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**Original Article**

# Exercise intensity when adjusted for an individual's maximal aerobic power positively affects executive functions in young adults

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**Abstract**
Problem statement: Acute exercise has been reported to positively affect a number of cognitive functions. However, the type and intensity of exercise that will be most beneficial is still unclear. Purpose: This studyevaluated the effect of aerobic exercise, adjusted to the maximal power of each subjects ona battery of executive functiontests. Methods: Twelve healthy, male students, 22–33years-of-age,visited the physiology lab on 3 occasions:Each underwent a treadmill-running test to determine$VO_2$ max. Participants were then randomly divided into two groups.Group A performed aerobic exercise followed by executive function tests.One week later,participants performed tests after resting, without exercise. Group B wastested in reverse order. Aerobic exercise included 20-minute tread-mill running at 70%of subject's$VO_2$ max.Cognition tests started 10-minutes post-exercise,consisting ofthe Stroop testparts1-3 , Trail making test 1-2, Serial seven and Word fluency. Results: Mean $VO_2$max was 49±3.5ml/kg/min, heart rate 189±5.8 beats/min, and Rate of Perceived Exertion19±1.1. For Stroop part 3, group B performed better after exercise compared to resting: 56.8±17.2 vs. 47.7±13.8words/minute ($p< 0.05$).Trail making part 1 was performed by group A in 26.5±7.6 and 31.7±9.7 seconds at rest and after exercise, respectively($p<0.04$). For part 2, group B performed better after exercise with57.3±9.8 seconds vs. 66.2±10.6 seconds after rest ($p<0.04$). For the Word fluency both groups showed better results after exercise compared to rest, however, only for group B differences reached statistical significance(14.7± 3.1 vs. 13±3.2words/min; $p<0.05$).Serial seven scores were unaffected by exercise stimuli. Conclusions: Acute exercise adjusted to the maximal aerobic power of subjects positively affects someexecutive functions in young adults;this is pronounced to a greater extend in complex rather than in simple cognitive tasks.
**Key words: cognitive functions, exercise stimulus, Stroop test, trail making test**

## Introduction

In the last decadesresearch has focused on the interaction between physical inactivity, brain health, cognitive functionand scholastic performance throughout the lifespan (Castelli et al., 2014).

Cognition as a general term, reflects different processes including memory, attention, reasoning, intelligence and executive function (EF) (Tomporowski et al., 2011). The latter refers,among others, to planning, scheduling, response inhibition, working memory and visuo-spatial processing (Tomporowskiet al., 2008;Tomporowski et al., 2011). In spite of the growing evidence that links the positive impact on these functions, it is at present not entirely clear which components of EF are more likely to benefit from physical exercise.

Improved EF following chronic and acute exercise has been reported inpreadolescent children (Sallis, 2010; Donnelly et al., 2016), in youth (Hillman et al., 2009; Esteban-Cornejo et al., 2015), in young adults (Chang andEtnier,2009), and among the elderly populations (Colcombeand Kramer, 2003). Recently, in a longitudinal study Hakala and colleagues (2019) reported that cumulative exposure to physical activity from childhood to adulthood,positively affects midlife cognitive performance. The authors emphasized that enhanced cognitive performance was related to childhood and adolescent activity habits and was independent of participants physical activities in other age frames.

A number of studies investigated the relation between physical activity habits, physical fitness and cognitive performance in childhood. School children who spent more time in sedentary behavior were characterized by low inhibition ability, whereas a higher total amount of physical activity was associated with better planning ability, as indicated by a battery of cognition tests (Van der Nietet al., 2015).Similarly, in a group of preadolescent children,greater aerobic fitness was associated with better performance in all threeof the Stroop conditions (Buck et al., 2008).Positive relation between aerobic fitness and overall cognitive functioning were reported later in studies by Hillmanet al.(2009).

In a broad, systematic review by Esteban-Cornejo and colleagues on physical activity and cognition in adolescents, 75% of the studies reported a positive relationship between physical activity and cognitive and/or


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academic performance (Esteban-Cornejo et al., 2015). The review indicated that the type of activity and some psychological factors such as self-esteem and depression, could mediate the association between physical activity and academic performance.

This interaction between fitness level and EF capacity was supported also by neuro-electric measures, including the Event-Related Potential (ERP) as reflected by the P3 wave. Hillman et al. (2005) reported higher P3 amplitude and shorter P3 latency in childrenwho were more physically fit, ascompared to those who were less fit. As indicated by Polich (2007), the amplitude of the P3 reflects the amount of attention in response to the stimulus, whereas the latency of the wave reflects stimulus evaluation speed.Thus, shorter latency indicates faster cognitive processing (Duncan-Johnson, 1981).The effect of fitnesson cognitive control that was documented also in older adults, was more pronounced withtasks that required greater amounts of cognitive control (Colcombeand Kramer, 2003). Unlike the general agreement regarding the relation betweenphysical fitness and cognitive function along life span,the effect of a single bout of acute exercise on cognitionraises some questions. There is some uncertainty regarding the type, duration and intensity of exercise that produces the greatest positive effect on cognitive performance, as well as the optimal time interval between the end of the session and the start of any cognitive task.

Harveson et al. (2016) exposed high school students to 30-minute sessions ofaerobic exercise, resistance trainingand a non-exercise resting session in a random, crossover design, and reported higher scores for the Stroop test after both aerobic and resistance exercise,as compared to the non-exercise session.For the Trail Making test part B, aerobic exercise led to improved performance over both resistance exercise and non-exercising group. Resistance exercise was found beneficial also in young adults, with a dose-response relationship between the intensity of exercise and cognitive performance (Chang and Etnier, 2009). A dose-dependent response between the duration of exercise and cognitive performance has also been suggested with the greatest improvement in accuracy and response time after 20 minutes aerobic exercise, as compared to 10 and 45 minutes duration (Chang et al., 2015a). Interestingly, 30-minute exercise session was found to be more beneficial than the 60-minute bout for various aspects of cognition, after exposure to the Loughborough Intermittent Shuttle Test (Cooper et al., 2019). With regard to the time interval between termination of exercise and cognitive challenge, Cooper and colleagues studied a group of adolescents 30 minutes before, immediately post and 45 minutes after a sprint-based exercise and once at rest.Forthe simple level of the Stroop test,response timeswere significantly quicker 45 minutesafter sprint-based exercise,whereas for the complex stage,response times were quicker immediatelyfollowing the sprint-based exercise (Cooper et al., 2016).Unlike Cooper's results Samuel and colleagues (2017) applied a bout of maximal intensity exercise in children and adolescents and reported that complex tasks such as verbal learning, were impaired when tests were applied immediately after the exercise bout. Yet, cognitive performance resolved and returned to baseline after one hour of rest. This temporary impairment was attributed to central fatigue which has also been observed when a dual-task, a combination of cycling and video-gaming was performed prior to executive performance (Douriset al., 2018).

Based on the published literature, it is evident that a number ofexercise characteristics should be considered when studying the cognitive response to the exercise stimuli(Tomporowski, 2003, Samuel et al., 2017; Cooper et al., 2016; 2019, Harveson et al., 2016). The present study therefore aimed to focus on the effect of exercise intensity which wasset relative to each subject's maximal aerobic capacity, and to study its effect on EF performance. We hypothesized that a single bout of aerobic exercise, performed at a relatively similar intensity of 70% of the subject's $VO_2$ max, would positively affect executive skills in young adult men.

**Materials and Methods**

Participants

Twelve healthy, male students, ages 22-33 years, participated in the study. All were studying for a B.Ed. in Physical Education. Subjects were selected based on the following inclusion criteria: age range 21-35 years, good health conditions, maintaining active life-style with 2-3 exercise sessions /week. Exclusion criteria included any chronic medical problem, acute medical problem 14 days prior to testing, and participation in any top competitive sport. The purpose and details of the study were explained and each participant voluntarily signed a written informed consent. They then completed a health status questionnaire and underwent a basic clinical evaluation prior to entering the study.The study protocol was reviewed and approved by the ethic committee of the college.

Measures

Body height was measured using a wall-mounted stadiometer (Seca 206, SecaGmbH, Hamburg, Germany). Body masswas evaluated using an electronic scale (Tanita BC418-MA, Tokyo, Japan). Body mass index (BMI) was calculated as body mass in kg divided by thesquare of stature in meters.

Design and procedures Participants visited the physiology lab at the college on three occasions.At the first visit, each subject underwent a treadmill-running test to determinemaximal aerobic power. They were then randomly divided into two groups and performed the study protocol in a cross-over design: subjects in group A performeda sub-maximal aerobic exercise followed byexecutive function (EF) testing on their second visit; one week later on theirthird visit, they performed the EF tests after a 10-minute rest and no exercise. Subjects in group B performed the tests in a reverse order: rest and EF test at visit 2 and exercise followed by EF test, at visit 3. This design was chosen to eliminate any effectof order on cognitive performance.Subjects were advised to refrain from heavy training during 24 hours prior to participation in any of the testing events. All tests were performed between 10:00-14:00 hours. The study protocol is illustrated in Figure 1.

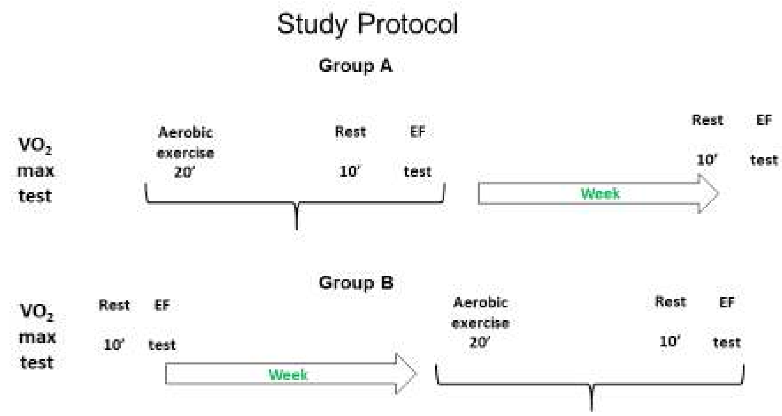


**Figure 1**: Study protocol. EF = executive function tests

**Laboratory tests**

a. Maximal aerobic test: Maximal aerobic power was evaluated using a treadmill-running test at a starting pace between 8-10km/h, according to training status of each individual. Speed increased by 1km/h every subsequent minute until a comfortable pace that can be maintained for the entire test, has been reached. Thereafter, ramp grade which started at 0% was elevated by 1% every minute until exhaustion. $VO_2$ max was determined when respiratory exchange ratio (RER) was > 1.1 and no further increase in $VO_2$ was indicated in-spite of further elevation of exercise intensity (Hanlin et al., 2012).

Face masks were fitted to participants. Oxygen uptake ($VO_2$ ), minute-ventilation (Ve), and end-tidal CO2 were measured and RER was calculated.$VO_2$ values were taken as the average of every 15 seconds and expressed relative to body mass in ml/kg/min.Gas exchange was measured using the ZAN metabolic system (ZAN 600 CPET: ZAN Messgerate GmbH, Oberthulba,Germany).Heart rate was continuously monitored by Polar watch and the rate of perceived exertion (RPE) using the Borg Scale (Borg, 1982) was documentedat the end of each minute throughout the entire test.

b. Sub-maximal exercise: according to the assigned group, each subject performed a sub-maximal aerobic run at 70% of his pre-determined$VO_2$max. The speed and grade of the treadmill were carefully adjusted to maintain the exercise intensitythrough the 20-minute run. Minor adjustments to speed or grade were applied,if required, to maintain the pre-determined exercise intensity.

c. Cognition tests:Cognitive performance was evaluated based on a battery of four EF tests: Stroop test (ST) parts 1-3;Trail-making test (TMT) parts 1-2;Serial sevens test (SST), and Word fluency.

1. The ST (Stroop, 1935) is a validated and widely used mean of assessing selective attention and cognitive flexibility. It is based on three increasingly demanding tasks, 60 seconds each.For the first task, participants were asked to read aloud the words blue, green, and red, printedin Hebrew letters in black ink on white paper.In the second task, subjects were instructed to identify the colors of the symbol XXX printed in blue, green and red, as they appeared from top to bottom and from right to left.In the Color-Word, the third and most complicated task, subjects were presented with non-corresponding color words,so that the word that expressed the color was printed in a different color, for example: the word blue was printed in green ink. Participants were instructed to state the color and not the printed word.Whereas parts 1-2 of the Stroop test evaluate processing speed and selective attention, part 3 with the two conflicting sources of color information is known as Stroop interference. It raises a conflict between the reflexive response: reading the word, and the naming of the ink color. It evaluate response inhibition which is an index of executive function ( Barella et al., 2010).

2. The Trail-making test (TMT) consists of two parts: part 1 requires an individual to draw lines sequentially, connecting 25 circled numbers distributed on a sheet of paper. In part 2, task requirements are similar but subjects must alternate between connecting numbers and letters (e.g., 1, A, 2, B, 3, C, etc.). This test which relies on the alphabet, imposes some limitations for non-English speakers, as explained by Kim et al. (2014). As an alternative, he suggested the Trail making test Black & White as a reliable new neuropsychological variant.

Based on this concept, we used a similar version but with yellow and pink rather than the black and white colors. Thus, in our study, subjects were instructed to draw a line between 25 circled numbers, alternating between the two colors. TMT provides information on visual search, scanning, speed of processing, and mental flexibility. The ability to draw a line connecting the most numbers with no errors reflects, to a great extent, the subject's inhibitory control while maintaining two lanes of thoughts simultaneously and shift between the two as fast as possible. It reflects another executive function skill (Salthouse, 2011).

3. In the SST(Smith, 1967),subjects were given a number between 100-250 and askedto subtract by 7 as rapidly as possible within 60 seconds.

4. The Word fluency test (Bruckiand Rocha, 2004) reflects semantic memory and language.Since our participants were not English speakers, we substituted Hebrew letters that sound like B, G and P for the English letters F, A, and S. Each subject was instructed to state within 60 seconds as many words that start with that letter,without including names, numbers and any verb more than once.

**Statistical analysis**

Based on the sample size of 12 participants, we chose not to apply regular parametric tests that require normal distribution. To study differences between Groups A and B we used the Mann-Whitney U-tests for independent samples. Wilcoxon signed-rank tests for dependent samples were performed to study within-group differences between measurements. Level of significance was set at $p< 0.05$.

**Results**

Anthropometric measurements of mean height, body mass and body mass index of the participants were: 173 ± 8cm, 77.4 ± 10.2kg, and 25 ± 2, respectively.

Maximal aerobic power measurements:$VO_2$max values ranged from 43-55ml/kg/min with a mean value of 48.9 ± 3.4 andmaximum HR was 175-212beats/min with a mean of 189±9.8. The mean RPEat maximal effort was 19±1.1.

Wilcoxon signed-rank test for dependent variables revealed enhanced performance in part 3of ST when executed after exercise, compared to after resting, with mean scores of 56.8±17.2 vs. 47.7±13.8 words/minute, respectively($p< 0.05$). In parts1 and 2 of the ST, differencesbetween conditions did not reach statistical significance. Thus, exercise had no enhancing effect on EF as reflected in these two stages.ST results are presented in Figure 2.

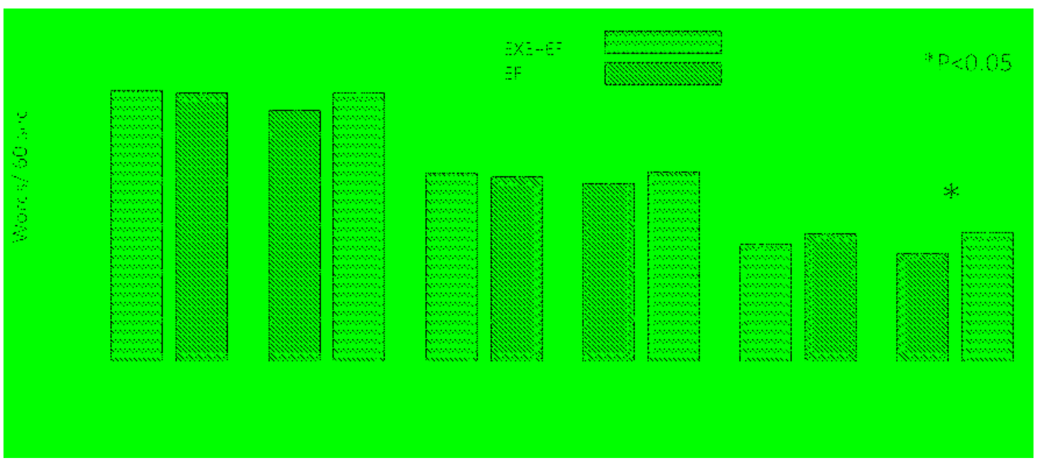


**Figure 2**: Stroop test scores parts 1,2,3 after exercise (EXE+EF) and at rest (EF)

**Figure legends**

Figure 1: Study protocol. EF = executive function tests
Figure 2: Stroop test scores parts 1,2,3 after exercise (EXE+EF) and at rest (EF)
Figure 3: Trail making test (TMT) scores, part 1 and 2 after exercise (EXE+EF) and at rest (EF)
Figure 4: Word fluency scores after exercise (EXE+EF) and at rest (EF)

TMT part 2, scores were better when performed after the exercise bout compared to rest. Subjectsin group Bcompleted this part in 57.3±9.8 seconds after exercise and in 66.2±10.6 seconds after rest ($p<0.04$). Interestingly, group A performed part 1 of the TMT faster after rest, as compared to post-exercise (26.5±9.7 vs. 31.7±7.6 seconds, respectively; $p< 0.04$). In the TMT part 2, no significant difference was observed between the two conditions for this group. The possibility of a learning effect on the TMT results can therefore be excluded.TMT results are presented in Figure 3.

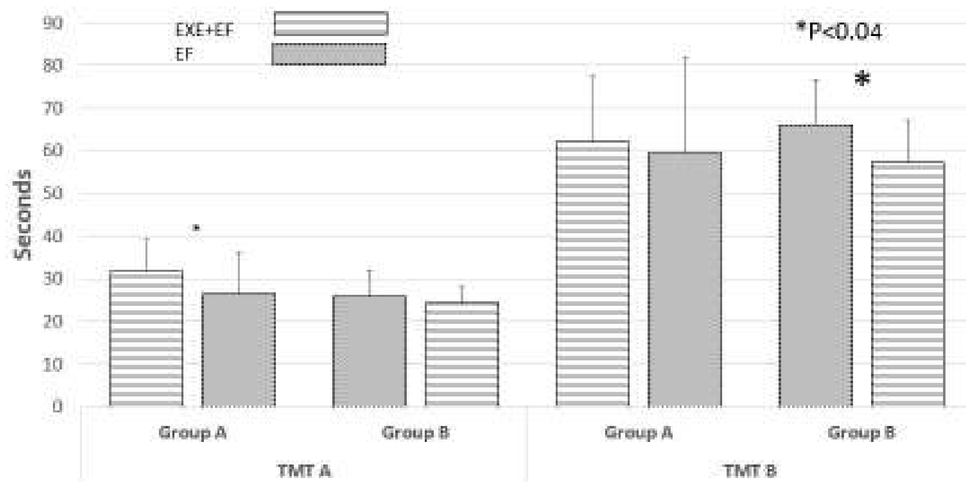


**Figure 3**: Trail making test (TMT) scores, part 1 and 2 after exercise (EXE+EF) and at rest (EF)

For SSTboth groups A and B performed similarly with no differences between exercise and the rest conditions.

In the Word fluency test,group B scored betterafter exercise, as compared to the resting condition (14.7±3.1 vs. 13±3.2 words/min; P <0.05). Word fluency scores are presented in Figure 4.

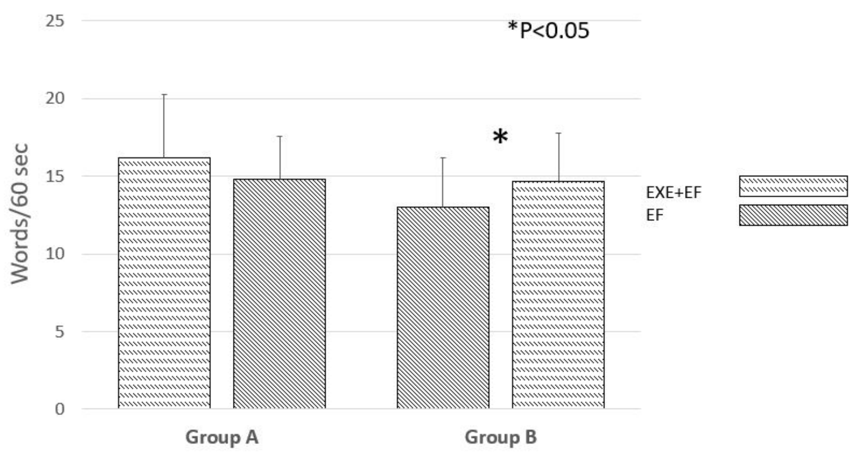


**Figure 4**: Word fluency scores after exercise (EXE+EF) and at rest (EF)

Based on the results of this study, we suggest that one bout of acute aerobic exercise performed at a moderately-high intensity has a positive effect on selected cognitive skills in young adult men.This beneficial effect was greater as the complexity of the skill increased. This relation wasdemonstrated in STpart 3but not in parts 1 and 2, and similarly, in TMT part 2but not in part 1.With regard to the Serial substracting number scores, we did not find a positive effect of exercise on performance in either group; a result that did not match our hypothesis.

**Discussion**

The aim of this study was to examine the effect of exercise intensity which is set relative to the subject's maximal aerobic capacity, on the EF performance. We hypothesized that a single bout of exercise, performed at a relatively similar intensity of 70% of the subject's $VO_2$ max, would positively affect executive skills in young, male, students. This hypothesis has been confirmed for some but not all of the cognitive tasks that were tested.

Our testing battery focused on task relevant attention and blocking interfering information, speed of information processing and task switching.In accord with the task-dependency theory as presented by Tomporowski (2003) it may be assumed that physical effort has a specific impact on some but not all executive functions. Three out of the four tests that were included in our battery were positivelyaffected by the exercise stimulus; better achievements were observed in the more challenging tasks, as seen in the Stroop Color- Word and in the Trail Making part 2 tests. The effect on cognitive skills such as task relevant attention, blocking interfering information and response inhibition,as reflected in Stroop Color-Wordin our study, accord well with previous reports by Douris and colleagues in young adults (2018), Alves et al. in middle-aged women (2012) and

Harveson and colleagues in a group of adolescents (2016). Successful performance in the Stroop tasks is based on the subject's ability to inhibit the basic response and to activate an unexpected response to a given visual stimulus instead.

Our results of Trail making part 2 compare favorably with those of Harveson (2016). This task is indicative of attention, visual search speed and information processing.Yet, one should note the differences between the study groups; whereas Harveson studied high school adolescents, our participants were all young adults, college students. In accord with Alves et al. (2012) and Chang et al. (2015a),the Word fluency test which evaluates semantic memory and language, was better performed after the exercise session as compared to rest. This test is frequently used for diagnostic purposes, when poor results are seen in patients with focal cortical brain lesions (Brucki and Rocha, 2004). As for the Seven substitute test we did not observe any effect of the exercise stimulus on the results. As interpreted by Kartzmark (2000), this skillis mainlyinfluenced by basic arithmetic abilities rather than by a stimulus of acuteexercise.

Various protocols have been applied in an attempt toinvestigate the exercise intensity and duration that will positively affect EF performance. A dose-response effect has been suggested by Chang et al. (2015a) in favor of 20 minutes exercise as compared to 10 and 45 minutes. Cooper et al. reported better results after 30 minutes compared to 60 minutes of the Loughborough Intermittent Shuttle Test (Cooper et al.,2019). Other protocols ranging from 15 minutes of cycling (Schneider et al., 2009) and 20-40 minutes of moderately-vigorous intensity in overweight children (Davis et al., 2011) have also been applied. Based on these reports and as previously suggested by others (Chang et al., 2012), we applied in the present study a 20 minutes exercise as an optimal stimulus to achieve a positive effect on cognitive performance. By reviewing the literature it is evident that the exercise intensities that were applied, largely differ between studies. Therefore, one can assume that the exercise stimulus varies not only between studies, but also among participants in each single study group(Douris et al., 2018, Alves et al.,2014 ). Moreover, when exercise intensity has been calculated based on age-predicted maximal HR, one should note that this value has limited accuracy and has been previously shown to deviate to some extent from the actual maximal HR values (Shargal et al., 2015). Therefore, in the present study we tested each of our participants for maximal aerobic power determination. We then applied the exercise session to be at 70% of the subject's VO2max. so the relative exercise stimulus was the same for all our participants.

The mechanism underlying the beneficial effect of aerobic exercise on cognitive performance is not entirely understood. It is to some extent attributed to improved hemodynamics; increased blood flow to the prefrontal cortex,the area which is responsible for some executive functions (Giles et al., 2014;Mekari et al., 2015). However, after a very high exercise intensity (Samuel et al.,2017) as well as after a dual-task performance (Douris et al., 2018) a reduction in cognitive performance was reported.Some investigators speculated that decreased cerebral oxygenation, which is an immediate response to a maximal effort, leads to cerebral fatigue and is therefore responsible for the impaired cognitive performance observed (Shibuya et al.,2004, Mekari et al.,2015).Alves et al. (2014) suggested that it is not the absolute exercise intensity, but rather the fatigue induced by the exercise load that affects cognitive stimulus. This assumption accords with Kashihara and colleaguestheory that inverted U-relationship exists between exercise intensity stimulus and cognitive function(Kashihara et al,2009). This concept supports the exercise protocol that has been chosen forour present study. We applied an exercise intensity set at 70% of each participant's maximal aerobic capacity, based on his pre-determined maximal aerobic power test. Thus, the exercise stimulus was relatively similar for all subjects and was well tolerable by all of them. At this moderately- high exercise intensity, subjects could maintain a steady state oxygen consumption and heart rate at 150-166 beats/min for the entire 20 minutes effort, with only minor adjustments of speed and grade, if required. Moreover, as indicated by our participants the exercise load in our study induced subjective sensation of fatigue ranging 9-12, based on Borg scale's rate of perceived exertion (Borg,1982).Sensation of fatigue is known to result from an accumulation of physiologic, neurologic and energy determinants (Wilmore &Costill, 1994, p. 114-119), all of which are beyond the scope of this study;yet, the argument as have been raised by Alves (2014) may support the rationale used in the current study: standardizing the relative work load and thus, the expected impact of the exercise stimulus on the cognitive tasks performance among our subjects. The health benefits of active lifestyle and physical fitness have long been documented as protective among the elderly,young adults, children and adolescents (The 2018 Advisory Committee Scientific Report on Physical Activity Guidelines). In the last decades the effect of exercise on brain health and cognitive capacity has also been widely studied. However, as stated by Donnely et al. (2016), we still do not have enough knowledge to prescribe the optimal mode, duration, frequency and intensity of exercise that will yield significant benefits for cognition.

**Conclusions**

Since the fatigue sensation induced by the exercise load is known to affect cognitive stimulus, we suggest that exercise intensity should be applied according to each individual's aerobic power, in order to standardize the cognitive stimulus among all participants. Based on theresults of the present study we conclude thata bout of acute aerobic exercise which isperformed at moderately-high intensity of 70% of maximal aerobic power for 20 minutes, has a positive impact on a selection of cognitive skills, mainly on those that require higher attention and cognitive flexibility. It may also be suggested that this type ofexercise iseasily tolerated by healthy, young adults and can therefore be used as a practical tool prior to engaging in cognitive tasks, both in the academic field and in certain sport disciplines. These recommendations are at the moment relevant to a specific population of healthy, young male adults. Further research is needed to study possible gender differences in their cognitive response to an acute exercise stimulus. Also, more questions regarding the mechanism that relates physical effort and cognition remain,at the moment, to be investigated.

**What Does this Article Add?**

In an attempt to study the potential effect of exercise on cognitive performance, a wide range of exercise duration and intensity protocols have been applied. It may be assumed that the physical load imposed by the bout of exercise varies between individuals in each study group and is primarily related to the fitness capacity of each participant; therefore, the impact on cognition performance varies accordingly. In the present study we aimed at equalizing the physical load so that all of our participants were exposedto a relative similar stimulus prior to the cognitive challenge, based on each individual aerobic power. To the best of our knowledge, not many studies standardized the exercise load to achieve similar exercise stimuli. The combination between duration and intensity that we used can be tolerated by healthy individuals, and at the same time is effective enough to enhance cognitive performance.

**Conflicts of interest**: None

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