued over the subsequent 4 trials were interpreted as an indication of the rate of verbal learning. After the fifth trial, the participants were told that they would now hear a different list, called "List B". Once List B had been played to the participants, they were asked to recall as many of the words from List B as possible (Trial 6) using the same method as for Trials 1–5. Trial 6 served the role of an interference trial, which prevented participants from continuing STM strategies (i.e., rehearsal) to recall items from List A. Following Trial 6, and without hearing List A again, participants were asked to recall as many words from List A as they could remember (Trial 7) by writing the words on a sheet of paper. Performance on Trial 7 is later referred to as brief-delay recall and was considered a measure of LTM.

LTM was also assessed after a 24-hr delay using a recognition task (11) which consisted of identifying words from List A and List B out of a list of 50 words (all 15 words from List A, all 15 words from List B, and 20 new words). Each participant was given a sheet of paper with all 50 words. They were instructed to place an "A" next to the words they believed to be from List A, a "B" next to the words they believed to be from List B, and to not write anything next to the words they believed to be new words (i.e., not on either List A or List B). This measure was considered to reflect long-term recognition memory.

PACER

The PACER (Progressive Aerobic Cardiovascular Endurance Test) is a valid and reliable measure of aerobic capacity that is a part of the FITNESSGRAM (9,10). This test is commonly used in school settings to provide an estimate of aerobic capacity (16). The test is progressive in that the intensity changes from easy to hard across the course of the test. Thus, participants perform much of the test at submaximal levels, but perform the final stage at maximal effort (12). The protocol for conducting the PACER test was followed as described in the FitnessGram Test Administration Manual (14). Specifically, participants were instructed to cover the distance of 20 m at an increasingly quicker pace determined by the PACER protocol and delineated by an audible tone that informed participants when to start running and a second audible tone that indicated when they should have completed the run. Each participant had a partner who counted and recorded the number of completed laps performed. The partner also informed the runner when he/she had failed to cross the line before the second beep. For each participant, the PACER was considered to be completed when he/she failed to cross the line in time on two occasions. In this study, most of the participants were familiar with the PACER test because they had performed it three times during their 5th grade year as part of their regular physical education regimen.

Procedures

All data collection took place during the physical education class's regular meeting time. The research team consisted of six members to ensure the efficient and precise collection of data for 43 children. One week before data collection, the research team visited the school to introduce themselves to the potential participants as well as to explain the study and answer questions. Informed consent and informed assent forms were sent home with the participants in order for their parents/legal guardians to become aware of the research opportunity and to approve their child's participation. All participants returned signed parental consent forms and child assent forms before participation.

The first day of testing took place during a physical education class held at 12:40 pm. Upon arrival at the gymnasium, participants were reminded of the activities for the day. In the no-treatment control condition, participants performed the memory test at the beginning of their physical education class before performing any exercise. These students reported to the gymnasium and were taken into nearby classrooms in groups of 3–5 to perform the memory test.

Following performance of the memory task, these participants returned to the gymnasium and performed light physical activity (i.e., slow walking) and stretching (i.e., yoga) for the remainder of the class period (approximately 15 min). In the exercise condition, participants began by performing a warmup (e.g., jogging laps around the gym, stretching) for approximately 5 min and then completed the PACER test in their physical education class. Upon completion of the PACER test, students were taken into nearby classrooms in groups of 3–5 to perform the memory test. Following completion of the memory test, the physical education class period ended and these students went back to their normal class schedule.

The next day, researchers returned to the physical education class to collect the delayed recall data. At this time, all participants in the study went to a large classroom and were asked to complete the delayed recognition test.

Statistical Analysis

Descriptive data are presented relative to performance on the PACER and the mile run test. A one-way analysis of variance (ANOVA) was conducted to assess whether there were differences in fitness (mile run test) between the two conditions (exercise, control). A chi-square analysis was conducted to ensure that the random assignment resulted in equivalent numbers of boys and girls in each treatment condition. A 2 × 5 x 3 mixed ANOVA was used to test the effects of the between-subjects factor of condition (exercise, control) and the within-subjects factors of trial (Trials 1–5) and serial position (primacy block: words 1–5, middle block: words 6–10, recency block: words 11–15) on recall of the List A words. Linear and quadratic within-subjects contrasts for the condition x trial interaction were used to test for group differences in rates of verbal learning across trials. Two 2 × 3 mixed ANOVAs were used to test the effects of condition and serial position on LTM by assessing the effects on Trial 7 performance (brief-delay recall) and on correct List A responses on the delayed recognition task (long-term recognition memory). Serial position was included as an independent variable to allow for comparisons with the findings of Pesce et al. (15). Lastly, between-subjects ANOVAs were also used to test the effects of condition on recall measures that were adjusted for learning. Specifically, the number of words correctly recalled in Trial 7 relative to the highest number of words recalled in Trials 1–5 (peak) was calculated (recall percentage) and the number of words correctly identified at the 24-hr recognition assessment relative to peak was calculated (recognition percentage). These analyses were conducted so that memory could be adjusted for learning during the initial 5 trials. Mauchly’s test of sphericity was examined when appropriate, and if the assumption of sphericity was violated, the Huynh-Feldt correction was used. Post hoc analyses were conducted as appropriate to follow up significant effects.

Results

Students participating in this study completed the mile run test in times that ranged between 6 min 42 s and 20 min with an average completion time of 9 min 53 s (SD = 2 min 39 s). There was no significant difference, $F(1,37)=0.25$, $p > .05$, in fitness levels between the exercise group (M = 10 min 7 s; SD = 3 min 3 s) and the control group (M = 9 min 41 s; SD = 2 min 19 s). Participants in the exercise condition completed between 15–67 laps in the PACER test (M = 40.63, SD = 15.78). The time to complete the PACER ranged from 2 min 2 s to 7 min 46 s. Only one girl and two boys failed to meet the FitnessGram standards for the healthy fitness zone (7).

There was no significant difference in the proportion of boys to girls in the treatment conditions, $\chi2$ (1, n = 43)=0.06, $p > .05$. Descriptive statistics for memory performance by the control and treatment conditions are presented as a function of trial (see Table 1) and as a function of serial position by trial (see Table 2).

Results from the Condition × Trial × Serial position ANOVA indicated that there were significant main effects for condition, $F(1,41)=4.35$, $p = .04$, partial $\eta2 = 0.10$, trial, $F(3.46, 141.77)=274.73$, $p < .001$, partial $\eta2 = 0.87$, and serial position, $F(2,82)=6.97$, $p = .002$, partial $\eta2 = 0.15$. These main effects were superseded by significant interactions of trial x serial position, $F(8,328)=3.57$, $p = .001$, partial $\eta2 = 0.08$, and condition x trial, $F(3.46, 141.77)=3.51$, $p = .01$, partial $\eta2 = 0.08$. None of the other interactions were statistically significant ($p > .05$).

Examination of the means for the Trial × Serial Position interaction indicated that recall performance was significantly better at Trial 1 and Trial 2 for the primacy and recency blocks of the list as compared with the middle block, $p < .05$. At Trial 3, only recall for the primacy block was significantly different from the middle block, $p < .05$, and by Trials 4 and 5, no significant differences in recall were observed between any of the various blocks, $p > .05$.Examination of the means for the Condition × Trial interaction using independent samples t tests indicated that there were no significant differences in recall at Trial 1 or Trial 2, $p > .05$. However, there were significant

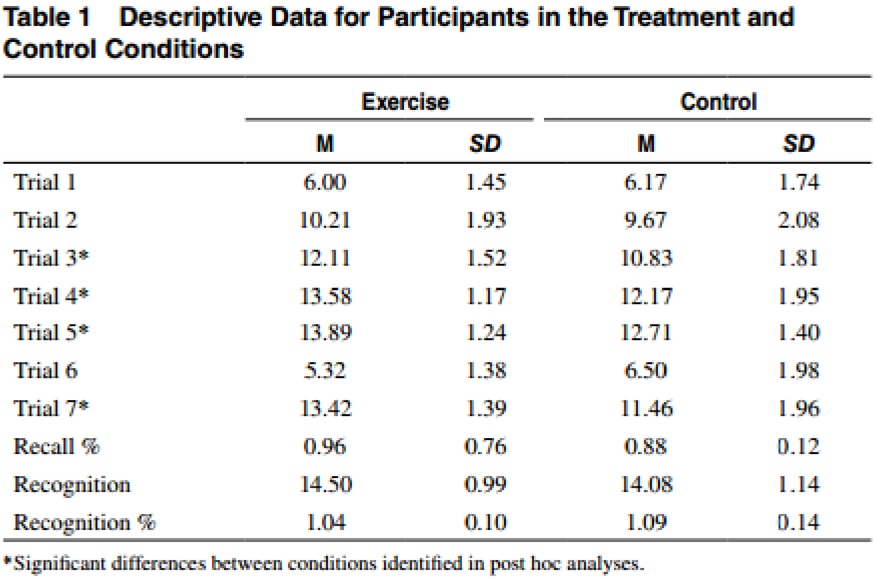

Table 1 Descriptive Data for Participants in the Treatment and Control Conditions

	Exercise		Control	
	M	*SD*	M	*SD*
Trial 1	6.00	1.45	6.17	1.74
Trial 2	10.21	1.93	9.67	2.08
Trial 3*	12.11	1.52	10.83	1.81
Trial 4*	13.58	1.17	12.17	1.95
Trial 5*	13.89	1.24	12.71	1.40
Trial 6	5.32	1.38	6.50	1.98
Trial 7*	13.42	1.39	11.46	1.96
Recall %	0.96	0.76	0.88	0.12
Recognition	14.50	0.99	14.08	1.14
Recognition %	1.04	0.10	1.09	0.14

*Significant differences between conditions identified in post hoc analyses.

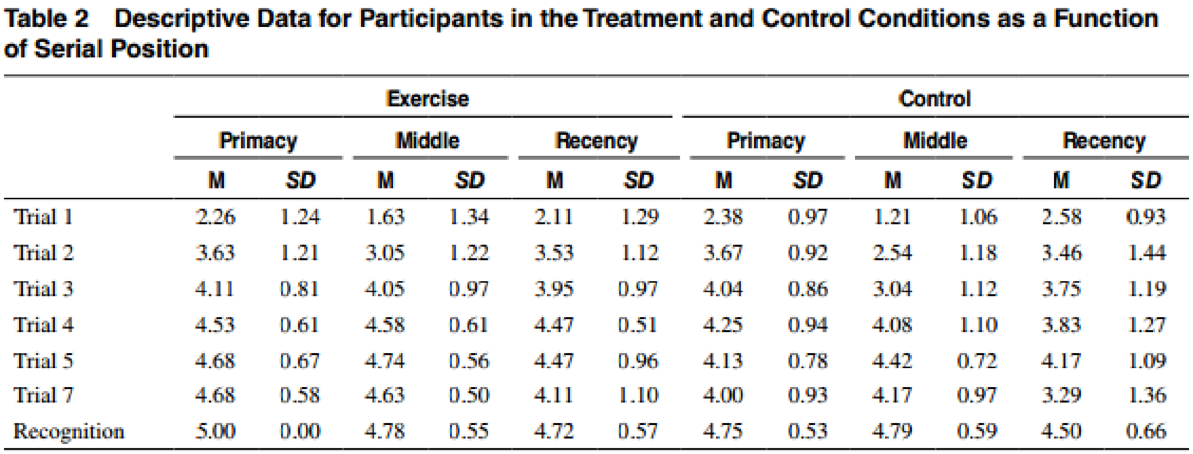

Table 2 **Descriptive Data for Participants in the Treatment and Control Conditions as a Function of Serial Position**

	Exercise						Control					
	Primacy		Middle		Recency		Primacy		Middle		Recency	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Trial 1	2.26	1.24	1.63	1.34	2.11	1.29	2.38	0.97	1.21	1.06	2.58	0.93
Trial 2	3.63	1.21	3.05	1.22	3.53	1.12	3.67	0.92	2.54	1.18	3.46	1.44
Trial 3	4.11	0.81	4.05	0.97	3.95	0.97	4.04	0.86	3.04	1.12	3.75	1.19
Trial 4	4.53	0.61	4.58	0.61	4.47	0.51	4.25	0.94	4.08	1.10	3.83	1.27
Trial 5	4.68	0.67	4.74	0.56	4.47	0.96	4.13	0.78	4.42	0.72	4.17	1.09
Trial 7	4.68	0.58	4.63	0.50	4.11	1.10	4.00	0.93	4.17	0.97	3.29	1.36
Recognition	5.00	0.00	4.78	0.55	4.72	0.57	4.75	0.53	4.79	0.59	4.50	0.66

differences in recall performance between conditions at Trial 3, t(41)=2.45, p = .02, Trial 4, t(38.51)=2.94, p = .005, and Trial 5, t(41)=2.90, p = .006, with participants in the exercise condition recalling significantly more words than those in the control condition (see Figure 1). In addition, significant linear, F(1,41)=7.29, p = .010, partial η2 = 0.15, and quadratic, F(1,41)=4.26, p = .045, partial 2 = 0.094, trends were observed for the Condition × Trial within-subjects contrast, which indicates that the exercise group increased the number of words recalled during Trials 1–5 more quickly than did the no-exercise control group.

The ANOVA testing the effects of condition x serial position on Trial 7 performance yielded significant main effects for condition, F(1,41)=13.66, p = .001, partial η2 = 0.25, and serial position, F(1.76, 72.02)=7.34, p = .002, partial η2 = 0.15, but the interaction of Condition × Serial position was not significant, F(1.76, 72.02)=0.38, p = .66, partial η2 = 0.01. Examination of the means relative to condition indicated that Trial 7 performance was significantly better for those in the exercise condition than for those in the control condition (see Figure 1). Results of the main effect for serial position indicated that memory was significantly worse for the recency portion (M = 3.65, SD = 1.31) of the list as compared with the primacy (M = 4.30, SD = 0.86) and middle (M = 4.37, SD = 0.76) portions. When memory was assessed using recall percentage, results indicated that those in the exercise condition (M = 0.96, SD = 0.08) remembered a significantly greater percentage of the words they had learned than did those in the control condition (M = 0.88, SD = 0.12), F(1,41)=5.71, p = .02, partial η2 = 0.12.

There was not a significant difference in long-term recognition as a function of condition, F(1,40)=1.82, p = .19, partial η2 = 0.04, serial position, F(2,80)=3.06, p = .053, partial η2 = 0.07, or the interaction of Condition × Serial position, F(2,80)=0.89, p = .41, partial η2 = 0.02. There was also not a significant difference in recognition

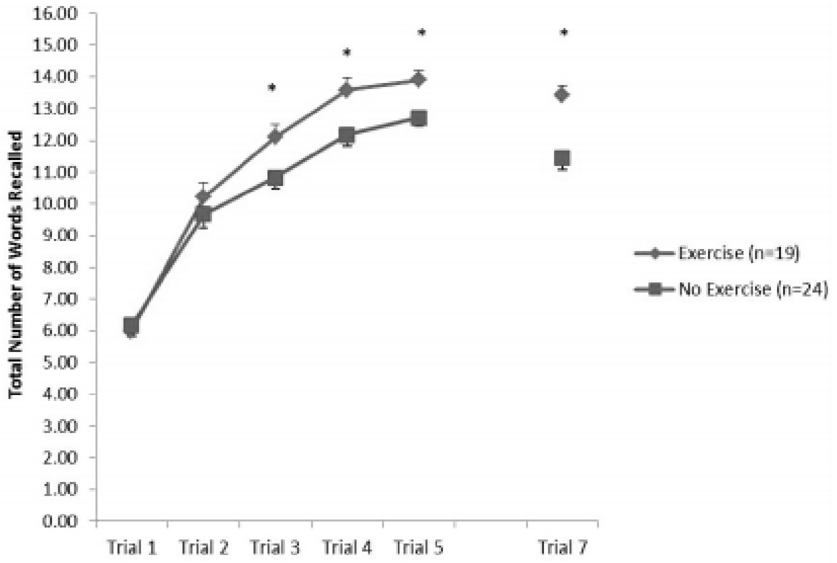

Figure 1 — Performance on the AVLT as a function of Condition × Trial (maximum possible score = 15 words).

percentage as a function of condition, F(1,40)=2.11, p = .15, partial η2 = 0.05.

Discussion

Sixth-grade students were asked to perform a memory task either on a day when they had not done any physical activity (control) or immediately following performance of the PACER test (exercise). Based upon the results of recent literature (5,15,26), it was expected that performing exercise before the memory task would benefit immediate recall (Trial 1) and learning of a novel word list (immediate recall Trials 1–5), memory for word-list items after a brief delay (Trial 7; free recall) and memory after 24-hr (long-term recognition). Results partially supported this expectation. In particular, students who exercised recalled significantly more words at Trials 3, 4, and 5 and learned words significantly faster across Trials 1–5 than did students in the control condition. Although recall at Trials 1 and 2 did not differ by condition, significant linear and quadratic trends for condition by trial indicated that the overall rate of verbal learning was quicker for participants in the exercise condition. In addition, following an interference task (Trial 6), students in the exercise condition recalled significantly more words on Trial 7 than did those in the control condition. Importantly, this advantage in recall after a brief delay was also evident when recall memory percentage was assessed, thus providing evidence that students in the exercise condition retained a greater percentage of words learned during Trials 1–5 than students in the control condition. However, no differences in word recognition were observed following a 24-hr delay. Thus, the results of this study demonstrated that a single session of aerobic exercise benefited students' ability to learn a novel word list and to recall that list after a brief time period during which an interference task was administered.

Exercise participants in the current study exhibited greater verbal learning through progressive trials as compared with the control participants. In the only other study to examine the effect of acute exercise on the rate of verbal learning, Winter et al. (26) reported that young adults required an average of 4 training blocks to achieve learning criterion for a novel vocabulary word-list following the intense running condition compared with an average of 5 training blocks to achieve criterion following moderate running and sedentary conditions. The authors interpreted these results as a 20% improvement in learning speed. However, Winter et al. based this interpretation solely on polynomial contrasts and did not report any significant differences in percentage of correct responses between conditions at any training block. In addition, mean differences in correct responses by condition were not sustained through the fifth training block, at which point the percentage of correct responses was roughly equivalent for all conditions. Similar to the results of Winter et al., significant linear and quadratic trends for the condition-by-trial within-subjects contrast in the current study suggested a faster rate of list-learning for the exercise group. However, this difference in slopes was accompanied by significant condition-by-trial differences in the total number of words recalled at trials 3–5, which provides stronger evidence for improved list-learning following the exercise condition.

It is not surprising that condition-by-trial differences were not observed for the first two learning trials. Early trials of the RAVLT are more reliant on STM processes, with Trial 1 being strictly a measure of STM (22, p. 785); whereas, performance on later trials becomes progressively more indicative of LTM processes (17). In the current study, the absence of significant condition effects at Trials 1 and 2 (see Table 1) indicates that differences in recall performance across later trials were not a product of increased word span. That is, these results do not suggest that acute exercise benefited STM processes, including the total number of words participants were able to hold within STM at one time. Had increased word span been the mechanism for the condition-by-trial differences, performance differences would have been most expected for trials that occurred soonest following the end of the exercise session. Instead, the emergence of recall differences at Trial 3 and the maintenance of those differences through Trial 5 suggest that exercisers were able to more effectively stabilize initially recalled words into LTM. It may have been the case that more effective stabilization of initially attended and recalled words allowed exercise participants to devote more attentional resources in subsequent trials to other words on the list (e.g., middle items) that had not previously been consistently recalled. This could explain the process by which exercisers maintained better recall than controls through the end of the learning trials.

The assertion that exercise influenced LTM processes was further supported by better recall from exercisers at Trial 7, which was a recall trial that followed exposure to and recall of an interference word list, but was itself not preceded by any reexposure to the original word list. These results are somewhat consistent with those found by Pesce et al. (15), who reported a beneficial effect of exercise on recall of recency items following a 12-min delay, which included interference that prevented mental rehearsal. This observation was interpreted by Pesce et al. as evidence that the amount of rehearsal necessary before information becomes stabilized into LTM is reduced following physical activation. Though that benefit to recall was only observed for a portion of the word-list—likely the result of the single-exposure paradigm—the results generally support the interpretation of findings in the current study that acute exercise impacted LTM, but not STM processes.

Somewhat unexpectedly, the results of this study did not support a beneficial effect of exercise on long-term recognition. After a 24-hr delay, there was no significant difference in the number of words remembered as a function of the treatment condition. This was true regardless of whether performance was assessed as overall recognition, as recognition by serial position, or as recognition percentage. The null finding after a 24-hr delay was unexpected given the significant main effect of condition on recall at Trial 7. One possible interpretation of this null finding is that it demonstrates an abatement of the beneficial effects of exercise on learning and memory observed on the first assessment day. However, an equally plausible explanation is that the recognition task was not sensitive enough to observe differences. Examination of mean performance (see Table 2) shows that both groups identified list items at near-ceiling levels at the 24-hr recognition. This suggests that the recognition task may have been too easy to detect group differences with this sample. A common observation among declarative memory tasks is that participants are able to remember more items on a recognition task than on a recall task. This phenomenon is currently explained through a multiple-systems theory of memory, which argues that memory is composed of many systems that operate in distinct fashion from one another (18, p.128). Applied to the current study, the multiple systems approach would suggest that recognition memory could have been impacted through retrieval (which is the process upon which recall is dependent), as well as through direct judgments of familiarity and through a priming effect of multiple recent exposures to the target words from the previous day (25). According to this perspective, elevated performance by both groups on the recognition task, relative to the delayed recall trial (Trial 7), should be expected given the learning protocol used in the current study. This elevation in performance resulted in a ceiling effect, which masked potential differences in memory for the target information following the 24-hr delay. However, in the absence of further study, it remains unclear whether the failure to observe differences at the 24-hr assessment suggests that the effects of exercise on memory dissipated over time or that the effects of exercise were masked by some qualitative difference in the recognition task (e.g., decreased sensitivity due to prompting). Future study should include assessment of free-recall, rather than recognition, following a 24-hr delay to disambiguate this result.

In an effort to give guidance for future research, it is perhaps important to consider the overall findings and design of this study relative to those of the Craft (5) and the Pesce et al. (15) studies which provide the only other reports of the effects of acute exercise on memory performance by children. The findings of this study which support benefits of acute exercise for memory appear to be in contrast to those of Craft who reported no benefits of exercise for memory performance by children. In comparing the current study with the Craft study, it is important to note the differences in the type of memory outcomes that were assessed. In the current study, the RAVLT was used and this provides measures of verbal learning, short-term auditory verbal memory, and long-term retention. Of the measures used in the Craft study, only Digit Span and the Visual Sequential Memory task are considered measures of memory, while Coding is considered a measure of processing speed. More specifically, both the backward portion of the Digit Span (participants must repeat back a string of digits in reverse order) and Visual Sequential Memory tasks rely primarily upon WM processes; whereas, only the forward portion of the Digit Span (participants must repeat back a string of digits in the original order) relies primarily upon STM processes (2). Therefore, appropriate comparisons of the current results to those reported by Craft are limited to early recall trials of the RAVLT and the forward portion of the Digit Span. As was previously noted, the similar between-groups results in recall at Trials 1 and 2 suggest that exercise did not influence STM processes in the current study either. Thus, there appears to be some consistency between the results observed here and those reported by Craft in that a short bout of acute exercise did not have a significant effect on STM processes.

In comparing this study to the Pesce et al. (15) study, the results from both generally support beneficial effects of acute exercise on memory; however, there are subtle differences in the findings that may be due to the differences in outcome measures between the studies. As has been mentioned, one important difference between the studies is that Pesce et al. used a memory measure that consisted of only one exposure to a list of words while in this study, participants received 5 word-list exposures and 5 immediate recall trials, allowing for measures of verbal learning in addition to STM and LTM. Though beneficial effects of exercise and physical activity on memory were observed in Pesce et al., these effects were limited to items located in the primacy (first 5 words) and recency (last 5 words) positions on the word lists. The present study did not yield treatment condition differences in recall of words by serial position. A main effect of serial position was observed during early learning trials that were still heavily reliant on rehearsal strategies, but these effects began to abate by the third learning trial and were no longer present by the fourth learning trial. It is likely that the deliberate learning process built into the administration of the RAVLT is why in this study LTM effects were observed for total words recalled and were not limited to words from primacy and recency blocks of the word list. This is an important extension of the results reported by Pesce et al., in that it contributes to our understanding of the extent to which learning and memory processes are impacted by acute exercise.

One other area of difference between past memory studies involving children (5,15) and this one is with regard to the exercise protocol. The exercise protocols employed in these three studies were different in both duration and intensity. In the Craft study, participants were asked to pedal on a bicycle ergometer for 0, 1, 5, and 10 min, at a speed of 18–20 kph, at a resistance level eliciting heart rates averaging 170 beats per minute. Craft reported that most participants "showed signs of exhaustion at 10 min" (p. 980), thus suggesting that this was a high intensity exercise bout. Each exercise level was completed on separate days, with cognitive measures administered after exercise was completed. The various durations of exercise used in the Craft study (1-min, 5-min, 10-min) were similar to the length of time needed to complete the PACER test in the current study (range: 2 min 2 s—7 min 46 s; M = 5 min 1 s), but the exercise intensity was likely somewhat different. Although participants in the current study were asked to give their best effort on the PACER and the PACER is considered to provide a measure of maximal aerobic capacity, subjective observations of participants' behaviors after completing the PACER suggested that most were actually performing at a moderate intensity level ("noticeable increases in HR and breathing") rather than a vigorous intensity level ("substantial increases in HR and breathing"; 1, p. 28). In the Pesce et al. (15) study, participants averaged approximately 30 min of moderate to vigorous physical activity during a 1-hr physical education class. Thus, participants in the Pesce et al. study likely experienced similar intensity levels to those in the current study, but obviously a much longer duration of activity as well. Thus the Pesce et al. and this study each reported beneficial effects of exercise on memory despite these differences in the exercise protocols, while the Craft study suggests that the different results are due to differences among the aspects of memory assessed. However, these differences underscore the need for future study to elucidate the interplay between exercise duration and intensity as they relate to effects on memory and to incorporate physiological (e.g., heart rate) and/or psychological (e.g., ratings of perceived exertion) measures to confirm the intensity of the exercise.

In conclusion, the results of this study indicate that a single session of exercise benefits verbal learning and memory for healthy children. Given that these effects were observed in a school setting rather than in a laboratory, the findings may suggest that learning and memory processes benefit from taking place following physical activity performed in a physical education class. However, future research will be necessary to determine how these findings for an auditory verbal learning test translate to learning that is relevant for academic performance. In addition, as with any empirical study, the results of this study actually lead to more questions than answers. In particular, future research exploring the effects of acute exercise on memory performance by children will be necessary to determine if exercise characteristics (i.e., intensity, duration, and/or mode) are important and to clarify how exercise affects various types of memory (e.g., STM vs. LTM, recall vs. recognition, etc.). Similar to conclusions drawn from reviews of the literature exploring the effects of exercise on executive function, it is important for researchers in this area to recognize that memory is not a generic term and hence the effects of exercise might vary depending upon the particular aspect of memory being tested.

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