Association between physical fitness and cognitive performance in 19-24 year old males

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ABSTRACT: The present study aimed to explore the association between physical fitness (PF) and cognitive performance in a sample of 19-24 year old males. Two hundred and eleven young males (20.2±1.5 years) participated in the study. Cognitive functioning tasks including information processing speed and inhibitory control were measured in addition to PF and motor fitness components such as aerobic fitness, static strength, explosive strength, agility and speed. Regression analysis showed that after adjustment for potential confounders (e.g. age, socioeconomic status, adiposity and physical activity), aerobic fitness (represented by shorter time in the one-mile run) was positively associated with composite inhibitory control scores (standardized β=0.17; p=0.04) and negatively associated with Δ Simon (standardized β= -0.21; p=0.04). Explosive strength was negatively associated with composite information processing scores (standardized β= -0.24; P=0.01), and composite inhibitory control scores (standardized β= -0.22; p=0.02). Speed of movement, agility and static strength were not associated with any of the cognitive tests. In conclusion, aerobic fitness and explosive strength but not speed, agility or static strength might be indicators of underlying cognitive functioning tasks in 19-24 year old males.

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INTRODUCTION

Evidence shows that higher levels of cardiorespiratory fitness (CRF) are inversely associated with metabolic risk factors in youth [1]. Furthermore, there is growing evidence to suggest that CRF is associated with better cognitive functioning in either young [2,3] or older people [4]. Some theories have been suggested for the link between CRF and cognition, including increase in cerebral blood flow [5], enhanced levels of neurotransmitters such as brain-derived neurotrophic factor (BDNF) and other growth factors that promote synaptic plasticity and neurogenesis [6].

Fitness is a multi-faceted concept which includes: 1. physical fitness (PF) as a set of measurable health and skill-related attributes such as cardiorespiratory fitness, muscular strength and endurance, body composition and flexibility; and 2. motor fitness (MF) which includes an individual's performance abilities such as speed, agility, coordination, balance and power [7]. Most of the studies which have explored the association between cognitive function and fitness have focused on the importance of CRF. However, there is also evidence that other fitness components may also influence brain functions [8-10]. For instance, it has been suggested that exercises which need specific mental processing (e.g. MF components such as agility) might be more effective to trigger global cognitive development than aerobic exercises alone [11,12].

Furthermore, there are other components of fitness (e.g. skill-related fitness) which may be a stronger predictor of cognition than aerobic fitness [13]. Batouli and Saba [14] in a review paper found that type of physical activity (e.g. aerobic, coordination or strength training), duration and volume of physical activity have different influences on brain structure and functionality. Ruiz-Ariza et al. [9] concluded that not only CRF, but also motor coordination, speed-agility and perceptual-motor skill are associated with cognitive function in adolescents. However, no clear association between cognitive function and strength or flexibility in adolescents was observed. The authors suggested that more research looking at other fitness components and potential confounders (e.g. age, socioeconomic status, adiposity and physical activity) is needed. This will help to understand the causes of the differential effect of fitness components on cognitive function [9]. Van der Fels et al. [10] discussed the association between motor skills and cognitive function in children and indicated inconsistent associations. However, they observed a weak to strong association between some motor skills and underlying cognitive skills tests and suggested the complexity of motor skills as an important factor in this association. Furthermore, they indicated a stronger association between motor and cognitive skills in pre-pubertal children compared to pubertal children.

It should be noted that the existing literature underlying the association between cognitive function and CRF as well as other components of fitness (e.g., muscular strength, speed, agility, etc.) has mainly focused on children or adolescents, when the brain is still developing, or elderly people, when there is a cognitive decline [9,10,16]. However, this study focuses on individuals at the age between 18 and 25, which is a distinct developmental period, lying between childhood and adulthood, and the association of cognitive function with different fitness components (either PF or MF) in this period of life has received limited attention [3,15].

Inhibitory control is the ability to prevent planned or ongoing although inappropriate actions in a given situation and plays an important role in choosing proper behaviours in daily life [17]. Likewise, it has been shown that information processing speed tasks (e.g., reaction time tests) are associated with health and general cognitive ability [18,19]. Thus, exploring the association between various components of fitness and cognitive functioning tasks such as inhibitory control and information processing speed tasks in youths may help to extend our knowledge regarding their influence. According to our knowledge, the association between fitness components and various cognitive skills such as working memory, attention, visual processing and others has already been explored (see the review papers of Ruiz-Ariza et al. [9] and Van der Fels et al. [10]). However, there are not many studies which explore the association between various components of fitness and cognitive functioning tasks such as inhibitory control and information processing in young people.

It should also be noted that the existing literature underlying the association between cognitive function and CRF as well as other components of fitness (e.g., muscular strength, speed, agility, etc.) has mainly focused on children or adolescents, when the brain is still developing, or elderly people, when there is a cognitive decline [9,10,16]. In this study we will focus on individuals at the age between 18 and 25, which is a distinct developmental period, lying between childhood and adulthood, as this has received limited attention [3,15].

Therefore, the aim of this study was to explore the association of different components of PF (i.e. aerobic fitness and muscular strength) and MF (i.e., speed and agility) with cognition (processing speed and inhibition) in a sample of 19-24 year old participants. We hypothesized that not only higher levels of CRF (as an important component of PF) but also higher levels of some other PF components (e.g. muscular strength) are associated with better cognition in youths. Studies from the literature have shown [9,10, 20-22] that muscular strength tests (i.e., static and explosive strength) are associated with cognitive tests in youths. Therefore, we also hypothesized that complex MF tests (such as agility) would be stronger indicators of underlying cognitive tests in youths [10,23].

MATERIALS AND METHODS

Participants

The present cross-sectional study was conducted in a sample of 19-24 year old male students from a university in the North West of Iran, during 2015 and 2016. Due to socio-cultural reasons only male students were included in the sample. The procedure of the study was explained to students during the physical education (PE) lesson when they were invited to participate. Participants were excluded if they had musculoskeletal problems or chronic diseases, were older than 24 years, were using medications or were not interested in

TABLE 1. General characteristics of the participants (n= 211 men).

Variables	Components	Mean ± SD
Physical activity	SDLT (score)	2.75 ± 0.75
	PADLES (score)	2.7 ± 0.6
Motor fitness components	Speed (s)	6.5 ± 0.6
	Agility (s)	10.2 ± 0.7
Physical fitness components	SLJ (cm)	210.1 ± 24.2
	Grip strength (kg)	43.6 ± 6.0
	One-mile run (min)	7.8 ± 1.5
Information processing	RT_{clin} (ms)	200.9 ± 20.7
	SVRT (ms)	300.6 ± 33.8
	SART (ms)	323.4 ± 64.6
	4-CRT (ms)	482.4 ± 58.8
Inhibitory control	$Sim_{Con}RT$ (ms)	535.9 ± 91.8
	$Sim_{Incon}RT$ (ms)	582.9 ± 91.9
	$Stro_{Con}RT$ (ms)	732.6 ± 152.9
	$Stro_{Incon}RT$ (ms)	773.1 ± 159.1
	∆ Simon	47.0 ± 45.1
	∆ Stroop	40.5 ± 39.2

PF: physical fitness; MF: motor fitness; PA: physical activity; PADLES: PA during leisure excluding sport; SDLT: sport during leisure time; 4-CRT: 4-choice reaction time; RT_{clin}: clinical reaction time; SVRT: simple visual reaction time; SART: simple audio reaction time; $Sim_{Con}RT$: reaction time for congruent Simon task; SimInconRT: reaction time for incongruent Simon task; $Stro_{Con}RT$: reaction time for congruent Stroop task; $Stro_{Incon}RT$: reaction time for incongruent Stroop task; SLJ: standing long jump; ∆ Simon: Time on InconRT minus time on ConRT; ∆ Stroop: Time on InconRT minus time on ConRT participating. The present study was approved by the Human Ethics Committee of the University of Mohaghegh Ardabili and the experiment was performed in accordance with the ethical standards of the committee and with the Helsinki Declaration.

Four hundred and eighty-one participants were invited to participate in the study. However, 154 students did not meet the inclusion criteria or were not interested in participating. From the 327 eligible students, 116 did not complete all the measurements or left the study. Therefore, 211 students were included in the analyses.

Mean age, height, weight and fat% of the participants (n= 211 men) were 20.2±1.5 years, 177.2±6.1 cm, 70.5±12.1 kg, and 21.5±10.7%, respectively. Physical status (including PA and fitness) and cognition data are shown in Table 1.

Procedures

Measurements were performed during regularly scheduled PE lessons. The students were instructed to avoid caffeinated drinks and to not participate in any vigorous physical activity (PA) on the same day or the day before the fitness or cognitive tests.

At the first visit, age, socioeconomic status and body composition variables were measured. Cognitive and fitness tests were then measured after familiarization. Physical fitness tests (i.e. static strength, explosive strength and aerobic fitness) were measured at the first week and MF tests (i.e. speed and agility) were performed in the following week.

The cognitive tests were performed in an empty room, with participants seated at rest. Four tests were used to measure information processing speed. These were performed in the same order for all participants and included: clinical reaction time, simple visual reaction time, simple audio reaction time and 4-choice reaction time. Inhibitory control was then measured by Simon and Stroop Tasks. Rest breaks of 5 min were allowed between each test to prevent fatigue [24]. Response accuracy was recorded for each trial and error trials were excluded from the analysis.

Outcomes

Anthropometric variables

Body mass was measured with minimal clothing and without shoes using a calibrated electronic scale (Type SECA 861) to the nearest 0.1 kg. Height was measured barefoot in the Frankfurt horizontal plane with a telescopic height measuring instrument (Type SECA 225) to the nearest 1 mm.

Fitness tests

Physical fitness tests

Aerobic fitness: The one-mile run test was used for measuring aerobic fitness and has been previously validated [25]. The objective of the test was to cover a mile in the shortest time possible. The students were encouraged to run throughout the test and to take walking breaks as needed. They were also reminded to avoid starting too fast to avoid premature fatigue.

Static strength: The hand grip strength test was used to assess static strength of participants. The test was performed by squeezing a calibrated digital hand dynamometer (Takei, Japan) as forcefully as possible with both hands. The mean score for both hands was calculated. It has been suggested that hand grip strength is a valid test for predicting muscular strength and is associated with whole body and upper body strength [26].

Explosive strength: The standing long jump (SLJ) test was used to measure explosive strength and has been validated to measure explosive muscular strength in youth [27]. The students stood behind the starting line and pushed off vigorously with their feet together and jumped forward as far as they could. The distance was measured from the start line to the place where the back of the heel landed.

Motor fitness tests

Speed: The 40-meter sprint measured maximum speed. In this test participants had to run a single maximum sprint over 40 m.

Agility: The 4x9 m shuttle run test was used to measure agility [27]. On command, participants had to run across the field to pick up one block, return, put the block behind the starting line and run back again to pick up the second block and run back to the starting line again.

A hand-held stopwatch was used to measure time (for the one-mile run, speed of movement and agility tests) at the nearest 0.01 s (Joerex, ST4610-2, China). For the grip strength, SLJ, speed of movement and agility tests, the best value of 2 to 3 consecutive maximal- effort trials separated by a recovery period was used for the analysis.

Cognitive tests

Information processing speed

Simple visual reaction time (SVRT) and 4-choice reaction time (4-CRT): Participants performed the Deary-Liewald computer-based reaction time (RT) as a valid test for measuring either SVRT or 4-CRT [19]. The SVRT task included eight practice and 20 test trials. The participants were required to respond (press space bar) to a single stimulus as quickly as possible. The 4-CRT task included eight practice trials followed by 40 test trials. In the 4-CRT participants were requested to press the key which corresponded to the correct response to four stimuli. Response accuracy for the 4-CRT task was 0.93.

Simple audio RT (SART): For the SART participants were required to press a default key (space bar) as soon as possible, using the index finger, every time a "beep" sound was heard. A headphone was provided to improve clarity of sound. Each participant completed eight practice trials and 20 data acquisition trials using RT software (developed by the University of Mohaghegh Ardabili) [23]. The test-retest reliability of the SART was r=0.88.

Clinical Reaction Time (RT_{clin}): In the RT_{clin} test [28] each participant used a validated RT_{clin} apparatus [28]. The apparatus was a measuring stick (0.8 m long), coated in high-friction tape and marked in

5 mm increments and embedded in a weighted rubber disk. The distance the apparatus fell before being caught by the participant was recorded in meters (m). The formula for a body falling under the influence of gravity ($t=0.45\times\sqrt{d}$) for each trial was used to calculate RT_{clin} in seconds (s), where "d" is for distance (m) and "t" is for time (s). Each participant executed four practice trials which were followed by 10 data acquisition trials. Mean and standard deviation of the 10 RT_{clin} trials were calculated.

Inhibitory control

Simon task: For this task a small white square was positioned at the centre of the display and remained throughout the trials (n=100) as a gaze fixation point [30]. Participants were requested to respond as accurately and quickly as possible to the colour of an oval (delivered either to the right or to the left of the white gaze-fixation square) by pressing the appropriate response key. The task included two equiprobable trial types: 1. the congruent ($Sim_{Con}RT$) trial in which the spatial location of the stimulus corresponded to the task-relevant aspect of the stimulus (for example, right stimulus/right response); and 2. the incongruent ($Sim_{Incon}RT$) trials in which the spatial location of the stimulus corresponded to the opposite spatial location of the response (for example, right stimulus/left response). The difference between scores was calculated to measure inhibition (Δ Simon: time on InconRT minus time on ConRT) where a larger difference indicates worse performance. The ability to inhibit incorrect response impulses, measured by the Simon task, is a crucial element of cognitive control [31].

Stroop Task: This is a commonly used neuropsychological test which measures multiple cognitive processes such as executive control, information processing speed, selective attention and the ability to inhibit habitual responses [32]. Like the Simon task, this test consisted of both incongruent and congruent conditions. Stimuli in the congruent conditions were three colour words (red, blue and green) presented in the same colour (e.g., the word Blue printed in blue colour). Stimuli in the incongruent conditions were the colour words shown in either of the two colours that did not match the colour word (e.g., the word Green printed in red colour). Each participant completed 45 trials with a mixture of both congruent ($Stro_{Con}RT$) and incongruent ($Stro_{Incon}RT$) trials [30]. A difference score was also calculated to measure inhibition (Δ Stroop: Time on InconRT minus time on ConRT). As with Δ Simon, a larger difference indicates worse performance of the Stroop task.

For either the Simon task or Stroop task [30], the software was designed to not save the wrong responses and repeat the performance until the trials have been completed. Thus, response accuracy for either the Simon or the Stroop task equals 1.0.

Possible confounders

Overall body obesity was measured using skinfold measurement as a more reliable obesity index than BMI (body mass index). Body fat percentage was determined by measuring the thickness of three sites on the right side of the body (chest, abdomen and thigh) using the Lange skinfold calliper and body fat percentage was calculated using the Jackson-Pollock method [33].

Socioeconomic status (SES) was computed from parents' occupational and educational status using a similar tool as in a previous study [34]. Physical activity (PA) was measured using the 12-month recall Baecke PA questionnaire [35], which is a reliable and valid PA

TABLE 2. Factor analysis.

Cognitive variables	**Principal component factor analysis**			
	Factor 1 Information processing	**Factor 2 Inhibitory control**	**Factor 3 Δ Simon**	**Factor 4 Δ Stroop**
RT_{clin}	0.73*	0.05	0.09	0.09
SVRT	0.71*	0.11	-0.05	-0.09
SART	0.55*	0.49	-0.20	-0.17
4-CRT	0.59*	0.48	-0.09	0.09
$Sim_{Con}RT$	0.02	0.88*	-0.03	-0.11
$Sim_{Incon}RT$	0.05	0.91*	-0.04	0.21
$Stro_{Con}RT$	-0.01	0.71*	0.37	-0.21
$Stro_{Incon}RT$	0.05	0.64*	0.47	-0.16
Δ Simon	-0.01	-0.01	0.07	0.96*
Δ Stroop	0.00	-0.17	0.82*	0.15

Table shows the Varimax rotated factor loading

*Represents the loading of variables on each factor. Four factors representing the cognitive domains were extracted from the analysis.

TABLE 3. Association between composite cognitive scores and participants' characteristics.

Independent variables	Information processing	Inhibitory control	Δ Simon	Δ Stroop
Demografic and obesity variabels				
Age	0.03	0.19*	0.07	0.09
SES	-0.08	-0.19*	-0.07	-0.01
%Fat	0.10	0.07	0.02	-0.09
Physical activity				
SDLT	0.02	-0.17*	-0.05	0.02
PADLES	0.05	-0.06	0.08	0.10
MF components				
Speed	-0.01	0.06	0.06	0.06
Agility	0.07	0.13	-0.03	-0.16
PF components				
Explosive strength	-0.23**	-0.24**	0.05	0.10
Static strength	-0.06	0.02	-0.06	0.04
Aerobic fitness	0.02	0.13	-0.18*	-0.08

* Significant at $p \leq 0.05$; ** Significant at $p < 0.01$.

TABLE 4. Multiple regression analyses between composite cognitive scores, PF and MF tests after adjusting for possible confounders (i.e. age, SES, adiposity, and PA).

Fitness variables	Information processing (Standardized *B*; SE; *p*)	Inhibitory control (Standardized *B*; SE; *p*)	Δ Simon (Standardized *B*; SE; *p*)	Δ Stroop (Standardized *B*; SE; *p*)
Motor fitness components				
Speed	(*B*=-0.03; SE= 0.11; *p* =0.72)	(*B*=0.02; SE= 0.02; *p* =0.87)	(*B*=0.06; SE= 0.19; *p* =0.57)	(*B*=0.08; SE= 0.55; *p* =0.47)
Agility	(*B*=0.05; SE= 0.14; *p* =0.63)	(*B*=0.09; SE= 0.03; *p* =0.34)	(*B*=-0.05; SE= 0.24; *p* =0.62)	(*B*=-0.15; SE= 0.71; *p* =0.19)
Physical fitness components				
Explosive strength	(*B*=-0.24; SE= 0.08; *p* =0.01)	(*B*=-0.22; SE= 0.02; *p* =0.02)	(*B*=0.08; SE= 0.15; *p* =0.44)	(*B*=0.07; SE= 0.28; *p* =0.50)
Static strength	(*B*=-0.09; SE=0.11; *p* =0.22)	(*B*=0.06; SE= 0.09; *p* =0.38)	(*B*=0.02; SE= 0.19; *p* =0.77)	(*B*=-0.02; SE=0.44; *p* =0.80)
Aerobic fitness	(*B*=0.02; SE= 0.11; *p* =0.86)	(*B*=0.17; SE= 0.02; *p* =0.04)	(*B*=-0.21; SE= 0.19; *p* =0.04)	(*B*=-0.08; SE= 0.58; *p* =0.47)

inventory. The questionnaire consists of sixteen questions organized into three sections: PA at work, PA during leisure excluding sport (PADLES) and sport during leisure time (SDLT). Since almost all the students were not working, the PA at work section was removed. Questions in each section were scored on a 5-point Likert scale (always, often, sometimes, seldom, never).

Statistical analyses

Descriptive statistics were processed for all variables. Data were checked for normality using the Kolmogorov–Smirnov test. Appropriate transformations using natural logarithms (transformation by an exponential value) were applied when necessary (e.g. SVRT, SART, 4-CRT, SimConRT, SimInconRT, StroConRT, StroInconRT, Δ Stroop, Δ Simon and SDLT, SES and one-mile run records were transformed). Before further analysis, through factor analysis all the cognitive measures including information processing measures (i.e., RT$_{\text{clin}}$, SVRT, SART, and 4-CRT), inhibitory control measures (i.e., Sim$_{\text{Con}}$RT, Sim$_{\text{Incon}}$RT, Stro$_{\text{Con}}$RT, Stro$_{\text{Incon}}$RT) and Δ congruent and incongruent measures (Δ Simon and Δ Stroop) yielded four factors –information processing speed, inhibitory control, Δ Simon and Δ Stroop with Varimax rotation – for principal components analysis. The four factors account for 70.30% of the total variance (Table 2). Initial Pearson product–moment correlations were conducted on composite cognitive scores, demographic variables, adiposity, PA and fitness tests. Multiple linear regression analyses using the Enter method and adjusting for possible confounders were conducted between composite cognitive scores and fitness components. All calculations were performed using SPSS v.21.0 software for Windows. Statistical significance was set at $p\leq 0.05$.

RESULTS

Pearson correlation for exploring the association between composite cognitive scores and study variables

Pearson product moment correlation (Table 3) showed that age was positively associated with composite inhibitory control scores (p=0.025). SES and SDLT were negatively associated with composite inhibitory control scores (p=0.020). Explosive strength was negatively correlated with composite information processing scores (p=0.006), and composite inhibitory control scores (p=0.005). Aerobic fitness was only negatively associated with Δ Simon (p=0.04).

However, after adjustment using Holm's correction for multiple correlations [36], significant associations were only observed between explosive strength and composite information processing scores (p= 0.001) and composite inhibitory control scores (p=0.002); and between aerobic fitness and Δ Simon (p= 0.02).

Multiple linear regression analyses between composite cognitive scores and fitness components

Table 4 shows the linear regression analyses between composite cognitive scores and PF and MF components after adjustment of possible confounders. Results of this regression analysis indicated no association between the underlying cognitive tasks and speed of movements, agility and static strength.

Multiple regression analysis revealed a significant negative association between explosive strength and composite information processing scores (standardized β= -0.24; p= 0.01), showing that participants with greater explosive strength had shorter information processing speed. Furthermore, regression analysis showed a significant negative association between explosive strength and composite inhibitory control scores (standardized β= -0.22; p= 0.02), indicating that participants with greater explosive strength had shorter inhibitory control.

A significant positive association was observed between aerobic fitness (represented by shorter time in the one-mile run) and composite inhibitory control scores (standardized β= 0.17; p=0.04), suggesting that higher aerobic fitness was associated with shorter inhibitory control in participants. Furthermore, aerobic fitness (represented by shorter time in the one-mile run) was negatively associated with Δ Simon (standardized β= -0.21; p=0.04), showing that participants with higher aerobic fitness presented better Δ Simon.

DISCUSSION

The present study aimed to explore the association of cognitive function with PF and MF in youths. The results show that explosive strength was a significant predictor of both information processing speed and inhibitory control, but aerobic fitness was only a significant predictor of inhibitory control and Δ Simon. Static strength and components of MF (speed and agility) were not related to any of the underlying cognitive tasks measured in participants.

Higher CRF levels have been reported to be a significant predictor of various [2,5,9,12,16] but not all [4,15,37] types of cognitive tasks in the literature. The results of the present study agree with the results of studies in older adults [4,38] in which CRF shows a positive effect across multiple aspects of cognition but a smaller effects on others such as information processing speed. Batouli and Saba [14] discussed the differences between types of physical activities and their influence on the brain. For instance, it has been shown that coordination training promotes activation of the visuospatial network, while aerobic training increases activation of the sensorimotor network [39], whilst resistance training changes the activity in the brain areas associated with response inhibition [40]. Therefore, it is possible that enhancing other PF components might influence the brain differently [40].

The results of this study also indicate that greater explosive strength was significantly associated with both information processing speed and inhibitory control. In contrast, we observed no association between static strength and any of the underlying cognitive tests in the youths. This finding contradicts the results seen among older adults in which a positive association was observed between static strength and cognition [41]. However, it should be noted that reduced muscle strength (measured mostly by grip strength) in older people may be an early marker of a delayed in nervous system processing with age which might be reflected in cognitive function [20]. On the other hand, our results are consistent with the results of Aberg et al. [3], who observed no association between static strength and cognitive function among a large sample of youths.

The association between explosive strength and cognition has been explored by other studies. Roebers and Kauer [3] studied a sample of children and observed a significant positive correlation between cognitive function and jumping. It is known that SLJ not only measures lower body explosive muscular strength but is also highly associated with upper body muscular strength [42]. The test has been suggested as a general index of muscular fitness [42] and positive determinant of bone mineral density in young people [43]. The reason for the significant association between the cognitive tasks and explosive strength (but not static strength) in the youths seen in our study is not clear. A possible explanation for the significant association between explosive strength and cognitive tasks could be that they share the same physiological mechanism. It has been argued that jumping does not depend on the muscles' ability to generate power, but rather on their capability to produce an impulse [44]. Muscle fibre type and composition determine, to a large extent, the impulse and neuromuscular stimulus in the following order: 1. arrival of the stimulus at the sensory organ; 2. conversion by the sensory organ to a neural signal; 3. neural transmission and processing; and 4. muscular activation [21,22]. Therefore, participants who can develop faster muscle activation will be able to generate a greater impulse and have a faster reaction in cognitive tasks compared to those with poorer physical characteristics [21,22].

Another important finding of this study was the lack of association between underlying MF and cognitive tests in the youths, which has limited evidence from the literature. Recently Moradi and Esmaeilzadeh [29] observed a significant association between information processing speed and agility (but not running speed) in a sample of apparently healthy preadolescent children. In a recent review by van der Fels et al. [10], it was suggested that speed and agility are weak predictors of cognition in apparently healthy children. However, most recently Hartman et al. [13] studied a sample of children with intellectual disabilities or borderline intellectual disabilities and observed that skill-related physical fitness (e.g. agility and coordination) was significantly associated with inhibition and cognitive flexibility. However, no significant association between aerobic fitness and executive function was observed.

The present study has some strengths including the use of linear models to assess the association between the variables and the inclusion of potential confounders (e.g. SES, adiposity and PA). However, the study has some limitations. Due to the cross-sectional nature of this study, causal inferences cannot be made. Therefore, longitudinal and intervention studies are needed to explore the effects of increased explosive strength versus CRF on underlying cognitive tasks in young males. Second, the present study has only explored part of the cognitive functioning and further studies are needed to explore other dimensions of cognition (e.g. working memory, long-term memory, task-switching). Third, due to cultural reasons we did not include participants of both sexes. Therefore, the results cannot be generalized for females. It is important to note that a systematic review showed evidence that gender differences might affect the association between fitness and cognition/academic performance in young people [2]. Finally, although we invited 481 individuals to participate, only 211 met the inclusion criteria and completed all the measurements. This is below the targeted sample of 250 for stable estimates of correlation [45].

CONCLUSIONS

In summary, this study shows that PF components such as explosive strength and aerobic fitness are associated with underlying cognitive tasks in the youths. However, MF components, as well as static strength, were not related to cognitive performance in youths. Although CRF has been reported as the most important aspect of PF, [2,5,9,12,16], the results of the present study indicate that other PF components such as explosive strength (impulse) may also be an important indicator of cognitive performance in youths. These results suggest that PA programmes aiming to enhance cognitive function in young adults might need to include not only aspects of aerobic fitness but also explosive strength. However, more research is needed on the relationship between aspects of MF and cognition in youths.

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Conflict of interest

The authors have no conflicts of interest to declare.

Authors' contributions

Samad Esmaeilzadeh designed the study, analyzed data and wrote the paper. Samad Esmaeilzadeh, Reza Farzizadeh and Hassan-Ali Kalantari contributed to the acquisition of data. Esther Hartman, Liane B. Azevedo, Inga Dziembowska and Alicja Kostencka made substantial contributions to designing the study, language editing and revision of the paper. Mohamad Narimani and Akbar Abravesh helped in statistical analysis and revising the paper. All authors have read and approved the final version of the manuscript and agree with the order of the presentation of the authors.

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