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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 39(0)

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Publication Date
2017

Peer reviewed

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Abstract

Research on the relationship between acute physical activity and cognition in children has often found beneficial effects of exercise on a variety of cognitive abilities. One domain that remains underexplored, however, is the relationship between exercise and long-term memory in children, and in particular whether the general-domain effects observed in previous studies could translate to a school-based learning activity, such as vocabulary learning. To address this issue, this study focused on the possible effects that a bout of moderate, aerobic physical activity could have on the immediate and delayed recall of newly acquired word forms and form-meaning connections of children in a school setting. In line with previous research, the results show a positive effect of exercise, but only for word form recall. This study expands our understanding of the differential effects of exercise on memory, while raising questions regarding the possible moderating influence of gender and memory consolidation.

Keywords: language acquisition, acute physical activity, memory, vocabulary learning, child cognition.

Introduction

Research on the effects of physical activity has consistently shown that children who lead an active lifestyle also have healthier bodies, and that exercise plays a significant role in the prevention and control of certain diseases, including, but not limited to, obesity and cardiovascular disease (Kesaniemi et al., 2001). The effects of exercising, however, are not purely physiological. Over the last couple of decades, a growing body of research has concentrated on the effects of physical activity on the developing mind, mainly focusing on whether acute or chronic physical activity can influence cognition.

Interest in the effects of exercise on cognition was sparked by the observation that exercising provokes a series of transient cardiorespiratory, hormonal and metabolic changes that affect the brain's function and organization. These changes ultimately influence the way in which humans, and other animals, perform cognitive activities, including those involving executive function, attention, and memory (Coles & Tomporowski, 2008; Hötting & Röder, 2013; McMorris, Turner, Hale, & Sproule, 2016). In recent work, memory consolidation has emerged as a process that could be particularly affected by physical activity (Robertson & Takacs, 2017). The possible pathways by which exercise-induced arousal may affect long-term memory are still not entirely understood. However, it has been suggested that exercise-induced upregulation of catecholamines, cortisol or brain-derived neurotrophic factor (BDNF), a protein shown to be involved in neurogenesis and neuroplasticity, could underlie the effects of acute physical activity on memory processes (McMorris et al., 2016; Roig et al., 2016).

Regarding child cognition, few studies have focused on the possible effects of physical activity on children's long-term memory. An exception would be the work of Pesce and colleagues (Pesce, Crova, Cereatti, Casella, & Bellucci, 2009) who studied the performance of a group of 11 and 12-year-old students in an immediate and delayed (12 minutes later) free-recall test. The participants attended several learning sessions, two of which were preceded by a physical education class, one involving high cognitive and social demands (team games) and one with low demands (circuit training). Delayed recall improved for both exercise conditions when compared with the rest condition, whereas immediate recall improved only after the team games. More recently, Etnier, Labban, Piepmeier, David, & Henning, (2014) observed children's performance on the Rey Auditory Verbal Learning Test - intended to evaluate verbal learning and memory, administered after a period of physical activity or rest. The participants were tested immediately and 24 hours later. Results showed that participants who exercised had better memory retention immediately, but not 24 hours later.

These studies provide interesting insights regarding the effect of exercise on children's memory, yet they focus on general-domain cognitive abilities, tested through tools that do not closely resemble ordinary classroom activities. In both experiments, the participants were tested on their recall of already known words, a task that, though related to different aspects of memory, does not involve learning new linguistic information, such as word forms or form-meaning connections. Learning such linguistic information is at the core of one standard part of school curricula around the world: second/additional language learning. Therefore, it would be of interest to extend the findings of these studies by assessing whether the advantages noticed in these general memory tasks could translate to a particular language learning activity, such as vocabulary learning.

There is some precedent for this type of studies in research done with adults. For example, despite some differences in the experimental designs, benefits of a moderate to intense bout of exercise were found for vocabulary learning, achieved through the association of translation equivalents (Schmidt-Kassow et al., 2013; Schmidt-Kassow, Kulka, Gunter, Rothermich, & Kotz, 2010) or through a statistical, associative learning paradigm (Winter et al., 2007). These encouraging results, however, have not yet been observed in children.

Based on the brief review of the literature presented above, the primary purpose of this study was to assess the possible effects of a bout of aerobic, moderate physical activity on children's memory for language learning. In particular, we were interested in observing whether exercising before encoding could lead to a higher rate of recall immediately after learning and after a delay. Acquiring new vocabulary items is a complicated process that involves many different learning activities, from item segmentation to the integration of novel items to existing networks. In this instance, however, we have chosen to focus on only two of these activities: the acquisition of the word's phonological/orthographical form and the linking of the newly acquired form to a meaning. From the results of previous studies and the theorized mechanisms underlying the exercise-cognition effect, we hypothesize that children in the exercise group would exhibit increased recall of both forms and meanings in the delayed tests, after a period of consolidation including sleep.

Method

Participants

51 school-aged children (mean age = 9.3, 25 females) were recruited at their school to participate in this experiment. All children were monolingual Spanish speakers, with no knowledge of other languages besides school-level English. None of the children had visual or hearing impairments, nor cardiac or respiratory conditions that would prevent them from exercising at a moderate pace. As reported by their parents or tutors, the children had normal sleeping patterns, with an average sleeping time of 8.5 hours per night.

Materials

Pseudowords Twenty-four bisyllabic, pronounceable pseudowords were created using legal Spanish consonant/vowel combinations. All pseudowords were four letters long and followed a CVCV pattern. Care was taken to ensure that an equal amount of pseudowords were 'masculine' (ended with 'o') and 'feminine' (ended with 'a').

Pictures Twenty-four pictures of everyday objects extracted from a subset of Rossion & Pourtois' (2001) pictorial set, which was based on Snodgrass & Vanderwart's (1980) original standardized set of visual stimuli but with added detail and colour. For this experiment, we transformed the pictures to greyscale to preserve the enhanced details while avoiding the distraction of colour. Pertinent country-specific normative data was used to assess the concreteness and imagery ratings of the objects depicted (Manoiloff, Artstein, Canavoso, Fernández, & Segui, 2010). Following Pesce et al's (2009) procedure, the objects were evaluated by classroom teachers to ensure that they would be recognizable and familiar to the children.

Learning lists Each pseudoword was randomly paired with one of the pictures selected. We divided the pseudoword/picture pairings into two lists of 12 items, that would be presented in different experimental sessions. The order of presentation of both the learning and testing stimuli was randomized for each group.

Procedure

The experiment used a within-subjects design, counterbalancing the order in which the children participated in each of the experimental conditions, exercise, and no-exercise (control).

The experiment was carried out at the participants' school, during school hours, with the assistance of classroom and physical education teachers. Participants attended six sessions spread over three weeks. The first and fourth sessions started with an intervention stage, where participants either performed a 30-minute bout of aerobic physical activity (exercise condition) or remained in the classroom doing a passive activity (drawing and colouring) for the same amount of time (control condition). After the intervention, and after a 5-minute recovery time for the exercise group, the children performed the vocabulary learning activity. In the final stage of the first session, the children were asked first to write down all the words they remembered, regardless of the order of presentation (free recall) and later to write down the words corresponding to the pictures shown in posters by the teachers (cued recall). The free and cued recall tasks constituted the first testing session (immediate test).

This testing phase was repeated on sessions two and three for the pairings learnt in session one, and on sessions five and six for the pairings learnt in session four.

All participants were exposed to both learning lists and took part in both intervention conditions (exercise or control); the order of the interventions was counterbalanced and randomized so that some participants exercised on session one while others exercised on session four.

The experimental procedure is schematized in Figure 1.

Vocabulary learning activity The children were exposed to the lists of 12 pseudoword/picture pairings, presented in printed posters, and shown at a regular interval. The classroom teachers led the presentation, reading the pseudoword aloud and asking the children to repeat it back. This exposure was repeated three times.

Testing tasks Two testing tasks were intended to separately measure children's ability to recall the phonological form as well as the form-meaning connections of the pseudowords learnt in the exposure phase.

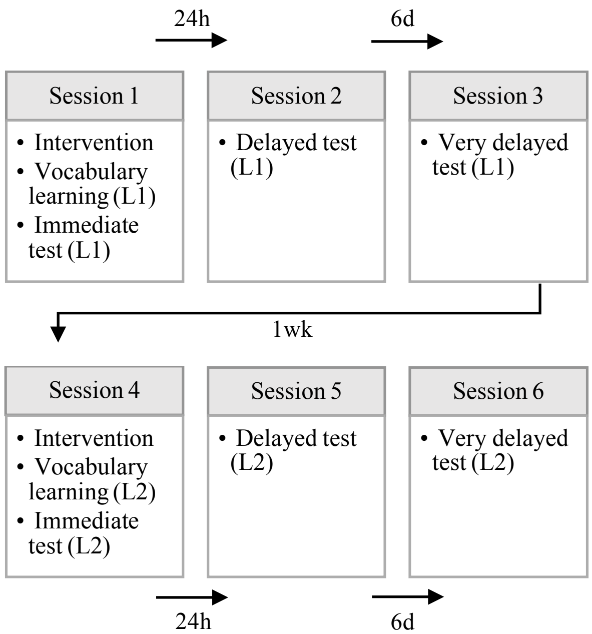

Figure 1: Experimental procedure. L1 = word list 1, L2 = word list 2, 24h = 24 hours later, 6d = 6 days later, 1wk = 1 week later.

The first task, free recall, was designed to assess whether the participants could remember the phonological forms of the newly acquired pseudowords, without prompting from their associated meanings. To perform this task, the teachers instructed the students to write down all the pseudowords they could remember, irrespective of the order of presentation or their ability to associate the words with the drawings.

For the second task, cued recall, the teachers showed the students only the pictures, and the children had to write down which pseudoword corresponded to each picture shown. The pictures were shown at a steady pace, and the children were instructed to leave blank spaces for the pictures they did not remember. This test intended to observe if children could recall the form-meaning connections they had previously learnt.

Physical activity intervention The physical activity intervention consisted of 30 minutes of child-adapted circuit training, focalised on activities that would engage the aerobic system. We chose this type of exercise task since it maintains a major focus on aerobic exercise - as opposed to group games, for example, that may be more cognitively and socially demanding - while still being part of what students normally do in their physical education classes, and thus ecologically valid. The task took place in the school's playground under the supervision of the children's physical education teachers (student-to-teacher ratio = 15:1).

We used a modified Borg Scale of Perceived Exertion (Borg, 1998) to assess exercise intensity. It was administered to the children in the exercise condition while they were performing the activities. This scale has been widely used for children in similar contexts and has proved to be reliable not only in assessing intensity but also in determining the nature of the exercise being conducted (aerobic versus anaerobic). By maintaining the general perceived exertion of the group in the second tier (considered "moderate" in our scale), it was assured that the children were performing aerobic exercise at a moderate intensity.

Results

Data pre-processing

Ten participants were removed from the final sample, two for reporting learning or psychological conditions that might interfere with the experiment's outcome and eight for not having participated in either of the two experimental conditions (exercise or control). Given that a significant number of children were absent on the day of the very delayed test, for reasons not related to the experiment, we excluded the very delayed test (sessions three and six) in the reported analyses. To keep the design balanced, we additionally removed two participants for not having completed the delayed testing session. All analyses were carried out on the remaining 39 participants (mean age = 9.32, 21 females).

We computed an accuracy score for each testing activity (free or cued recall) by summing all the correct responses given at each testing time. Participant responses were given one point when they matched exactly one of the taught pseudowords (e.g. lofa/lofa), and half a point if the answer had one substitution (e.g. lofa/lifa). For the cued recall task, the responses had to match one of the pseudowords in the taught set in addition to matching the corresponding picture. Partial matches that were placed with the correct picture were awarded half a point.

All statistical analyses were performed using R (R Core Team, 2016) and the `ez` package (Lawrence, 2016).

Free recall

A two-way analysis of variance was conducted to evaluate the effects of the experimental condition and testing time on the number of items recalled in the free recall task. Experimental condition (exercise vs. control) and testing time (immediate vs. 24 hours later) were included as factors. No significant effect of experimental condition, $F(1, 38) = 1.092$, $p = .302$, or testing time, $F(1, 38) = .032$, $p = .574$ was found. However, the interaction between exercise intervention and testing time was significant, $F(1, 38) = 5.932$, $p = .019$, $\eta_g^2 = .006$). As shown in Figure 2, it would seem that, whereas there is no difference in the immediate test for the experimental conditions (exercise: M = 5.97 [49.7%], SD ± 2.73; control: M = 6.07 [50%], SD ± 2.59), participants recalled more items in the delayed test if they had exercised prior to encoding (exercise: M = 6.26 [52%], SD ± 2.71; control: M = 5.5 [45.8%], SD ± 2.94).

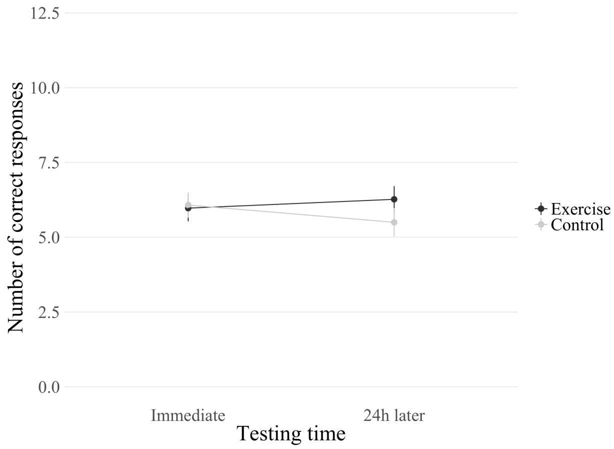

Figure 2. Free recall correct responses per condition and testing time.

Gender differences were also taken into account in the analysis. Figure 3 displays the number of correct responses in each experimental condition, grouped by gender and testing time. From this graph, it is possible to see that, overall, girls seem to remember the same or a larger number of items when compared to boys. Furthermore, the profiles of performance per experimental condition appear to be similar for both genders: when in the exercise condition, the number of accurate responses is either maintained or increases from the immediate to the delayed test, whereas when in the control condition performance decreases. However, while the girls' performance does not seem to be particularly affected by the exercise intervention in either of the tests (exercise immediate: M = 5.28 [44%], SD ± 2.72; exercise delayed: M = 5.85 [48.8%], SD ± 2.86; control immediate: M = 6.04 [50%], SD ± 1.8; control delayed: M = 5.71 [47.6%], SD ± 2.93), the boys recalled more items immediately (exercise: M = 5.22 [43.5%], SD ± 2.79; control: M = 4.33 [36%], SD ± 2.95) and 24 hours (exercise: M = 5.33 [44.4%], SD ± 2.63; control: M = 4 [33.3%], SD ± 2.76) when they exercised before encoding.

Given the unequal number of boys and girls in the sample (female = 21, male = 18), which limits the possibility of comparing the groups, a two-way repeated measures ANOVA, including experimental condition and testing time as factors, was conducted on a reduced dataset comprising only the boys' data. The effect of experimental condition was significant, $F(1, 17) = 5.101$, $p = .037$, $\eta_g^2 = .035$, indicating that the difference between experimental conditions (exercise vs. control) observed in Figure 3, albeit numerically small, may be worth further exploration.

Cued recall

To assess the effects of experimental condition and testing time, a two-way, repeated-measures ANOVA was performed. As shown in Figure 4, no significant main effects of experimental condition, $F(1,38) = .026$, $p = .872$, or testing time, $F(1,38) = .638$, $p = .429$, were found. The interaction between both independent variables was also non-significant, $F(1,38) = .014$, $p = .9$, $\eta_g^2 \leq .001$. These results indicate that exercise did not influence the cued recall of form-meaning connections in this sample, either immediately (exercise: M = 5.43 [45.2%], SD ± 2.93; control: M = 5.51 [45%], SD ± 2.52) or 24 hours after encoding (exercise: M = 5.64 [47%], SD ± 2.48); control: M = 5.66 [47.2%], SD ± 3.05).

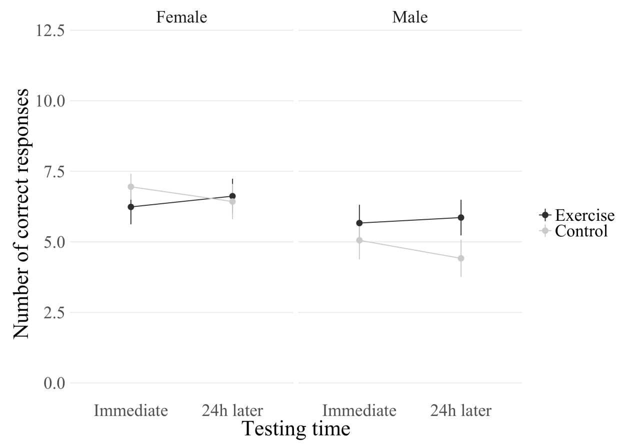

Figure 3. Free recall correct responses by gender, experimental condition and testing time.

A visual inspection of the plotted cued recall data divided by gender showed no indication of a differential effect of exercise. Hence no additional analyses were conducted.

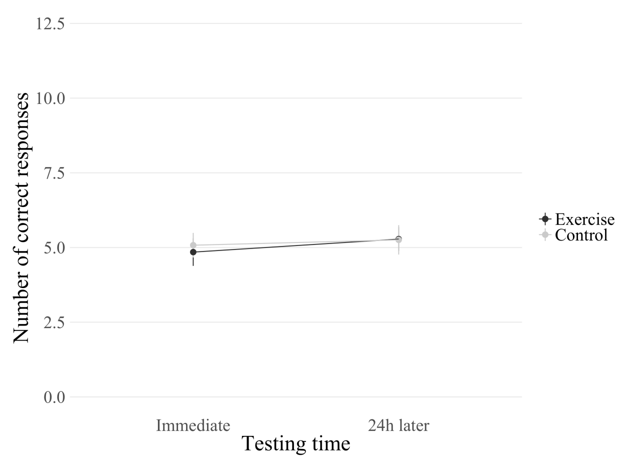

Figure 4. Cued recall correct responses per condition and testing time.

Discussion

The purpose of this study was to assess whether a bout of aerobic, moderate physical activity performed before encoding could affect children's retention of newly acquired pseudowords and their meanings, immediately after learning and with a delay. In particular, we were interested in observing the possible effects of physical activity in the recall of novel word-forms (pseudowords) and meanings (pseudoword/picture association). These questions were motivated by the scarcity of studies focusing on exercise and language learning, particularly with child participants.

The free recall test focused on the children's retention of word forms. Data from this task showed that exercising before encoding facilitated recall, but only on the delayed test (24 hours after learning). This outcome may indicate that exercising before learning could help reduce time-dependent forgetting on a moderate scale. This finding concurs with previous research outlining the beneficial, rather than detrimental, effects of acute exercise on children's recall (Etnier et al., 2014; Pesce et al., 2009). However, in contrast to these studies, in which increased memory performance was noticed in the immediate test (or after a very short delay), in this experiment the influence of exercise appears to affect the delayed test, performed 24 hours later and after a period of sleep. This may indicate a possible link between acute physical activity and memory consolidation. A relationship between exercise and consolidation has already been postulated for healthy adults (e.g. Coles & Tomporowski, 2008; Labban & Etnier, 2011; Robertson & Takacs, 2017), but would require further exploration to extend it to child memory consolidation. The discrepancy between the results of the present study and previous work could also suggest that, consistent with several meta-analyses (Chang, Labban, Gapin, & Etnier, 2012; Lambourne & Tomporowski, 2010; Tomporowski, 2003), the effects of physical activity on cognition could be selective. Since the learning activities used in Etnier and colleagues and Pesce and colleagues' work were focused on the recall of already known linguistic information, and not on the acquisition of entirely novel forms as was the case in this experiment, the tasks rely on different memory processes that may be differentially affected by exercise.

A bout of physical activity before encoding did not affect recall of form-meaning connections. This finding is somewhat unexpected, given that previous research had found an influence of bouts of aerobic physical activity on associative memory in adults (Schmidt-Kassow et al., 2013; Schmidt-Kassow, Kulka, Gunter, Rothermich, & Kotz, 2010; Winter et al., 2007). Since this experiment required children to learn forms and form-meaning connections simultaneously, it may be that the acquisition of the form was privileged to the detriment of the formation of form-meaning connections. This could have been reinforced by the order of the testing activities – always free recall followed by cued recall – that could have made the recall of forms more prominent. To our knowledge, this is the first study that addresses the effect of a bout of physical activity on the formation of form-meaning connections in children; as such, it only begins to describe the effects observed. Further research could help elucidate whether the effects of exercise seen on standardized associative memory tests could transfer to memory-supported activities that more closely resemble the tasks performed by children in a learning environment.

Another surprising effect was the difference observed in boys and girls. A tentative explanation of this difference, based on the assumption that exercise works as a stressor, would fall in line with research highlighting gender-based differences in brain reaction to stressors, both of an emotional and physical nature (for a review, see Cahill, 2006). Furthermore, because this gender difference appears on the second day, the possibility of the existence of gender differences in offline consolidation, that could be enhanced by exercise, should also be considered. Some evidence points towards greater motor skill memory gains obtained by males after a period of offline consolidation (Dorfberger, Adi-Japha, & Karni, 2009), an advantage that may be related to differential responses to cortisol levels (Andreano & Cahill, 2006). Cortisol is a stress hormone shown to be affected by acute exercise interventions, and that plays a role in memory consolidation. It should nonetheless be noted that since not all previous studies on the effects of exercise on cognition have addressed gender differences, and as it was not the primary purpose of this study, it is hard to draw conclusions from this result.

There are some limitations that should be considered in relation to the current study. First, the sample size is relatively small when considering the number of variables addressed. Furthermore, the effects found, although significant, were subtle and can therefore only be considered with caution. Future experiments should also include more information about the sample, including a measure of fitness level and baseline memory performance, as well as some indication of school achievement (e.g. grades). The inclusion of these data could help disentangle variation that might be motivated by external factors not related to the experimental manipulation.

Overall, this study expands our knowledge of the effects of acute, aerobic physical activity on children's cognition, in that it includes a 'learning element' that had been thus far overlooked. The fact that participants had to learn novel word forms, as well as their connection to meaning, after exercising makes this experimental activity more closely related to regular classroom language learning activities, thus providing an initial glimpse into the effects of physical activity in a school environment. The finding that the experimental condition affected free- but not cued-recall in this experiment could suggest a selective effect of exercise on children's memory, but it could also underline the need to utilize more nuanced tests to assess associative memory in this context. Future research on this topic could build upon these findings, by adding more and more sophisticated tests of relational memory, as well as addressing some of the questions that this study has raised, such as the possible moderating effect of gender and the influence of acute physical activity on memory consolidation in children.

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