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The effect of physical fitness and physical activity level on memory storage of Italian pre-adolescent secondary school students

GABRIELE RUSSO[1], FEDERICO NIGRO[1], GAETANO RAIOLA[2], ANDREA CECILIANI[1]

Abstract
Introduction. **Physical activity could enhance some psychological functions, and it is crucial for the growth of individuals.** Aim of Study. **The present investigation aimed at testing pre-adolescent students' memory functions to understand whether physical activity and physical fitness can increase memory storage.** Material and Methods. **A battery of physical tests (MOTORFIT) and questionnaire (PAQ-C, RSES – self-esteem) were administered to identify the physical and psychological characteristic of the students. A Free Recall Memory Test was performed by the children in order to assess their memory skills. In the memory test, participants had to memorize as many words as possible from a list of 20 words presented. Participants had to write down as many words as possible in two different times, 100 seconds after the presentation (e.g., immediate recall) of the 20 words and after 12 minutes (e.g., delayed recall).** Results. **The results showed an effect of physical fitness but did not show an effect of physical activity level. In particular, results highlight that students with high physical fitness are able to remember more words than pre-adolescent with low physical fitness.** Conclusions. **Our results provide evidence that physical practice could lead to an enhancement of memory functions.**

KEYWORDS: schoolchildren, physical education, delayed recall, immediate recall, reactivation stage.

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Corresponding author: russo.gabriele@gmail.com

[1] *University of Bologna, Department for Life Quality Studies, Bologna, Italy*

[2] *University of Salerno, Department of Human, Philosophical and Education Sciences, Salerno, Italy*

Introduction

Physical activity and related physical fitness are essential for individuals' physiological and psychological development [14, 15, 24, 33, 44, 45]. However, in our society the, level of sedentary lifestyle across countries is increasing. For instance, children spend much time playing computer games and/or watching television [6, 13, 22, 29, 36, 41]. This behaviour could lead to a deterioration of physical fitness that could consequently bring to a decrement of general wellness and well-being [12]. In the last years, much research has been focused on the modulatory effects of physical exercise on cognitive functions in childhood and late adulthood [9, 11, 14, 15, 18, 37, 40, 42]. Specifically, researchers have focused their attention on the relation between physical activity and physical fitness on cognitive functions and academic achievement. Some scholars have tried to summarize the results through meta-analyses and systematic reviews [2, 3, 8, 16, 27, 35]. The outcomes were relatively similar across the investigations. All reviews and meta-analyses highlighted a positive relationship between physical activity and cognitive functioning. However, the authors reported that these effects are small and inconsistent, probably due to some research design limitations.
Furthermore, according to these reviews and meta-analyses, not all cognitive functions are affected by physical activity in the same way. For instance, a meta-

analysis conducted on children by Sibley and Etnier [35] showed a positive relationship between physical exercise and perceptual skills except for memory capacities. A more recent systematic review of Donnelly et al. [8], where both single bout and intervention increased cognitive functioning measured through attentional paradigms (i.e., D2 attentional test, Stroop Task) and academic achievement. These results were supported by another systematic review performed by Rasberry et al. [27], which highlighted that physical activity could have a neutral or positive effect on cognitive skills. However, recent independent investigations (e.g. [33]) failed to find a strong relationship between cognitive functioning and physical activity. Specifically, an intervention study by Russo et al. [33] confirmed that physical activity could affect cognitive functioning differently.

In summary, according to the reviews and meta--analyses mentioned above, the results in this domain are usually weak, and the effects are small or moderate. Thus, further research is needed to understand the phenomena thoroughly. Furthermore, the investigations were often focused on primary school children instead of pre-adolescents and adolescents. Moreover, when considering the relevance of this age for the development of most motor and cognitive abilities, the positive effect of physical activity should be further investigated to understand the potential development of physical training that consequently can be useful in improving motor and cognitive skills.

This experiment focused on the relationship between physical fitness and physical activity levels on memory capacity in a large sample of pre-adolescent children. Memory skills are fundamental in the learning process because during school lessons, children should hold information in their memory and recall it when necessary. This interest was motivated by the lack of systematic works on the modulatory effect of physical activity and memory functions [26, 35]. To test memory functions, a similar experimental paradigm was used by Pesce et al. [26], Russo et al. [32], and Coles and Tomporowsky [5]. Instead, physical fitness was assessed through a physical test battery (MOTORFIT test battery) [25]. Because of the possibility that some children should have higher physical fitness but low physical activity level, the results of the physical tests were controlled through the Physical Activity Questionnaires – children (PAQ-C [17]). Moreover, we controlled the effect of self-esteem (RSES) [30] because it could influence these performances. Specifically, according to some investigations, it is possible to consider that physical activity could indirectly affect cognitive functioning through self-esteem [10, 31, 38].

Thus, in this experiment we assumed that students with high physical fitness and high physical activity level should have better memory capacity than pre-adolescents with low physical fitness and low physical activity. Furthermore, we controlled the age effect, dividing the sample into three different levels of age, and controlled self-esteem's role in memory performance. In the former case, we expected a possible increment of memory performance with increasing age. In the latter case, if self-esteem influenced memory performance, we expected better results in participants with high self-esteem than those with low self-esteem.

Methods

Participants

Students of a middle school located in Rimini (an Emilia Romagna County – Italy) were recruited. Specifically, they were 93 (47 females) students with an average age of 12.21, SD = 0.93 y.o. (female: 12.17, SD = 0.96 y.o.; male: 12.30, SD = 0.89 y.o.). In order to analyze the age effect, students were divided into three groups according to their age. Three age groups (G) were created. The G1 group was composed of 25 (15 females) participants of 11 y.o., G2 was formed by 30 pre-adolescents (15 females) of 12 y.o. and G3 was composed of 38 students (17 females, 13 and 14 y.o.).

Moreover, participants were sorted according to the median of Physical Activity Questionnaire (PAQ-C) [17] score, the Self-Esteem Questionnaire (RSES) [30] score and according to the score obtained in the Physical Fitness tests (MOTORFIT. See Section: *Physical tests and Physical Activity Questionnaire*) (25).

The Physical Activity Questionnaire median was 2.68 points. Thus, the sample was divided into High Physically Active (HPA) students and Low Physically Active (LPA) students. Seventy-four students (26 females) were highly physically active, while 76 (50 females) formed the LPA groups. The median of the Rosenberg questionnaire was 31 points. Participants were divided according to the median of the sample in the High Self-Esteem Group (HSEG) and the Low Self-Esteem Group (LSEG). Seventy-four pre-adolescents (34 females) formed the LSEG, while 75 pre-adolescents (42 females) composed the HSEG.

The study obtained approval by the ethics committee from the Local Bioethics committee. In addition, parents and pre-adolescents were informed about the experiment and signed the informed consent form.

Physical tests and Physical Activity Questionnaire

Participants performed the MOTORFIT physical battery test [25]. The tests administered included the 10 m shuttle run, the Cooper, the sit-up, the long jump and the flexibility test. We excluded the local muscle endurance for the upper limb due to the lack of suitable equipment. In the 10 m shuttle run test, participants had to run 5 meters at their maximum speed in 10 repetitions. In the Cooper test, participants had to run continuously for 12 minutes, trying to cover as much distance as possible. In the sit-up test, participants performed as many sit-ups as they could in 30 seconds. In the stationary long jump test, participants had to perform a horizontal jump from a stationary position. Instead, in the flexibility test participants in the sitting position with the inferior limbs extended had to try to reach or go over the toes with their hands.

The Physical Activity Questionnaire for Children (PAQ-C) was filled to understand the level of physical activity for each participant. Through a series of questions, the PAQ-C questionnaire provides an estimation of participants' physical activity levels. In this questionnaire participants reported performance of the activity/ies in the previous week and the time spent on it. If participants were sick, the questionnaire was removed.

Regarding the Physical Fitness Test (MOTORFIT test), we assigned a dummy value (i.e., 0 or 1) for each participant. If they performed better than the MOTORFIT [24] guideline average of that particular test, we assigned the value of 1; if they performed below the average of that specific test, we assigned the value of 0.

The sum of each score was calculated, and the Physical Fitness Index (PFI) was created. Thus, the sample was divided according to the median of PFI scores in High and Low PFIs (HPFI and LPFI, respectively). The High PFI group was composed of 66 participants (36 females), while in the Low PFI group there were 84 (40 females) students.

Rosenberg self-esteem questionnaire

The self-esteem (RSES [30]) questionnaire is a valid instrument developed by Rosenberg in 1966. Participants are asked to respond to ten questions concerning their perception of themselves on a 4-point Likert scale.

Free Memory Recall Test

Memory skills were tested through the Free Recall Memory Test [21], previously adapted and used by Pesce et al. [26] and Cole and Tomporowsky [5]. One hundred and fifty-six words were chosen according to their imaginable and concreteness indexes. Specifically, according to the Normative list of Paivio [23], words with an index of over 6.40 for both these indices were selected. A total of 177 words were selected to be suitable for the experiment. Afterwards, through the MATLAB software (MathWorks, version 2018a), the randomization of the words previously selected was performed, and three lists with the first 20 items were selected (Figure 1). With teachers, we discussed the lists of the words created. Thus, only one list was chosen. The experiment was programmed in Open Sesame (https://osdoc.cogsci.nl/ [20]), and the words were projected on the whiteboard of the classroom. They were black coloured with a height of 10 cm. The height of the words was determined according to the best visual angle. The students were seated at a variable distance. However, the height of the letters was sufficient for every participant to see adequately the words projected. Students had normal or corrected vision during and before the experiment. A series of 5 words were presented to explain the task and examine whether the participants were able to read the words projected.

The words were randomly presented. After 100 seconds, the last word was presented. The students could write down the word (immediate recall) on a blank piece of paper and after 12 minutes (delayed recall) on another blank piece of paper provided by the researchers/teachers. Participants had 120 seconds to write down the words. For each correct word reported on the blank sheet of paper, we assigned 1 point, also the words with plural and grammatical errors.

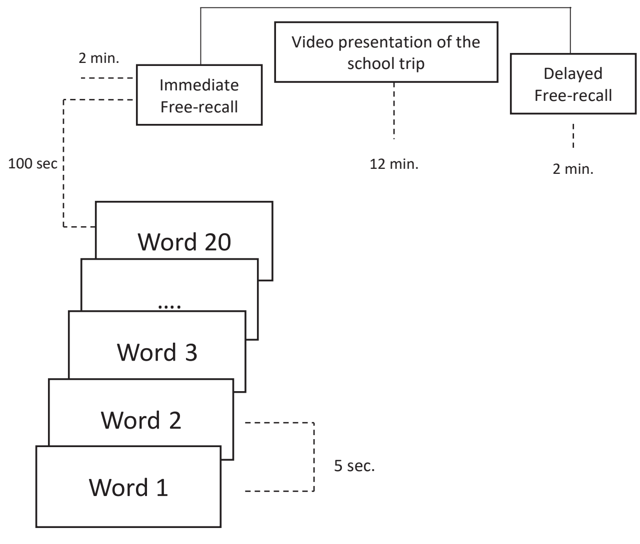

Figure 1. The scheme shows the procedure of the free-recall memory test. Modified figure on the basis of Pesce et al. [26]

General procedure

All the tests were performed during class hours and under the supervision of the physical education teacher and at least one researcher. Each student performed all the tests and the questionnaire in the same week. They filled the questionnaires (PAQ-C and RSES) and performed the Free Recall Memory Test in the classroom before moving into the gym, where they performed the physical strength and endurance tests, in this order.

Physical tests procedure

The MOTORFIT tests [25] were performed in the following way. Each class carried out the MOTORFIT tests during their physical education hours. Due to the organizational and time problems, each class performed the Cooper test together. The other tests, such as the long jump, the sit-up and the speed test, were performed individually.

Data analysis

Statistical analysis was conducted using the R Studio software (version 1.1.463, www.rstudio.com) [34].

A linear mixed-effects model was created with the "lme4" package [1] to analyze the memory skills of children. The dependent variable was the number of words recalled in each session. The independent variables were PFI (2 levels, HPFI and LPFI), PA (2 levels, HPA and LPA), Self-Esteem (HSEG, LSEG), Session (2 levels, Immediate Recall (IR) and Delayed Recall (DR) and Age Group (3 levels, G1, G2 and G3). When necessary for multiple comparisons, the Tukey post-hoc analysis was performed. Step-wise regression analysis was employed in order to find the final regression model. In order to reduce the non-normality of data, the score of the memory test was rank transformed.

Moreover, in order to check the linear mixed-effects regression, we conducted a MANOVA analysis following Pesce et al. [26]. The dependent variables were the scores of Immediate and Delayed Recall Sessions. The independent variables were PFI (2 levels, HPFI and LPFI), PA (2 levels, HPA and LPA), Self-Esteem (HSEG, LSEG) and Age Group (3 levels, G1, G2 and G3). When necessary, ANOVA post-hoc analysis was performed to analyze the possible differences between the groups.

Results

Step-wise regression revealed that a single factor PFI was significant ($F(1, 90) = 7.64$, $p = 0.007$) where HPFI remembered more words than LPFI (M = 11.14, SE = = 0.31 words vs M = 10.11, SE = 0.29 words) (Figure 2). Also the single factor PA was significant ($F(1, 90) = = 5.94$, $p = 0.02$). The LPA group performed slightly better than the HPA group (M = 10.88, SE = 0.29 words vs M = 10.20, SE = 0.31 words) (Figure 3). The Self-Esteem, Age Group and Session factors were non-significant ($F < 2.81$, $p > 0.05$).

MANOVA analysis revealed a significant main effect of PFI ($F(1, 87) = 3.29$, DPillai = 0.07, $p = 0.04$) as well as a significant single factor PA ($F(1, 87) = 2.53$, DPillai = 0.08, $p = 0.03$). Single factors Self-Esteem and Age Group were non-significant ($F < 1.79$, $p > 0.05$).

Post-hoc ANOVA analysis for the Immediate Recall Session revealed that PFI was significant ($F(1, 90) = 6.44$, $p = 0.01$), the performance of HPFI was better than LPFI (M = 11.08, SE = 0.42 words vs M = 9.96, SE = 0.37 words). In turn, a trend toward significance for a single factor PA emerged ($F(1, 90) = 3.19$, $p = 0.08$). LPA showed a better performance than HPA (M = 10.62, SE = 0.39 vs M = 10.23, SE 0.41 words).

Post-hoc ANOVA analysis on the Delayed Recall Session revealed no differences between HPFI and LPFI groups ($F(1, 90) = 1.60$, $p > 0.05$), while PA single factor was significant ($F(1, 90) = 6.88$, $p = 0.01$). In particular,

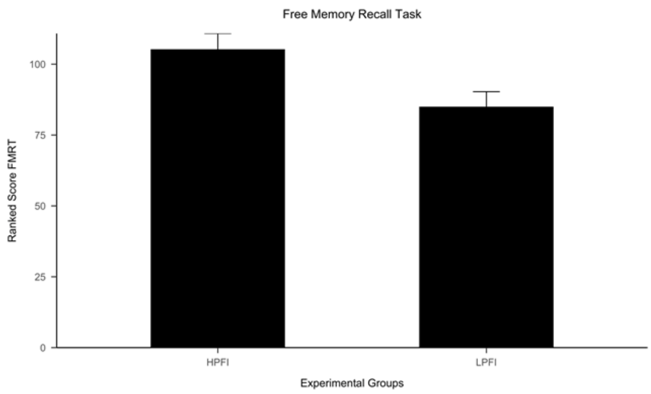

Figure 2. Significant differences ($p < 0.05$) between HPFI and LPFI in the Free Memory Recall Task

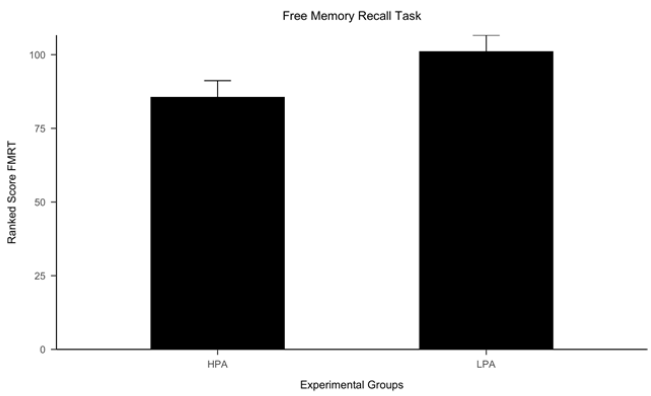

Figure 3. Significant differences ($p < 0.05$) between HPA and LPA groups in the Free Memory Recall Task

LPA performed better than HPA (M = 11.15, SE = 0.45 words vs M = 10.15, SE = 0.47 words).

Discussion

The effects of physical activity on cognitive functioning have been extensively studied throughout the years due to the great importance that can bring the development of an excellent physical education lesson. Thus, it can be transformed as a teachers' tool for the students' psychophysiological development [8].

Despite the benefit of these results, that should be considered for the development of the individual's physiological and psychological traits. In our society, the level of sedentary lifestyle is increasing, leading to some problematic issues. For instance, the risk of incurring some pathologies and decrementing our children's cognitive functions will be increasing [19, 43]. Thus, to avoid these issues, if well planned, physical education could be a low-cost instrument to employ to enhance well-being in our society.

In this experiment, we aimed at investigating the role of physical fitness and physical activity on memory functions in a large sample of pre-adolescent children. In particular, we tested the memory skills through the Free Recall Memory Test [5].

The Free Recall Memory Test analyzed both short-term and long-term memory. Participants had to remember a series of words immediately after their presentation (100 seconds) and after 12 minutes. The PAQ-C questionnaire [17] and the MOTORFIT test battery [25] were involved in analyzing the physical activity level and physical fitness of pre-adolescents, respectively. Furthermore, we controlled two confounding factors: self-esteem and age.

Overall, our results highlight the effect of physical fitness on memory skills, where pre-adolescents with high physical fitness performed better than students with low physical fitness. However, a no-interactive effect with the Session factor emerged. At the same time, results concerning physical activity showed an opposite effect, where the pre-adolescent participants who reported to be less physically active had a slightly higher performance compared to the students who reported to be more physically active. Furthermore, the analysis indicated that self-esteem did not influence performance actively. Thus, our results provide evidence that regular physical activity practice could enhance memory skills, and these results could extend the research of Pesce et al. [26]. Indeed, in contrast to Pesce et al. [26], our attention was focused on chronic exercise instead of the acute effect of physical exercise.

However, we found a discrepancy between physical activity and physical fitness. It is important to remember that the former is usually referred to as any bodily movement that requires energy expenditure, whereas the latter refers to a general state of well-being that brings a low risk of premature disease development and which participate in a plethora of physical activities [12]. Thus, it is possible that pre-adolescent children may incorrectly report the time spent in physical activity or even when the pre-adolescents reported it correctly, the activities performed during the day could not increase the general physical fitness. In the latter case, it is possible that the intensity of physical activities does not influence physical fitness; thus, if this is true, high-intensity exercises should be promoted.

Conclusions

According to the above-mentioned reviews, physical activity can enhance cognitive skills such as attention and perceptual skills. Moreover, it could improve academic achievements [28].

Instead, the studies focused on memory abilities are relatively controversial, and not all the investigations were able to find better children's memory skills improved by an increase in daily physical activity [35]. On the other hand, Pesce et al. [26] found that high-intensity physical activity and a single bout of activity can help to increase the memory skills of the children. In this study, we provided evidence that physical fitness can improve the memory function of children. Our results are in line with the results reported by Pesce et al. [26]. Together with their results, it may be assumed that physical fitness and chronic exercise may have a positive effect on short-term memory skills. Furthermore, our results are similar to the findings of Chaddock et al. [4]. A neuroscience study reported better memory performance for high physically fit children than less physically active ones. Moreover, the results highlighted that physical activity could modify the brain structure, increasing the hippocampus volume (for a review concerning the role of physical activity in the modification of brain structure, see [7]).

However, our results are in contrast with a recent investigation [32], where the positive relationship between physical activity and memory function was not found. Nevertheless, according to the authors, there are important limitations affecting the research that could lead to result inconsistency.

Furthermore, our research indicated an important discrepancy between physical fitness and physical activity level. Thus, to better understand this discrepancy, researchers should monitor both direct and reported measures. For instance, physical activity could be monitored through accelerometers [39] to understand better the effect of physical activity level on cognitive functions.

In conclusion, sport/physical activities could enhance some psychological aspects of pre-adolescents. The results are quite relevant for subsequent studies, where both cognitive abilities and psychological characteristics of the children should be taken into account. Furthermore, teachers should consider these results to employ physical education as a tool for other school subjects. For instance, physical education lessons could help students in memorizing poems and/or mathematical multiplication tables. To do that, teachers could create games or relay races that should be performed at high intensity. At the same time, participants during these exercises have to memorize a fair amount of information that should be recalled in the following exercise. In this way, children's aerobic fitness, general strength and cognitive functioning should be increased.

However, this research is not free of limitations; particular importance has to be given to the motivational aspects in the task and how to control them. Specifically, it is difficult to understand whether the students were more motivated to perform at their best; thus, in future research, their motivation should be analysed [21].

Future studies

Further investigations are required to gain insight into how physical activity could influence the cognitive aspects. It is possible to propose different physical activities to understand which activity could better enhance the participants' mental functions. Moreover, different cognitive and psychological tests should be necessary to examine all the components in depth. Again, in future studies it is recommended to better understand the effect of chronic physical activity according to different physical activities practised (e.g., open and closed skills activities), or to the teaching methods adopted by teachers (e.g. inductive and deductive methods). This could allow us to understand how physical education lessons should be planned and which teaching methods should be adopted by teachers in order to enhance cognitive functioning.

Another possible future investigation is to investigate within a longitudinal study how physical activity affects cognitive functioning at different stages of maturity, such as in adolescence and when the maturation is complete.

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