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A single bout of physical exercise does not affect young adults' executive functions

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Summary

Study aim. The purpose of the current study is to determine the impact of single bouts of physical exercise of different duration and intensity on young adults' executive functions.

Material and methods. The study employed 81 participants (37 females, 44 males) ranging between 19 and 39 years (mean age: 24.6 ± 4.08 years; mean height: 168 ± 9.67 cm; mean weight: 67.2 ± 13.0 kg). The executive functions were assessed through the Stroop task, the Tower of London test, and the Corsi block test. Participants were randomly assigned to one of the three experimental conditions (30-second Wingate test condition, an incremental intensity exercise test, and a submaximal constant-intensity test) or the control group.

Results. For all the conditions, repeated measures ANOVA revealed a significant effect of time on executive function performances, meaning that participants improved their performance between pre-test and post-test, while the interaction time x activity was in the expected direction but nonsignificant.

Conclusions. Apparently, a single, brief, high-intensity bout of exercise has no effects on young adults' cognitive functions, but the same experiment should be replicated with a bigger sample.

Keywords: Executive functioning – Stress condition – Exercise intensity – Cognition – Exercise programme

Introduction

A lifestyle characterized by regular exercise has beneficial effects on mental health, through the maintenance of high levels of self-esteem, balanced mood regulation and cognitive performances, specifically referring to executive functioning [11, 17].

According to Adele Diamond's model [15], three main functions are considered under the general executive function category: inhibition, working memory and cognitive flexibility [28, 30]. The combination of general executive functions results in higher-order executive functions, such as reasoning, planning and problem solving. Specifically, some studies have assessed the influence of exercise on inhibition, defined as the capacity to suppress irrelevant information and response tendency [23, 33]. Peruyero et al. [33] analysed the effect of three physical education classes with the same duration but different intensities on adolescents' inhibitory control performance in an ecological environment, finding that the inhibitory control increased greatly in the group with the highest exercise intensity. This result is in contrast with other studies showing that low-intensity exercise interventions, induced by a slight increase in heart rate during and after exercise (from 90 to 120 bpm), allow greater information processing, while higher intensity exercise interventions, obtained by a long-lasting exercise (more than 15 minutes with a heart rate greater than 160 bpm) impair the performance on tasks requiring a certain amount of information processing [20]. During the last decade, the impact of physical exercise has been widely assessed for potential improvements in cognitive performance [8, 13, 41], relating to a sport situation during a match or

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competition [3, 35], or to the academic outcomes [22]. Currently, scientific literature is focusing on the effects of physical activities on executive functions [25, 42], which are higher-order cognitive abilities that coordinate basic cognitive functions and emotional regulation involved in goal-directed behaviours [18].

A general improvement in working memory was found after acute aerobic exercise of moderate intensity, but not after a standard session of acute resistance exercise [34]. In contrast, Hsieh et al. [24] found that after an acute session of resistance exercise in young and older males, working memory increased in both age groups, with a larger effect in older adults regarding complex memory demands. Moderate exercise has also been connected to an increase in working memory in post-stroke patients [31], and an increase in brain-derived neurotrophic factors, which may also explain why such an increase in working memory occurs [21]. Less is known about the effect of physical exercise on visuospatial working memory. A study by Cooper et al. [14] analysed the effects of a sprint-based exercise on different aspects of cognition. However, the results showed that visuospatial memory was unaffected by the exercise intervention. Results in contrast to those of Northey et al. [32] indicated a moderate increase in all cognitive components after both aerobic and resistance exercise. Regarding the impact of physical exercise on higher-order executive functions, the ability to plan and problem-solving seem to be improved by moderate-to-vigorous exercise, while no differences were found in the violation and time-related scores [10].

Most of the above-reported studies investigated the influence of physical activity through repeated exercises, but few studies have analysed the impact of a single bout test on executive function task performance. For example, a work from Schwarck et al. [36] examined the impact of a single bout of physical exercise (an acute exercise of 20 minutes) on executive function task performances (attention, inhibitory control, cognitive flexibility), hypothesizing that it could improve people's performance, especially in the case of single sessions of moderate intensity, compared to high-intensity exercise. Moreover, this study analysed the potential differences in cognition between respondents, who were people showing physical improvement, and non-respondents, whose performance did not change or got worse. The results of this study showed no significant effect of a single bout of physical exercise on cognition, but instead highlighted that only in one of the cognitive tests performed (i.e., the Trail Making Task) after a moderate intensity condition exercise did people perform better than those from the high-intensity condition.

Finally, no studies have been found on the impact of an immediate single bout, maximal intensity physical exercise on cognitive performance.

For this reason, the present study aims to determine the impact of single bouts of physical exercise of different duration and intensity (30-second Wingate test, incremental intensity exercise test condition and submaximal constant-intensity exercise for 20 min at 60% HR max condition) on young adults' executive functions (inhibitory control, visuo-spatial working memory, plan and problem solving). Specifically, in line with scientific literature, we expected an improvement in cognitive functioning in the 60% HR condition, then in the incremental intensity exercise test . Since this is the first study on the impact of an immediate single bout of maximal intensity, we do not hypothesize a direction of the effect (improvement/impairment of executive functioning).

Material and methods

Participants

The sample was composed of 81 participants, whose age was between 19 and 39 years (age: 24.6 ± 4.08 years; height: 168 ± 9.67 cm; weight: 67.2 ± 13.0 kg). Each participant signed a consent form, and this condition was mandatory to take part in the study.

The sample size was recruited within and outside the universities, making a social media announcement about the possibility to participate in the study. For participation in the study, young adults from 18 to 40 years were selected. Only participants who were able to perform the required motor and cognitive tasks were considered. Participants were excluded if medical issues were reported, in particular muscular, visual, or hearing disorders or mental disabilities.

The principles of the Italian data protection (196/2003) were guaranteed. The Ethical Committee of the University of Novi Sad approved the project (Ref. No. 128/2018). The study was undertaken in accordance with the deontological norms laid down in the Helsinki Declaration (Hong Kong revision, September 1989) and the European Union recommendations for Good Clinical Practice (document 111/3976/88, July 1990).

Procedure

Data were collected at the Sports and Exercise Science Research Unit of the University of Palermo (Italy) and the Sport Faculty of Novi Sad (Serbia), in an environment with a constant temperature and isolated from noises. All the participants were first required to sign an informed consent form. After the signature, participants were briefly instructed regarding the procedures they had to undergo.

Participants were required to complete a cognitive assessment battery, consisting of three cognitive tests (Stroop task, Tower of London test, Corsi block test), and were randomly assigned to one of other three physical tasks (hereinafter, experimental group or EG), namely, the 30-second Wingate condition (EG1 = 22 participants), the maximal aerobic test condition (EG2 = 20 participants) and the submaximal constant-intensity test (EG3 = 23 participants). Participants from the control group (CG = 16 participants) completed the cognitive assessment and were required to do ordinary life tasks for one hour, after which they were administered the cognitive test battery again.

The three single bout exercise protocols (EG1-2-3) were selected according to the different energy systems that are predominantly involved. The EG1 is well known to be an appropriate test for the anaerobic system/power [5]. The EG2 test stresses mainly the aerobic system pathways [1], and finally, the EG3 test is a maximal cardiorespiratory fitness test that mainly elicits the maximal metabolic capacity of the participants [1].

The EG1 participants had to initially perform the cognitive evaluation. Subsequently, they had to perform the required exercise condition, a Wingate anaerobic power test, and after 3 minutes of recovery a second evaluation of the cognitive measures was assessed. The EG2 participants had to complete the cognitive evaluation. Afterward, they had to perform an incremental intensity exercise test and a second evaluation of the cognitive measures was assessed after 3 minutes. The EG3 participants were evaluated on two consecutive days. On day one, the participants had to perform the exercise condition of the incremental intensity exercise group. During the second day, the cognitive assessment was administered. After the cognitive assessment, the group had to perform a submaximal constant-intensity test at 60% of their maximum heart-rate for 20 minutes. At the end of the test they had to recover for 3 minutes before performing the post cognitive assessment. The control group was asked to do ordinary life tasks between the pre-test and the post-test cognitive assessment (such as studying or listening to music) for one hour. Figure 1 visually indicates the study design and procedures.

In all the conditions, at t_1 participants were administered the cognitive tests in randomized order, while at t_2, cognitive assessment was repeated in the same order as the first assessment.

Measures

Cognitive assessment

Executive functions were detected through the Stroop task, in relation to inhibitory function, the Tower of London test, concerning planning and problem-solving skills, and the Corsi block test for visuospatial working memory. All of these instruments were administered through Milliseconds Inquisit 5 (Millisecond Software).

Stroop task. The Stroop task was used to detect the inhibitory control function [39]. In this study, the Stroop task was administered through the Millisecond library *Color Word Stroop with Keyboard Responding*. Participants are asked to indicate the colour of the word, but not its meaning, by pressing the key corresponding to the assigned colour as fast as they can, trying to make as few mistakes as possible. The Stroop task consists of three categories of trials: the congruent task, when word meaning and word colour are the same; incongruent task, when word colour

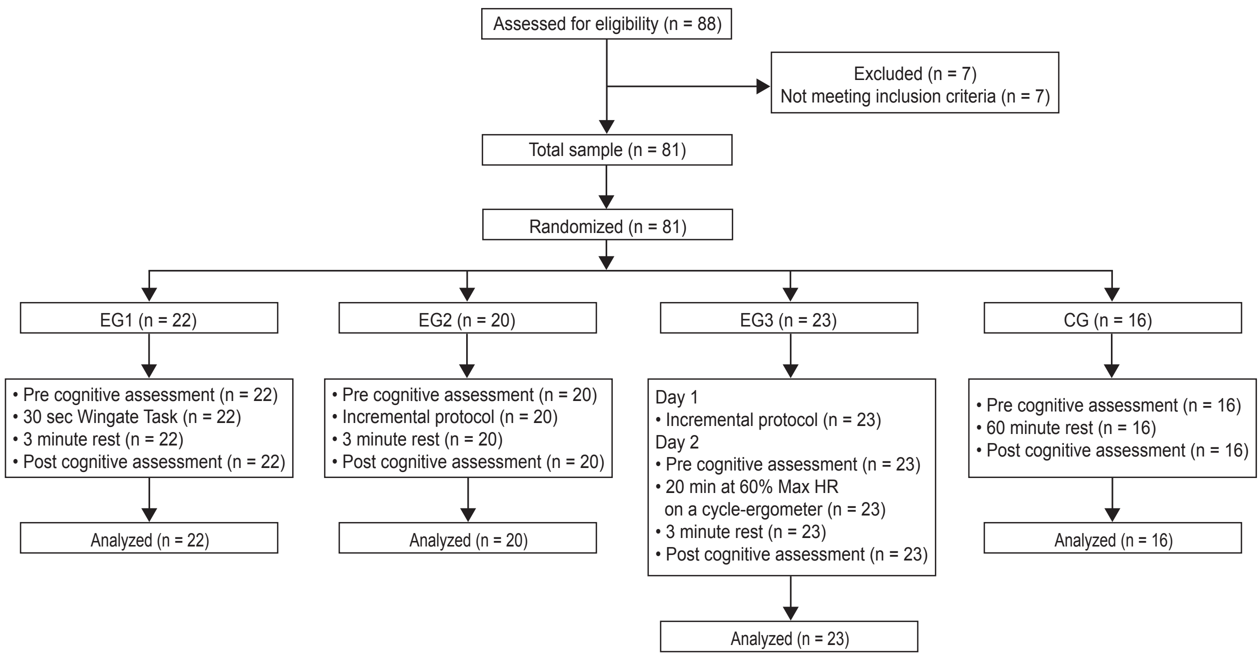

Fig. 1. Research design, the figure visually indicates the study design and procedures

and the word meaning are not the same; control trials when only coloured rectangles were presented. From the combination of the conditions, 84 trials resulted: 4 colours (red, green, blue, black) × 3 colour-stimulus congruency (congruent, incongruent, control) × 7 repetitions. The task requires approximately 2 minutes to complete.

In the current study, three reaction times were reported: congruent reaction time, incongruent reaction time and colour reaction time (the original term should be "control reaction time", but it was changed in order to distinguish it from the control group). The interference score was calculated by the logarithmic difference between incongruent reaction time and control reaction time, as suggested by MacLeod [29].

Tower of London test. The Tower of London test was used to assess planning and problem-solving capabilities [37]. It detects the ability to generate a sequence of operations that can be accepted or withdrawn by the individual according to the rated probability of success. In this test, participants see the blocks in a specific order and they have to reproduce the same sequence with the blocks put in a scrambled order. Participants are not able to access the subsequent trial until the previous one is successfully completed. The sum of individual problem scores defines the total score. The maximum achievable score is 36. The task requires approximately 10 minutes to complete.

Corsi block test. The Corsi block test was used for the assessment of visuospatial working memory [26]. It consists of a black screen showing nine boxes, lighting up in a pre-fixed sequence (constant across participants) and each participant is asked to click on the boxes in the same order the blocks light. The first sequence was made up of two blocks lightning up. The subsequent sequence increased the lightning up to 9. Participants had two chances to reproduce the sequence. If they ended a sequence correctly, a different one started. The total score is obtained through the product between the total span (from 2 to 9) and the number of correctly reproduced sequences, until the individual makes a mistake. The task requires approximately 5 minutes to be completed.

Motor Tasks

Wingate anaerobic power test (EG1). The standard procedure for the Wingate anaerobic power test, which is a valid test able to detect anaerobic capacity and to determine peak and mean power values [5, 38], was performed, by EG1, through a cycle sonar Ergomedic 894E Peak Bike (Germany). After a low-intensity warm-up which lasted thirty seconds, the participants were instructed to cycle at maximal speed. This task was performed without any external resistance. After three seconds one of the investigators inserted in the ergometer a standard resistance calculated for each participant (7.5% of each participants' body weight); each participant had to cycle for 30 seconds at maximal velocity. Each participant at the end of the test reached maximal HR and exhaustion; software recorded and stored resistance and cycle velocity variations during the test.

Incremental intensity exercise test (EG2). A modified FTP cycling ramp test was adopted in order to achieve an incremental intensity exercise. Such a protocol was performed by EG2 and EG3. The cycling task was performed on a cycle Cosmed Ergoline ergoselect 100k cycle-ergometer. The aerobic condition consisted of cycling on the cycle-ergometer at a constant cadence between 65 and 70 repetitions per minute (RPM). The test started at a resistance point offered by the cycle-ergometer of 50 W. After a 2-minute warm-up at 65-70 RPM and 50 W, an additional resistance of 25 W was added every 2 minutes, until the participant was able to maintain a cadence between 65 and 70 RPM. The peak effort and test conclusion were obtained when the revolutions dropped below 55 RPM or if the participant voluntarily interrupted the test due to fatigue. Heart rate was recorded during the entire exercise condition.

Submaximal constant-intensity test (EG3). A submaximal constant-intensity cycling condition was also adopted for EG3. The cycling task was performed on a cycle Cosmed Ergoline ergoselect 100k cycle-ergometer. The exercise condition consisted of cycling for 20 minutes at 60% of each participant's HR, at a cadence between 65 and 70 RPM. The maximal HR of each participant was obtained through the procedure above described for the incremental intensity exercise test. The test started at a resistance offered by the cycle-ergometer of 50% of the maximum aerobic power of each participant, which again was obtained through the procedure above described for EG2. The cycling power output was adjusted during the 20-minute task in order to allow each participant to maintain the HR at 60%Max, while cycling at a steady state. The cycling condition ended after 20 minutes. Every participant was able to complete the test.

Data analysis

Data were analysed through the R software (version 3.5.1). Descriptive analyses concerning age, height, and weight were performed. One-way ANOVA was performed for descriptive measures, to detect any potential influence of these variables across groups. Subsequently, repeated measure ANOVA considering time (pre-test vs post-test) x activity (Wingate vs. maximal vs. 60% HR max vs. control) was performed for all the groups to detect the effect of physical exercise on executive function performance, the learning effect across conditions, and the influence of descriptive measures. The figures were created through GraphPad Prism (Vers. 6.0) and difference between pre-test and post-test conditions across groups for all the cognitive measures were reported.

Results

The sample consisted of 81 participants (37 females, 44 males). Descriptive statistics concerning age, height and weight are shown in Table 1, while descriptive statistics of pre- and post-test scores are shown in Table 2.

No significant differences were detected across the four groups for height ($F_{3,77} = 0.07$, $p = 0.97$) and weight ($F_{3,77} = 0.40$, $p = 0.75$), but significant group differences were detected for age ($F_{3,77} = 3.81$, $p < 0.01$). For this reason, in the repeated measure ANOVA comparing pre-test and post-test conditions, age was at first considered as a covariate, but later removed since it showed no influences in all the analyses, except for the Tower of London test.

Regarding the Stroop task, a significant effect was found for the congruent reaction time concerning time ($F_{1,76} = 107.03$, $p < 0.001$, $\eta^2_p = 0.54$), but this learning effect was independent of the motor task performed ($F_{3,76} = 1.02$, $p = 0.39$, $\eta^2_p = 0.04$) (Fig. 2). Moreover, the inhibitory score was calculated as the measure of inhibitory control, according to the procedure suggested by MacLeod [29]. Therefore, we calculated the logarithmic difference between incongruent reaction time and colour reaction time, both in the pre-test and in the post-test. The repeated measure ANOVA did not reveal significant effects for time ($F_{1,76} = 0.12$, $p = 0.75$, $\eta^2_p = 0.001$) or concerning the interaction between time and activity ($F_{3,76} = 0.38$, $p = 0.76$, $\eta^2_p = 0.02$).

For the incongruent reaction time, the same learning effect was found ($F_{1,76} = 110.24$, $p < 0.001$, $\eta^2_p = 0.59$),

Table 1. Descriptive statistics regarding age, height, and weight of the four groups

	Experimental groups			Control group
	Wingate (n = 22)	Incremental (n = 20)	Submaximal (n = 23)	(n = 16)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Age [yrs.]	26.2 ± 4.53	22.9 ± 1.53	23.6 ± 4.22	26.0 ± 4.41
Height [cm]	168 ± 10.9	168 ± 8.77	169 ± 9.51	168 ± 10.1
Weight [kg]	65.0 ± 13.8	67.6 ± 12.9	67.1 ± 13.2	69.6 ± 12.5
BMI	22.7 ± 2.56	23.7 ±2.75	23.4 ± 3.55	24.8 ± 4.21

Table 2. Descriptive statistics regarding Stroop Inhibitory Score, Tower of London Test and Corsi Block Test of the four groups. Standard deviation in brackets

	Experimental groups						Control group	
	Wingate (n = 22)		Incremental (n = 20)		Submaximal (n = 23)		(n = 16)	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Stroop Inhibitory Score [–]	0.22 (0.24)	0.22 (0.15)	0.17 (0.22)	0.17 (0.18)	0.22 (0.19)	0.16 (0.18)	0.16 (0.21)	0.18 (0.11)
Stroop Congruent Task [ms]	1242 (434)	924 (322)	1216 (293)	828 (175)	1328 (536)	955 (336)	1150 (449)	914 (253)
Stroop Incongruent Task [ms]	1556 (578)	1167 (422)	1386 (305)	1040 (322)	1586 (497)	1166 (422)	1338 (512)	1072 (408)
Stroop Colour Task [ms]	1225 (415)	915 (275)	1176 (279)	856 (159)	1291 (488)	967 (238)	1126 (437)	889 (308)
Tower of London Test [points]	28.5 (5.06)	30.0 (5.39)	28.4 (4.58)	31.2 (4.34)	31.2 (3.27)	33.2 (2.61)	31.1 (4.61)	33.0 (3.68)
Corsi Block Test [points]	40.59 (12.31)	54.68 (23.25)	55.80 (20.58)	63.15 (22.59)	53.22 (20.09)	63.35 (22.83)	64.94 (26.67)	76.00 (28.43)

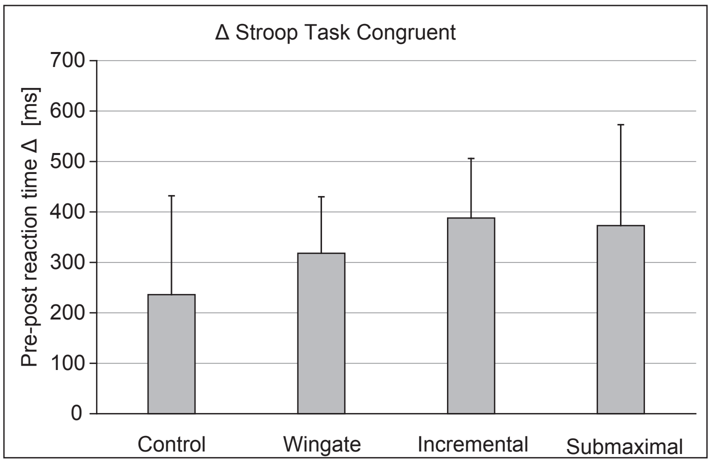

Fig. 2. Difference in reaction time between pre-test and post-test across conditions for the Stroop Task Congruent
A positive difference means that participants reduced their reaction times while responding, thus it has to be considered an improvement.

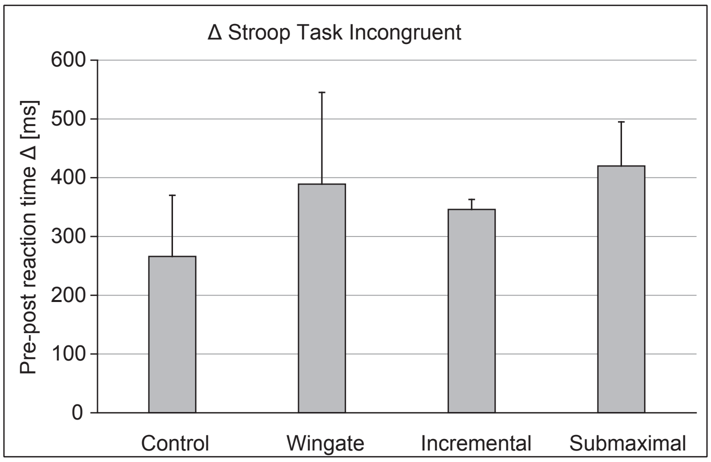

Fig. 3. Difference in reaction time between pre-test and post-test across conditions for the Stroop Task Incongruent
A positive difference means that participants reduced their reaction times while responding, thus it has to be considered an improvement.

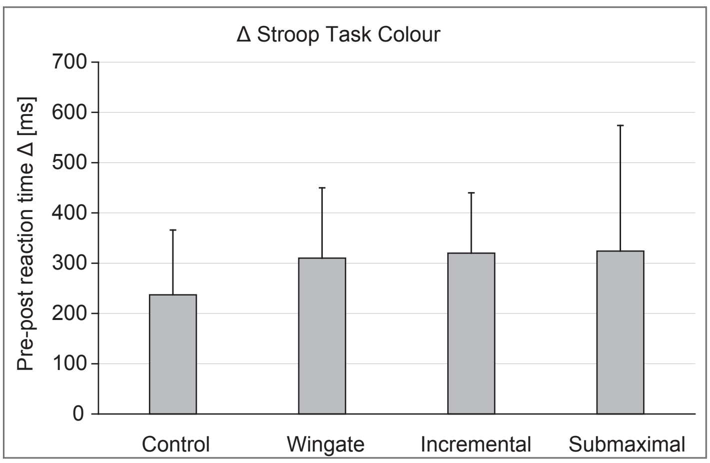

Fig. 4. Difference in reaction time between pre-test and post-test across conditions for the Stroop Task Control
A positive difference means that participants reduced their reaction times while responding, thus it has to be considered an improvement.

but still independent from the motor task performed ($F_{3,76} = 0.88$, $p = 0.453$, $\eta^2_p = 0.03$) (Fig. 3).

Concerning the colour reaction time, a significant effect of time was found ($F_{1,75} = 70.94$, $p < 0.001$, $\eta^2_p = 0.48$), without any effect dependent from the motor task ($F_{3,75} = 0.28$, $p = 0.83$, $\eta^2_p = 0.01$), indicating a learning effect (Fig. 4).

Concerning the Tower of London test, a significant effect of time ($F_{1,75} = 8.73$, $p < 0.001$, $\eta^2_p = 0.10$) and age ($F_{1,75} = 30.50$, $p < 0.05$, $\eta^2_p = 0.06$) was found, revealing a learning effect across groups and different outcome effects according to the age of the participants. No effects were found concerning the motor task performed ($F_{3,75} = 0.12$, $p = 0.94$, $\eta^2_p = 0.01$) (Fig. 5).

Regarding the Corsi block test, a significant improvement was found between pre-test and post-test conditions ($F_{1,76} = 21.98$, $p < 0.001$, $\eta^2_p = 0.22$), but again independent from the motor task performed ($F_{3,75} = 0.375$, $p = 0.39$, $\eta^2_p = 0.02$) (Fig. 6).

Discussion

The current work is a pilot study hypothesizing a relationship between single bouts of physical exercises and executive functions, namely inhibitory control, planning and problem-solving skills, and visuospatial working memory. The results of our analyses showed a general improvement in executive functioning across all the conditions for a learning effect between pre- and post-test measurements, independently from the condition. However, even though the interaction between cognitive assessment and physical exercise was non-significant, we observed a small, non-significant improvement in the expected direction.

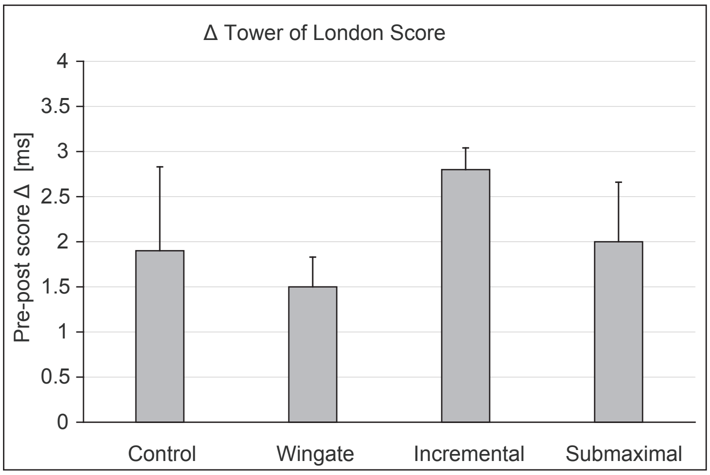

Fig. 5. Difference in scores between pre-test and post-test across conditions for the Tower of London Test
A post difference means that participants enhanced their score in the post-test, thus it has to be considered an improvement.

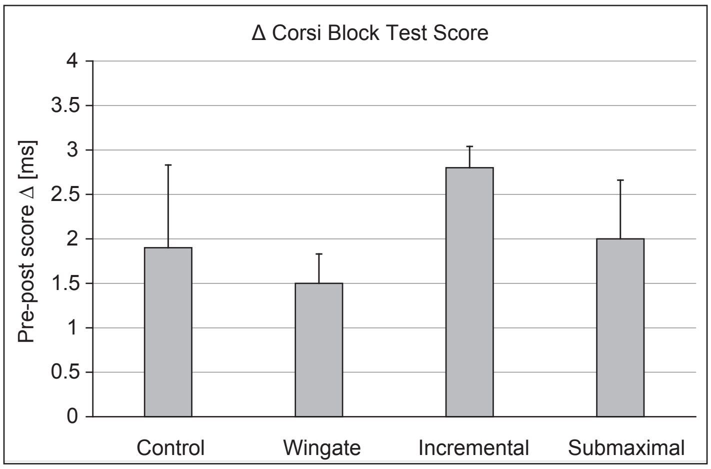

Fig. 6. Difference in scores between pre-test and post-test across conditions for the Corsi Block test
A positive difference means that participants enhanced their score in the post-test, thus it has to be considered an improvement.

Concerning the results of this study, vigorous exercise did not affect inhibitory control, and the same result was detected by another study [12]. Moreover, concerning planning and problem-solving activity, we did not find any significant effect across the three conditions. This result is opposite to what Chang et al. found in their study, where vigorous exercise improved planning and problem-solving ability, detected through the Tower of London test. Finally, our results did not confirm the possible benefit of single bouts of physical exercise on visuospatial working memory, as another study confirmed with a running programme [40].

The literature includes many studies and meta-analyses showing the beneficial effects of physical exercise on executive functioning, especially for people whose functioning has been impaired by a pathologic condition [2, 4, 7–10]. Moreover, considering that the brain is sensitive to environmental and physical variation, brain plasticity, that is the capability to adapt according to external stimuli, may explain the reason for detecting improvements after physical exercise [19]. The meta-analysis of Chang et al. [8] examined the impact of acute exercise on cognitive performance, categorizing the effects into three paradigms: intensity, duration and post-exercise delay. Such paradigms were based on the assumption that the immediate effect of physical activity may dissipate following exercise cessation. When the exercise intensity is low or moderate, a positive effect on cognitive tasks is achieved, but the same result is not achieved when exercise intensity is high or maximum. Hogervorst et al. [23] similarly hypothesized that executive functions would be negatively influenced by strenuous endurance exercise, which was performed on a cycle ergometer at an intensity of 75% of the participant's maximal work capacity up to the point these were able to sustain at least 60 RPM, but the authors detected an improvement of performance in inhibitory functions. Similarly, we found a small, nonsignificant improvement in the Wingate test condition, especially in the Corsi block test score.

In the Wingate test condition, the two aerobic cycle ergometer conditions (the maximal condition and the submaximal constant-intensity condition) showed non-significant results ì. In different studies analysing the effect of acute exercise duration on cognitive assessments [6, 27] when a motor task is performed for less than 20 minutes, it does not produce significant effects. However, considerable duration exercise tasks may impact cognitive performance due to fatigue or dehydration [33].

Together with intensity and duration, which seem to influence the cognitive outcomes, the time delay between the exercise and the cognitive assessment could have a role. A delay between 11 and 20 minutes seems to promote positive cognitive effects, while these effects seem to subside after periods longer than 20 minutes. In our protocol, all the experimental conditions had 3 minutes of delay/recovery between physical activity and the post-test evaluation.

When considering all the above factors simultaneously, exercise intensity and duration, and time delay after the exercise bout, it appears that the greatest effects on cognitive performance are achieved with low exercise intensities, with a duration of at least 20 minutes and after a delay of 11 to 20 minutes [8, 27]. Our research design considered a maximal intensity exercise of 30 seconds duration, an incremental intensity exercise test, and an aerobic exercise of 20 min, with a cognitive assessment repeated at three minutes after exercise, in which no increase in cognitive performance seems to be promoted by the exercise bout.

Concerning the age of the sample, Verburgh et al. [42] detected the effects of physical exercise of cognitive functions, distinguishing the effect sizes for preadolescent children, adolescents, and young adults, finding moderate effect sizes (preadolescent children, $d = 0.57$; adolescents, $d = 0.52$; young adults, $d = 0.54$) for all age groups, which means that exercise rather than age is the main variable to consider during cognitive assessment.

The present study has the advantage of removing the bias due to the administration of cognitive tests face-to-face, where human error might occur. However, there are some limitations: first of all, since it was a pilot study, a convenience sample was employed, without controlling for potential confounders that could have biased our results. Also, the small sample size led to a lack of power of the study, even though the results were in the expected direction, but non-significant. Moreover, for detecting variations during immediate single bouts, as the Wingate test, a more structured and invasive tool (such as f/MRI) should have been used. Finally, a clear learning effect was observed, since we used the same tests at t_1 and t_2. The learning effect, combined with reduced sample size, could have obscured the improvement resulting from the physical exercise. Considering these limitations, future research should deeply investigate the effects of single bouts of physical exercise with an adequate sample size and more sensitive tools, or parallel forms of the tests.

Conflict of interest: Authors state no conflict of interest.

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