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COORDINATION TRAINING PROGRAM IMPROVES VISUOSPATIAL, ATTENTIVE AND MNEMONIC SKILLS IN ADOLESCENTS

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Abstract:
The aim of study was to investigate the effects of a coordinative abilities training program on the visuospatial, attentive and mnemonic skills. Sixty healthy students (14-15 years) were assigned to experimental group (n=30; 15M, 15F) that performed a coordinative training program, or control group (n=30; 15M, 15F) that received a training program designed to improve psycho-physical wellness. At baseline and after 12 weeks, two motor ability tests and a cognitive skills test were administered. After intervention, significant improvements in the Throwing and Catching test ($p < 0.001$, $d = 0.83$) and Corsi's block-tapping test ($p < 0.001$, $d = 1.25$) were detected only in the experimental group. Findings suggest that a coordinative abilities training program may improve visuospatial, attentive and mnemonic skills in adolescents. Physical education teachers, by a coordinative exercises program, might enhance the academic performances of the students. However, further research is necessary to investigate the effects of physical education interventions on academic achievement.

Keywords: physical education; cognitive skills; physical fitness; high school

1. Introduction

Physical exercise represents the most natural and productive opportunity for cognitive development, through which the adolescent experiences his psychophysical abilities. For this reason, many studies examined the importance of physical exercise and its contribution to the academic success of adolescents (Tomporowski, Lambourne & Okumura, 2011).

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To date, advances in neuroscience demonstrated the existence of links between physical exercise and cognitive performance and brain structure and function; this suggests that young people that experience physical education may improve mental acuity, skills and strategies (Donnelly et al., 2016). Research supports that cognitive performance improves with aerobic exercise that makes adolescents more efficient in reaction time tasks and flexible in attention-orientation tasks (Muiños & Ballesteros, 2014, 2018). Aerobic exercise is capable to induce transient effects on determined cognitive functions after a single session and persistent effects on cognition, beneficial forms of neuroplasticity and behavioral plasticity, following regular exercise over several months (Fernandes, Arida & Gomez-Pinilla, 2017; Huebner, Godde & Voelcker-Rehage, 2017). Some of these long-term effects include improvements in most executive functions, such as attention, working memory, cognitive flexibility, inhibitory control, problem solving, and decision making (Roth, Goode, Clay & Ball, 2003).

In addition to aerobic exercise, recent studies have found a link between coordinative exercise and cognition (Hotting et al., 2012; Kwok et al., 2011). Cognitive performance seems to be influenced by bilateral coordinative exercise that shows the effects already after short bouts of exercise (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro & Gunter Tidow, 2008), particularly in tasks that involving executive function (Yu-Jung, Tai Ting & Tsung-Min, 2013). Coordinative exercise with both low and moderate intensities may also increase the attentional resources and shorten the time needed for neurocognitive processing (Yu-Jung et al., 2013). Currently, despite these positive relationships between coordinative abilities and cognition, the influence of an acute bout of coordinative exercise on cognition have yet to be well determined. This is especially because not all research has supported these results (Tremblay, Inman & Williams, 2000).

The cognitive skills training correlated to coordinative abilities is designed to prepare both the athlete and the student to be able to: sustain attention and focus; screen out irrelevant stimuli and to focus on the important aspects of a situation; shift quickly and smoothly from one activity to another; create a mental map of the state of gameplay; and take more information in at a glance with the effective use of peripheral vision, particularly in combination with visual discrimination (Hahn & Buttaccio, 2017). For all of these reasons, the effects of coordinative exercise on cognition could have important implications to improve the academic performance of the students and prevent academic failure through the development of new education models.

Therefore, in this study, we analyzed the benefits of coordinative physical exercise on cognition and wellbeing, based on the assumption that exercise is closely linked to visuospatial abilities, attentive capacity and mnemonic skills of the adolescents. First, we used two standardized motor tests to assess the baseline level of the students. Next, we conducted an experimental study to investigate the effects of the coordinative abilities training on cognitive function and hypothesized that coordinative exercise would improve cognitive performance.

2. Material and Methods

2.1 Study Design

In this research, a randomized controlled study design was used to investigate the effects of a coordinative ability training program on the visuospatial, attentive and mnemonic skills. The study was a high school-based intervention; the evaluation regarded 24 lessons in 12 weeks monitoring the students at the 1st and 12th week, respectively. Data were collected and recorded at baseline (pre-test) and after 12 weeks (post-test). After pre-test and randomization, the experimental group followed a coordinative abilities training protocol, designed for the improvement of cognitive skills, and the control group received a group training program for general psycho-physical wellness. To allow statistically meaningful comparisons between different type of activities, students were classified as participants in activities that shared similar characteristics.

2.2 Participants

Sixty healthy male and female adolescent students, aged 14-15 years (30 males and 30 females, age 14.4 ± 0.5, body height 167.5 ± 7.4 cm, body mass 60.1 ± 9.39 kg, BMI 21.36 ± 2.0 kg, mean ± SD), were recruited to participate to the study. The participants had the same socio-economic background and at the time of data collection, attended the first year of high school. Power calculations were conducted to determine the sample size required to detect changes in the dependent measures resulting from the intervention. An a priori power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) with an assumed type I error of 0.05 and a type II error rate of 0.10 (90% statistical power) was calculated and revealed that 46 participants in total would be sufficient to observe medium ($f = 0.25$) 'Time x Group' interaction effects.

Participants were matched into pairs based on gender and randomly allocated into an experimental group (n = 30) who received coordinative abilities training, or control group (n = 30) who received a group training program designed to achieve general psycho-physical wellness. Any student older than 15 years of age, with an individual education plan as a result of disability or who had an orthopaedic condition that would limit their ability to perform exercise, were excluded from the study. The study was conducted from March to May 2019 and all participants and their parents received a complete explanation in advance about the purpose of the experiment, its contents, and safety issues based on the Declaration of Helsinki, and parents provided their written informed consent before the study.

2.3 Procedures

The intervention was administered at a local public school during normal school days. Both the experimental and control group met twice per week for 60 minutes each day (approximately 40 minutes of activity time), under carefully monitored and controlled conditions. At least two days before the experiment began, subjects were led to the local school gym to undertake two standardized assessment motor tests. The motor tests were used to determine the starting level about the coordinative abilities of each participant. Furthermore, was conducted an assessment cognitive test used to investigate visuospatial abilities, attentive capacity and mnemonic skills of each student. The students were divided into two groups and testing took 30 minutes for each participant. The students were tested individually. The same tests were performed two days after the end of the training period, to allow pre- and post-testing data collection and to evaluate the effects of the intervention program. Each session of the intervention program involved the following stages: warm-up for 10 minutes, perform the main exercises for 25 minutes, and cool down for 5 minutes. Specifically, warm-up consisted of low to moderate intensity aerobic exercise, instead, the exercise phase was designed to reach and emphasized different coordination movement.

All study procedures were performed within a school gym. Initial and final examinations of physical fitness, cognitive testing and exercise program were obtained during the weekday morning, at the same time of the day and under the same experimental conditions. Each task item was explained and demonstrated before the participants started. Each participant was given verbal encouragement and support throughout the testing. If the participants made a procedural error, instructions and demonstrations were repeated and the participant made a new attempt. No stimulating food or soft drink was ingested before testing, but students maintained their normal intake of foods. The participants wore clothing appropriate for physical activity and sports shoes throughout the testing. The exercise program and all measurements for testing were instructed, performer and supervised by the same physical education teacher. All trials were performed using a standardized test protocol, observing the same conditions. After the intervention, the physical education teacher was also asked to give a judgment on the intervention program and the behaviour shown by children.

2.4 Measures

A. Slalom Bask Test

The first motor test used in the present study, called "Slalom Bask Test" (Donati, Lai, Marcello & Masia, 1994), was used to measure agility and coordinative abilities. The test assesses total body movement, requiring participants to palm a basketball and dribble around a set obstacle course as quickly as possible (Dajic, Kapidic & Kuna, 2017). It started with a 5 min warm-up. After the warm-up, subjects were instructed about the exercise to be performed. Both verbal instructions and demonstrations were provided using a standardized protocol and included verbal encouragements throughout all tests to ensure maximal effort. Every test started with a habituation period during which participants were familiarized with the test, with 5 minutes of resting before starting the actual measurement. To perform the test, a starting line and an ending line were drawn on the floor at a distance of 20 meters. 6 cones were put on the same road at a distance of 3 meters from each other. The first cone was at 3 meters from the starting line. Subject started behind the starting line and went towards slaloming around cones and palming with one hand. If the subject lost the ball it had to be recovered and the exercise resumed from where it has been interrupted. Participants had to turn at the end, sprint back, and repeat the same procedure once. The main outcome measure was manually recorded time. The time (s) was taken with the hand-held stopwatch and noted, and the best trial was recorded (ICC: pre = 0.85; post = 0.88).

B. Throwing and Catching Test

The second motor test, called "Throwing and Catching Test" (Buonaccorsi, 2001), started after all participants finished the first, with 5 minutes of resting between the two. The object of the test is to monitor the ability of the athlete's vision system to coordinate the information received through the eyes to control, guide, and direct the hands in the accomplishment of catching a ball (hand-eye coordination) (Dirksen, De Lussanet, Zentgraf, Slupinski & Wagner, 2016). At the end of a short warm-up, the subjects were instructed about how to perform the exercise. After a demonstration, in which participants were instructed to throw and catch the rhythmic ball as fast as possible, a short test phase of 5 throws and catches was carried out immediately before test start. To perform the test, a line was drawn at 3 meters from the wall and another one was drawn on the wall at a height of 1,50 meters (strictly indicative because the throw could be done at any height). The subjects were on the back of the line and threw the ball against the wall trying to get it back before it falls to the floor. The throw was valid if the ball didn't touch the ground and the subject didn't go over the line. The test ended up when the subject completed 10 valid throws and catching. The time (s) was taken with the hand-held stopwatch and noted, and the best trial was recorded (ICC: pre = 0.89; post =0.93).

C. Corsi's Block-Tapping Test

The cognitive assessment was conducted through the Corsi's block-tapping Test, that is a neurocognitive test used for the spatial and visual working memory assessment, which are extremely important in certain cognitive complex tasks, both in motor and school environment (Kessels, van Zandvoort, Postma, Kappelle & de Haan, 2000). Corsi's block-tapping test represents a valid research instrument to investigate visuospatial abilities, attentive capacity and mnemonic skills (Kessels et al., 2000). It consisted of a series of nine identical blocks arranged irregularly. The sides of the cubes facing the examiner were numbered 1 to 9. The examiner tapped the block in randomized sequence in increasing length, usually starting with two blocks. After each tapped sequence, immediately the subject attempted to reproduce it. The highest successful recall streak was called the Corsi span. The test began with a sequence of two units. The examiner presented 3 sequences for each series. If the subject exactly reproduced two sequences on three, a new increasingly long sequence was presented. Each time a maximum of five equal-unit sequences was tapped out. The test ended when the subject gets wrong 3 sequences of the same length. Corsi's test score was the longest number of items correctly reproduced at least two times and it represented the subject's memory spatial span. Testing time was between 10 to 15 minutes, including instruction and practice phase. Assessment protocol has been proposed before the beginning of the phase of observation and at the end of the intervention, to analyze any Corsi’s test score changes.

2.5 Exercise Training Intervention

The exercise training program has been described before starting to each participant. Both groups undertook the supervised exercise sessions in a school gym twice weekly for 12 weeks and the duration was approximately 60 minutes each time. The entire intervention program was implemented in 24 training session and each session was aimed at keeping the children effort at a medium-high level and to achieve a high volume, intensity and density of work. The rest period was very short in low-intensity activities, whereas it was complete lasting 2 to 3 minutes in activities of medium to high intensity. A physical education teacher supervised and performed the training exercises program with the collaboration of an experienced instructor who is graduate in physical education. To encourage the learning and achieving the objective of the study, the teacher has created a fun and active learning environment, used appropriate teaching styles and strategies, and developed each session using multiple intelligences (Ayers & Sariscsany, 2010).

Each training session started with a brief full-body dynamic warm-up and ended with cool-down exercises, for both groups. Warm-up included marching in place, wide toe touch, leg swings, arm swings, shoulder rotations, hip rotations, push-ups, lunges, walking jacks, jumping jacks, hip circles and bodyweight squats.

The experimental group was subjected to coordinative abilities training, following an exercise protocol designed for the improvement of cognitive skills. The protocol included:

- slalom circuits
- dexterity circuits
- jump rope exercises
- throwing and catching exercises
- static and dynamic balance exercises
- jumps and direction changes exercises
- rhythm exercises
- hand-eye coordination and foot-eye coordination activities
- motor responses exercises
- motor differentiation exercises

Control group was subjected to a group training program for general psychophysical wellness, followed the protocol described below:

- bodyweight exercises
- group exercises with small training gear
- joint mobility exercises
- calisthenics basic workout
- Pilates exercises

Following completion exercise programs subjects ended their training with a cool-down program. Cool-down consisted in 5 minutes of a variety of static stretching exercises which included glute stretch, standing quad stretch, side bench stretches, arm-cross shoulder stretch, overhead triceps stretch, lower back stretch, abdominal stretch and child's pose. It was important for muscles relax and for the improvement of joint range of motion.

2.6 Statistical Analysis

Statistical analyses were carried out using SAS JMP® Statistics (Version <14.3>, SAS Institute Inc., Cary, NC, USA, 2018). Data were presented as group mean values and standard deviations and checked for assumptions of normality (i.e. Shapiro-Wilk test) and homogeneity of variances (i.e. Levene test). An independent sample *t*-test was used to evaluate group differences at baseline. A two-way ANOVA (group (experimental/control) × time (pre/post-intervention)), with repeated measures on the time dimension, was conducted to examine the effect of the Multilateral Training on all dependent variables. When 'Group x Time' interactions reached the level of significance, group-specific post hoc tests (i.e., paired *t*-tests) were conducted to identify the significant comparisons.

Changes were calculated as [posttraining value – pretraining value]. The reliabilities of motor test measurements were assessed using intraclass correlation coefficients (ICC); scores from 0.8 to 0.9 were considered as good, while values above > 0.9 were considered as high (Vincent & Weir, 2012). Partial eta squared (η^2_p) was used to estimate the magnitude of the significant 'Time x Group' interaction and interpreted using the following criteria: small ($\eta^2_p < 0.06$), medium ($0.06 \leq \eta^2_p < 0.14$), large ($\eta^2_p \geq 0.14$). Effect sizes for the pairwise comparisons were determined by Cohen's *d* and interpreted as small ($0.20 \leq d < 0.50$), moderate ($0.50 \leq d < 0.79$) and large ($d \geq 0.80$) (Cohen, 1992). Statistical significance was set at $p < 0.05$.

3. Results

3.1 Overview

Physical education teacher gave a positive opinion on feasibility, repeatability and utility of the intervention program. Furthermore, he observed enthusiasm in participation, an improvement in relational dynamics (e.g. increased socialization and less aggressive behaviour) and a growing interest in physical activity by the participants. All participants received the treatment conditions as allocated and the average adherence to the intervention was 89.6 % (21.5 actual sessions / 24 intended sessions). No injuries were resulting from either training program. The groups did not differ significantly at baseline in anthropometric characteristics ($p > 0.05$). Pre- and post-intervention results for all dependent variables are presented in Table 1.

Table 1: Changes after 12-week coordinative abilities training program

	Experimental Group (n = 30)			**Control Group (n = 30)**		
	Baseline	**Post-test**	**Δ**	**Baseline**	**Post-test**	**Δ**
Motor Ability tests						
Slalom Bask Test (s)	15.90 (5.33)	14.40 (6.21)	-1.49 (4.59)	18.27 (5.59)	17.29 (6.00)	0.97 (3.58)
Throwing and Catching Test (s)	21.40 (6.91)	19.32 (5.70) †*	-2.08 (2.49)	23.04 (6.56)	22.77 (6.73)	-0.27 (1.16)
Cognitive Skills test						
Corsi's Block-Tapping Test (n)	3.93 (1.11)	5.53 (1.59) †*	1.60 (1.27)	4.33 (1.37)	4.70 (1.47)	0.36 (1.12)

Notes: values are presented as mean (± SD); Δ: pre- to post-training changes; †Significant 'Group x Time' interaction: significant effect of the intervention ($p < 0.001$). *Significantly different from pre-test ($p < 0.001$).

A. Motor Ability Tests
A two-factor repeated measures ANOVA found significant 'Time x Group' interaction for the Throwing and Catching Test ($F_{1,58} = 12.97$, $p < 0.001$, $\eta^2_p = 0.18$, large effect size). Post hoc analysis revealed that experimental group made significant improvements in the motor abilities performance ($t = -4.57$, $p < 0.001$, $d = 0.83$, large effect size), whereas no significant changes were found for the control group ($p > 0.05$).

B. Corsi's Block-Tapping test
A significant 'Time x Group' interaction was also found for the Corsi's block-tapping Test ($F_{1,58} = 15.72$, $p < 0.001$, $\eta^2_p = 0.21$, large effect size), with the experimental group that showed significantly greater improvements in cognitive skills performance ($t = 6.87$, $p < 0.001$, $d = 1.25$, large effect size) than control group ($p > 0.05$).

4. Discussion

This research aimed to investigate the relationship between physical fitness and cognitive skills, in particular, the effect of a 12-week coordinative exercise intervention program on visuospatial abilities, attention performance and mnemonic skills in a school setting. Two groups of adolescent students performed a coordinative exercises intervention or standard physical education program and were assessed by two standardized motor tests and a cognitive test. In this study, the results revealed that a 12-week of coordinative exercise intervention program significantly improved cognition. This supports the idea that the coordinative character of the exercise is responsible for the significant difference between the two groups.

The first important finding of the present study concerns the positive impact that coordinative exercise appears to have on visuospatial abilities. This was confirmed by the fact that the group who practiced coordinative exercise showed the better ability of the vision system to coordinate the information received through the eyes to control, guide and direct movement, than the control group. This finding reveals the presence of neurocognitive effects of the training on the visuospatial task. Perhaps the most striking finding of the present study was the capacity of the coordinative exercise program to improved attention span and mnemonic abilities. This result was a consequence of the fact that the experimental group manifested a better performance in the long-term retention of the learned ability. This type of exercise appears to improve cognitive learning through optimization of visual and spatial working memory. These changes allow the selection of a more appropriate cognitive control strategy (Ludyga, Gerber, Kamijo, Brand & Puhse, 2018).

In contrast to the positive effects founded, another important finding of our research concerns the null impact that coordinative exercise appeared to have on the improving agility and total body movement compared to the control group. This was confirmed by the fact that, compared to the control group, the experimental group showed the same results in completing its motor tasks. This result seems to be in conflicts with the nature of the coordinative exercise. Most likely, the acquisition and retention of the coordinative tasks, assessed through the test of agility and total body movement, require a longer period of training. Therefore, it would be appropriate to organize more complex forms of exercise, such us multilateral training (Fischetti & Greco, 2017; Fischetti, Acella, Cataldi, & Greco, 2017). In this way, the consolidation process of the agility might require a longer lead time than attention span and mnemonic abilities, which are more sensitive to exercise. Future studies will be needed to compare, extending the duration of related work, the time of acquisition, retention, stabilization and decay of the attention span, mnemonic abilities and coordinative abilities.

In connection with what was found in this study, the findings are in line with previous studies displaying correlations between coordinative exercise and cognition (Budde et al., 2008; Planinsec, 2002; Uhrich & Swalm, 2007; Yu-Kai, Yu-Jung, Tai-Ting & Tsung-Min, 2013). Several studies, which focused on the association between physical exercise and cognitive function during adolescence, have documented a positive relationship between physical fitness and academic achievement (Donnelly & Lambourne, 2011; Shephard, LaVallee, Volle, LaBarre, & Beaucage, 1994; Shephard, 1997). Many other studies have demonstrated that coordination training elicits a cascade of neurological changes in the hippocampus linked to memory consolidation and skilled actions (Gomez-Pinilla & Hillman, 2013; Rehfeld et al., 2017). The coordinative exercise training program is capable of optimizing brain networks (Phillips, Baktir, Srivatsan & Salehi, 2014) involved in working memory, attention span and visuospatial coordination (Hötting & Röder, 2013; Niemann, Godde & Voelcker-Rehage, 2016; Voelcker-Rehage, Godde, & Staudinger, 2011). It is also capable of creating a reserve of precursor cells that influence individuals' learning capabilities throughout the whole of their life span (Kopp, 2012). Additionally, coordinative exercise with both low and moderate intensities could increase the allocation of attentional resources and shorten the time needed for neurocognitive processing (Yu-Kai et al., 2013). Rogge et al. (2017) suggested that a combination of coordination exercise and balance training improved memory and spatial cognition among healthy adults (Dunsky, 2019). Furthermore, coordinative abilities training was associated with high activation in visual-spatial networks in the brain of older adults (Dunsky, 2019; Voelcker-Rehage et al., 2011; Niemann et al., 2016). Therefore, based on what was discussed, it is possible to claim that the behavioural results of the previous research support our hypothesis, in which students had significantly improved cognitive function following the coordinative exercise intervention.

Despite the contribution regarding the relationship of physical fitness to academic achievement, some limitations are to be considered in this study. First, the small sample size due to the difficulties in recruiting motivated students to participate. Second, the sample was recruited from a population of students at a single, large, public school, thus, the results may not be generalizable to students at other institutions or with other demographics. A third limitation was that the effect of exercise on mood and fatigue, which are both sensitive to acute exercise and could impact memory and attention, was not assessed. Future research would need to examine these issues to explain these variables. However, the results obtained could provide important indications for future studies. The strength of this study was that our results extend the knowledge base on coordinative exercise and add new evidence indicating that the benefits of this intervention on memory, attention and visuospatial span consolidation might generalize to other forms of cognitive skills.

5. Conclusions

Our results suggest that coordinative abilities training intervention can be used to enhance cognitive skills through an optimization of the consolidation of coordinative abilities. This positive effect of coordinative exercise has significant perspectives in both sports and school achievement. These findings could inform teachers that coordinative exercise, carried out twice per week, in 60-min sessions for 12 weeks might serve as a useful intervention to improve the academic performances of adolescent students. More studies will be required to determine if these promising results will create new perspectives in the search. Only then, we will be able to be accurate in the prescription of personalized coordinative exercise interventions to optimize cognitive abilities. Therefore, we believe that further research is necessary to better determine the role that physical education has on academic achievement. Most importantly, it would be to know the potential influence of a coordinative ability training program on the brain, in particular, on the increased synthesis and expression of BDNF (Brain-Derived Neurotrophic Factor). Specifically, it should be examined the relationship between this neurotrophin and both fitness and cognitive performance. Physical exercise would seem to lead a significant increase of BDNF expression (Jonasson et al., 2017), which can produce an improvement of visual, physical, and cognitive stimulation that leads to more neuronal activity and synaptic communication (Håkansson et al., 2017). Additionally, future research should progressively reach higher levels of challenges, by finding more complex forms of exercise involving both motor and cognitive tasks.

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