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Soccer Trained 6-11 year Old Children Demonstrate Better Executive Function Compared to Untrained Peers

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Abstract

The aim of the study was to compare the executive function (EF) between soccer trained (ST) and untrained (UT) 6-11 year old children. In addition, the relationship between EF and aerobic fitness was evaluated. In all, 18 ST children and 12 UT children participated in this study. EF was evaluated using the ADAM4 battery. Pulmonary oxygen uptake (VO_2) was measured during constant treadmill walking (6 km/h, 4% grade, 6 min) and during an increasing walking exercise (modified Balke test). The ST children demonstrated better visual tracking and attention (95.97 ± 1.74%/94.4 ± 1.59%), response inhibition (96.49 ± 1.35%/93.72 ± 3.16%), speed of processing and alternating attention with a motor speed component (97.18 ± 3.0%/93.72 ± 2.16%) compared to the UT children ($p<0.05$). The time constant of VO_2 kinetics during the constant walking exercise was shorter and the maximal VO_2 was higher in the ST children (16.88 ± 2.19 s; 57.2 ± 6.0 ml/kg/min) compared to the UT children (20.99 ± 1.46 s; 48.1 ± 7.4 ml/kg/min) ($p<0,05$). There was a significant negative correlation between the cognitive tests and time constant of the VO_2 kinetics. We concluded that the ST 6-11 year old children demonstrated and better as well as higher aerobic fitness EF compared with their UT peers. There was no correlation between aerobic fitness and EF indicators in any group of subjects.

Keywords: Oxygen uptake; Children; Executive function; Physical activity

Introduction

In times when children are less active [1], the significance of studies on the positive impact of sport on physical health, mental health, and cognitive functioning, is essential. Cognitive function is a general term reflecting different processes, such as working memory, memory, attention, pattern recognition, executive function (EF), intelligence, concept formation and reasoning and academic achievement [2]. Physical inactivity may be associated with lower cognitive function among adults and the elderly [2,3]. The influence of physical activity and aerobic capacity on cognitive function during childhood has only recently gained attention. There are hypotheses stating that physical activity may influence physiological changes in the brain and that physical activity may develop cognitive skills especially EF [3]. EF is a term that comprises inhibitory control, working memory, and attention flexibility that regulate goal-directed action and adaptive responses to novel, complex, or ambiguous situations [4]. These functions may be important prerequisite for successful learning in prepubertal children [5]. Within the preadolescent age range, meta-analyses have shown that enhanced cognitive functioning as a result of physical activity is most clearly seen in EF and attention [6] and the significant moderate positive effects of physical activity on children's EF are usually observed [7]. The longitudinal physical activity programs have positive small to moderate effect on EF [8]. Recently Bidzan-Bluma and Lipowska [9] have concluded that engaging in sports in prepubertal age positively influences cognitive and emotional functions. However the results regarding the influence of sports on cognitive functions in prepubertal children are contradictory. Some authors report that sports have a positive influence [10,11] particularly on EF. Others, however, do not confirm this positive influence of physical activity on cognitive functioning [12,13].

Hillman and colleagues have reported more improvement from pre-test to post-test in some aspects of cognitive performance and measures of brain function in children aged 8 to 9 years who followed the FITKids intervention versus a control group [14]. Schmidt et al. have found that in 10- to 12-year-old children the group that participated in a cognitively- and physically-demanding exercise intervention (team games) showed more improvement from pre-test to post-test on cognitive flexibility (i.e, being able to shift from one task to another) than the group receiving an aerobic intervention with low cognitive demands or the group receiving standard physical education with low physical and low cognitive demands [15]. On the other hand cross-sectional studies have demonstrated that aerobic fitness is positively related to executive control, with more fit children exhibiting superior attention, decision-making ability, and differential brain function compared with their lesser-fit peers [16,17].

There is a paucity of publications that investigate the impact of sports on prepurbetal children cognitive functions, or explore which cognitive functions are developed by which sporting disciplines. Such knowledge would be useful in developing training programs for pre-adolescents, aimed at improving cognitive functions that may guide both researchers and practitioners relative to the wide range of benefits that result from physical activity.

Soccer training and playing is associated both with development of motor skilled, tactical thinking, and increase in aerobic and anaerobic fitness. So, we have hypothesized that several years of soccer training should improve EF in prepubertal children.

Cross-sectional studies [16,17] have demonstrated that aerobic fitness is positively related to executive control, with more fit children exhibiting superior attention, decision-making ability, and differential brain function compared with their less-fit peers.

The aim of the study was to compare the EF between ST and UT 6-10 year old children. In addition, the relationship between EF and aerobic fitness was evaluated.

Participants

In all, 12 untrained (UT) and 18 soccer trained (ST) 6-11 year old children participated in this study (Table 1). UT children we invited children from general schools. These children did not have any specific physical education, except for physical education lessons in school (2 times/week, 45 min/time), which are obligatory for every healthy children in Lithuania. The ST children were soccer players with a training experience of 5.0 ± 1.5 years. All ST group children were invited from Kaunas soccer club. Participants had soccer training 3 times/week, for two hours. Children participated in soccer events, regional championships and soccer matches. Written informed consent was obtained from the parents, and written assent was obtained from the participants. The criteria that eliminated the participants from research were: heart disease, diabetes, epilepsy, and musculoskeletal problems, first signs of puberty. Ethical approval for the research was obtained from the Kaunas Regional Ethics Committee.

	UT (n=12, 7 boys, 5 girls)	ST (n=18, 13 boys, 5 girls)
Age (yr)	9.41 ± 1.92	9.95 ± 1.49
Height (m)	1.42 ± 0.18	1.44 ± 0.10
Weight (kg)	38.08 ± 7.1	37.96 ± 6.42
BMI (kg/m^2)	18.88 ± 0.94	18.55 ± 1.43
UT: Untrained Children; ST: Sport Trained children		

Table 1: Subject characteristics.

Materials and Methods

Anthropometry

The heights of the participants were measured to the nearest 0.01m using a stadiometer. Body mass was measured using a body composition analyzer, the TBF-300 (Japanese). BMI was calculated as the body mass (kg) divided by the height squared (m^2).

Constant walking exercise (CWE)

The exercise was performed on a motor driven treadmill (HP Cosmos, USA). To familiarize the participants with treadmill walking and give them a slight warm-up, the exercise started with slow walking on treadmill (at 3 km/h, 0% grade) for 3 min. Then, the participants stood on the sides of treadmill for 1 min. During this period of time treadmill speed was increased to 6 km/h and the slope to 4%. At the end of the minute, the participants stepped on the moving treadmill and continued walking for 6 min. After this, the treadmill was stopped and the participants rested in the supine position for 5 min.

Increasing walking exercise (IWE)

The modified Balke test was performed on the same treadmill. Following one min of standing, the participants started walking at 5.6 km/h and 0% for three min. After this, they continued walking at the same speed while the treadmill grade was increased every min by 2%. The subjects were verbally encouraged to give maximal effort during the test and continued walking until voluntary fatigue (exhaustion).

Pulmonary gas exchange

The pulmonary gas exchange parameters were continuously measured breath-by-breath with a portable telemetric system (Oxycon Mobile, Jaeger, Germany). The flow-volume sensor and the gas analyzer (gas mixtures containing 5% CO_2 and 16% O_2 were used) were calibrated using automatic calibration procedures, as provided by Jaeger, before each test session.

Heart rate

The HR was recorded with a "Polar" system. Children wore a pediatric wireless chest strap telemetry system to monitor the HR.

Cognitive function evaluation

The Automated Neuropsychological Assessment Metrics version 4 (ANAM4) was used to evaluate cognitive function. The four performance tests were, in the order of administration: the 2-Choice Reaction Time test (2CRT), Code Substitution-Learning (CSL), Go/No-Go test, and Simple Reaction Time (PRO) (Table 2). The specific tests assess areas or domains of cognitive functioning, including attention/concentration, reaction time, processing speed, working memory, visuospatial skills, motor speed, memory, reasoning and problem solving. Among a number of output measures, we utilized the percent correct #((NumCorr/(NumCorr+Numinc+NumLapse))) and throughput of correct responses #((=NumCorr/((NumCorr +Numinc)*Mean RT+NumLApse*Timeout))). The throughput metric is defined as the number of correct responses per minute and is thus a useful metric for overall cognitive efficiency. It took ~15-20 min for the participants to complete the tests [18].

#NumCorr: Number of trials with a correct response.

Numinc: Number of trials with an incorrect response.

NumLapse: Number of trials in which no response was made in the allotted time.

Meant RT: Mean response time of all items (correct & incorrect).

Test	Description of test	Cognitive domain
2CRT	This test measures choice reaction time by presenting the user with a "*" or "o" on the display. The subject is instructed to respond as quickly as possible by pressing the designated button for each stimulus as soon as the stimulus appears.	This test measures choice reaction time.
CSL	In this test, the subject must compare a displayed digit-symbol pair with a set of defined digit-symbol pairs or the key. The user presses designated buttons to indicate whether the pair in question represents a correct or incorrect mapping relative to the key. In the learning phase, the defined pairs are presented on the screen along with the digit-symbol pair in question.	Results of this test are used as an index of complex scanning, visual tracking, and attention.
Go/No-Go	The subject is presented with two characters, "x" and "o". The subject is instructed to respond as quickly as possible to the "x" by pressing a button each time the stimulus appears. When the "o" appears, the user is to do nothing.	This test assesses response inhibition.
PRO	The subject clicks the left mouse button (single-button response) when an asterisk stimulus is presented on the screen. This stimulus is presented at different intervals for 40 trials, and the reaction time for each trial is recorded. This subtest assesses reaction time.	Results of this test are used as an index of attention and visuo-motor response timing.

Table 2: Descriptions of the cognitive tests [18].

Study design

The participants came to the laboratory 3 times. The participants were asked to do cognitive tests on the first arrival. First, the participants were learning to do cognitive tests (performed 2 trials), and then, the true test was recorded for evaluation. It took approximately 20-30 min to complete the cognitive tests battery. The participants were asked to not undergo intense exercise at least for 24 h before the second arrival to the laboratory. During this visit, two CWE sessions (separated by 45 min) were performed. After 3 to 7 days, the participants arrived at the lab for the third time and performed IWE.

Data analysis

VO_2 kinetics during CWE was determined using a mono-exponential model. The following equation was used to model mono exponential VO_2 response kinetics: $VO_2(t) = VO_2(b) + A(1\_e\_t/\tau)$, where $VO_2(t)$ is the VO_2 at any time point; $VO_2(b)$ is the baseline VO_2 during 30 s before exercise; A is the amplitude of the VO_2 response; and $(1\_e\_t/\tau)$ is the exponential function describing the rate at which the VO_2 is rising toward the amplitude. In the exponential function, t is time; τ is the time constant. The initial 20 seconds of the test were not included in the analysis.

The peak oxygen uptake (VO_2peak) was determined as the highest VO_2 within a 20-sec period during the IWE.

Statistical analysis

All values are expressed as the mean ± standard deviation. The comparisons of the results were analyzed by one-way ANOVA. Significance was accepted at $p<0.05$. Pearson's correlations were performed using a correlation matrix to examine the relationship between the oxygen uptake parameters and cognitive tests results. Significance was accepted at $p \leq 0.05$.

Results

No statistically significant difference of age, height, weight or body mass index was found between ST and UT groups (Table 1).

The time constant of oxygen uptake kinetics during constant walking exercise was significantly different ($p<0.05$) between the UT (20.99 ± 1.46) and the ST (16.99 ± 2.37) 6-11 year old children.

The VO_2 peak during increasing walking exercise was significantly different between the UT (48.1 ± 7.41) and ST (57.26 ± 5.24) 6-11 year old children. The VO_2 peak was significantly different among the age groups in the ST and UT groups ($p<0.05$).

The executive function results are shown in Table 3.

ANAM4	Group	ProcCOR	p	Troughtput	p
CSL	UT	94.4 (± 1.59)	0.013*	58.39 (± 7.07)	0.675
	ST	95.97 (± 1.74)		58.00 (± 5.76)	
Go/No/Go	UT	93.72 (± 3.16)	0.006*	-	
	ST	96.49 (± 1.35)			
2CRT	UT	93.72 (± 2.16)	0.000*	136.04 (± 10.2)	0.697
	ST	97.18 (± 3.00)		134.56 (± 8.57)	
PRO	UT	93.96 (± 1.72)	0.213	90.15 (± 1.64)	0.049*

	ST	94.32 (± 1.94)		92.17 (± 2.74)	
*p<0.05					

Table 3: Results of executive function in untrained and soccer trained 6-11 years old children.

The CSL results were significantly different between the ST (95.97 ± 1.74%) and UT (94.4 ± 1.59%) children ($p<0.05$), and the Go/No-Go test results were significantly different between the ST (96.49 ± 1.35%) and UT (93.72 ± 3.16%) children ($p<0.05$). The 2CRT results were significantly different between the ST (97.18 ± 3.00%) and UT (93.72 ± 2.16%) 6-11 year old children ($p<0.05$).

Correlation in ST and UT groups between EF and aerobic fitness are shown in Table 4.

		Correlations							
		ST group				UT group			
		CHR	GNG	CSL	PRO	CHR	GNG	CSL	PRO
VO_2 peak	Pearson Correlation	0.084	0.082	0.063	-0.218	.613*	-0.081	.684*	.638*
	Sig. (2-tailed)	0.742	0.745	0.805	0.386	0.034	0.802	0.014	0.026
	N	18	18	18	18	12	12	12	12
t1	Pearson Correlation	-0.155	-0.413	-0.411	0.225	-0.313	0.265	-0.166	-0.321
	Sig. (2-tailed)	0.539	0.088	0.091	0.369	0.322	0.406	0.606	0.309
	N	18	18	18	18	12	12	12	12
*Correlation is significant at the 0.05 level (2-tailed)									

Table 4: Correlation in ST and UT groups between EF and aerobic fitness.

There was no significant correlation between aerobic fitness and EF indicators in any group of subjects.

Discussion

The main finding of this study is that 6-11 year old ST children demonstrated better a EF compared to their untrained peers. In addition, the aerobic fitness was significantly higher in ST group as well. But there was no significant correlation between aerobic fitness and EF indicators in any group of subjects.

Our results suggest that both training and playing soccer for several years and/or an increased aerobic capacity may have an influence on better EF. Several metaanalysis have revealed that physical activity has small to moderate positive effect on EF in prepubertal children [6-9].

However, the studies of the benefits of sports for EF are scarse. It has be suggested that sports might benefit EF more than aerobic exercise alone, since besides improving fitness, sports challenge EF (requiring sustained attention, working memory, and disciplined action) and bring joy, pride, and social bonding [19]. Children getting traditional Tae-Kwon-Do training were found to show greater gains of EF than children in standard physical education [20]. It has been recently shown that basketball activities enhanced EF and working memory scanning speed in adolescents [21]. Hillman and colleagues have reported more improvement from pre-test to post-test in some aspects of cognitive performance and measures of brain function in children aged 8 to 9 years who followed the FITKids intervention versus a control group [14]. Schmidt et al. have found that in 10- to 12-year-old children the group that participated in a cognitively- and physically-demanding exercise intervention (team games) showed more improvement from pre-test to post-test on cognitive flexibility (i.e., being able to shift from one task to another) than the group receiving an aerobic intervention with low cognitive demands or the group receiving standard physical education with low physical and low cognitive demands [15]. So, it seems that soccer playing and training may be very effective for EF in prepubertal children. Our findings show that, 6-11 year ST children demonstrate a higher processing speed and alternating attention with a motor speed component, reaction time, attention, response inhibition and an index of attention compared with untrained children.

Several mechanisms might explain the effects of physical activity on cognitive functions. First, acute physical activity is thought to immediately elevate the child's level of physiological arousal, which in turn facilitates the cognitive performance by an increased allocation of attention [22]. In addition acute physical activity leads to an increase of neurotransmitters (e.g. epinephrine, dopamine, brain-derived neurotrophic factors), which may enhance cognitive processes [23].

Secondly, regular aerobic physical activity over several weeks is thought to improve aerobic fitness and consequently improve cognitive performance [24]. It is suggested that EF is more strongly related to physical fitness than it is to physical activity [25]. Physical activity enhances the angiogenesis and neurogenesis in areas of the brain that support memory and learning, subsequently enhancing cognitive performance [16,26]. More recently, other researchers argue cognitively engaging physical activity is more beneficial for cognition. Physical activities with a relatively high cognitive engagement (e.g. sports games are suggested to have more effect on EF compared to physical activities with a relatively low cognitive engagement (e.g. long distance running, which involves more automated movements) [15,27]. Sport trained children are characterized as having larger brain volumes in the basal ganglia and hippocampus. This relates to a higher performance on tasks of memory and cognitive control and also to a higher brain function during tasks of cognitive control and better scores on tests of academic achievement [28]. Ortega et al., [29] proved that all physical fitness components, cardiorespiratory fitness, muscular strength and speed agility, were significantly related to the shapes of the subcortical brain nuclei. These associations were positive, indicating that a higher level of fitness in childhood is related to both expansions and contractions in certain regions of the accumbency, amygdala, caudate, hippocampus, pallidum, putamen and thalamus. Physical activity has a positive benefit for brain structure, brain function, cognition, and school achievement among 7-10 year old children [28]. Physical activity and healthy diets have a positive influence on cognitive outcomes even in early childhood [30]. Additionally, single bouts of moderate intensity exercise may be an effective means for modulating neural activity and can help regulate attention [31].

The sport trained children in our study demonstrated a 20% higher VO_2 peak than their untrained peers. This is a larger difference than that usually found in exercise training studies, in which the increase due to training or physical activity is approximately 5-6% [32,33]. In reviewing 15 studies, including 22 experimental groups of pre-pubertal (younger than 11 years old) child athletes, Armstrong and Barker [34] found a mean VO_2 max improvement of only~6.5%. Nevertheless, pediatric studies employing high-intensity training have typically shown VO_2 max gains of well less than 9% [35-37]. The participants in our study were training for soccer for several years which involves both long aerobic and intensive aerobic explosive strength activities. This may explain the rather high difference in aerobic capacity between the groups. It is even better than with recently published data of the study in which the group performing the high-intensity exercises increased their cardiorespiratory fitness by approximately 10% [38]. The physiological mechanisms of such a difference are not quite clear yet (for a detailed analysis [39]). In short, all of the training induced VO_2 max changes must be related to an increased cardiac output, an arterio-venous O_2 difference, or both. There are data suggesting that the maximal VO_2 differences of youth athletes and non-athletes are similar. It is suggested that pre-pubertal children are not able to activate fast motor units during daily activities or even during training, so they have less potential to increase the VO_2 peak and other aerobic parameters during training [40]. Therefore, training induced changes in the VO_2 peak have been associated with increases in oxygen delivery. Both morphological and functional adaptations of the myocardium have been hypothesized as explanations for an augmented stroke volume following training. Increases in the blood volume, left ventricular dimensions and mass, intraventricular and posterior wall thickness, shortening fraction, and ejection fraction have been postulated, but empirical evidence is sparse and conflicting [34,41].

In our study, a faster VO_2 time constant was found in the ST 6-11 year old children compared with their untrained peers. The difference (19.5%) is similar to that in the case of the VO_2 peak. Data on youth VO_2 kinetics trainability are, however, sparse and largely reliant on four comparative studies of trained soccer players and swimmers compared to untrained youth from two research groups [41]. As the trained pubertal girls exhibited faster [HHb] kinetics and HR kinetics than their untrained pubertal girls, the authors suggested that the faster τ could be attributed to both enhanced oxygen delivery and enhanced oxygen utilization [33,41].

McNarry and colleagues [42,43] contrasted the responses of swim-trained and untrained pre-pubertal and pubertal girls at the onset of heavy intensity exercise and indicated a shorter phase II τ in both trained groups than in their untrained peers during an arm-cranking exercise and a shorter Phase II τ during a leg-cycling exercise in the trained pubertal girls. On the basis of observing faster HR kinetics and HHb kinetics in the trained pubertal girls, McNarry et al. [42] hypothesized that their shorter phase II τ was a function of both enhanced oxygen delivery to the muscles and enhanced oxygen utilization in the muscles.

Some authors found that aerobic fitness is positively related to executive control, with more fit children exhibiting superior attention, decision-making ability, and differential brain function compared with their lesser-fit peers [16,17]. In our study the corerlation between EF and aerobic fitness within groups was not significant. It may be associated with small number of participants in groups and with not large dispersion of data correlated. On the other hand correlation does not show the causality of relationship so we cannot exlude the role of higher aerobic fitness in better EF in ST group due to mechanisms discussed above.

The limitation of the study may be associated with cross sectional study design which does not allow to assess the influence of initial fitness and cognitive function level on the differences found between groups. In the future there is need for longitudinal study of children involved in regular sports training.

Conclusion

6-11 year old ST children demonstrated better a EF compared to their untrained peers. The aerobic fitness was significantly higher in ST group as well. There was no significant correlation between aerobic fitness and EF indicators in any group of subjects.

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