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Influence of acute exercise on inhibitory control and working memory of children: a comparison between soccer, resistance, and coordinative exercises

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BACKGROUND: *The effects of resistance, coordinative, and comprehensive exercises on the executive function of children have not yet reached a conclusion due to inconsistent findings and paucity of evidence. This study compares the acute effects of resistance, coordinative, and soccer exercises on inhibitory control and working memory of children.*

METHODS: *A total of 145 Chinese children (71 girls and 74 boys) aged 10-12 years old were recruited to participate in a pretest-post test randomized group study. Participants were randomly assigned to 40 minutes of resistance training, coordinative training, soccer training, and control groups (watching of cartoons). The inhibitory control and working memory of participants were measured via Go/NoGo, 2-back test, respectively, before and after the assigned intervention.*

RESULTS: *Results of repeated analysis of variance (ANOVA) demonstrated that time × group interaction was significant in terms of accuracy rate of Go/NoGo test, and the reaction time and accuracy rate of 2-back test. Compared with those in the control group, participants in the resistance, coordinative, soccer training groups had shorter reaction time in the 2-back test, and better accuracy rate in Go/NoGo and 2-back tests. However, no significant difference was observed in the reaction time and accuracy rate of both tests between the three exercise intervention groups.*

CONCLUSION: *Acute resistance, coordinative training, and soccer training with moderate intensity have positive impacts on the inhibitory control and working memory of children, at least temporarily. No difference in executive function improvement was found in the three types of exercise.*

KEY WORDS: Coordinative exercise, Inhibitory control, Resistance exercise, Soccer, Working memory.

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Introduction

Executive function (EF) refers to individuals' neuropsychological ability to control and coordinate their thoughts and behavior, which need concentration and attention (Diamond, 2013). Several studies demonstrated that EF is related to the academic performance and social interaction of children (Best, Miller, & Naglieri, 2011; Brock, Rimmkaufman, Nathanson, & Grimm, 2009; Mcevoy, Rogers, & Pennington, 1993; Rothlisberger, Neuenschwander, Cimeli, & Roebers, 2013; Titz & Karbach, 2014). Therefore, EF is crucial to the psychological health development of children (Diamond, 2013). The three categories of EF are inhibitory control (IC), working memory (WM), and other EF tasks that do not fit into IC or WM (Ilieva, Hook, & Farah, 2015). IC is the ability to control one's attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external lure and perform appropriate or necessary action (Diamond, 2013). WM refers to the ability to hold information in the mind and mentally work with such an information (Diamond, 2013). Other EF tasks that do not fit into IC or WM may include but are not limited to attention or task switching and planning (Banich, 2009). The aim of the present study was to compare the acute effects of different exercise types on IC and WM of children.

In the past two decades, several researchers discovered that chronic aerobic exercise and acute aerobic exercise are conducive to the improvement of EF performance in children (Verburgh, Konigs, Scherder, & Oosterlaan, 2014). Chen et al. reported that acute aerobic exercise, such as 30-minute aerobic running, can increase the EF test scores of teenagers (Chen, Yan, Yin, Pan, & Chang, 2014). However, another study found inconsistent results: adolescents maintain their inhibitory control, whereas their working memory declines after walking on a treadmill at a moderate intensity (Soga, Shishido, & Nagatomi, 2015). Ludyga et al. summarized data from 40 experimental studies and concluded that acute moderate aerobic exercise has slight positive impacts on EF (Ludyga, Gerber, Brand, Holsboer-Trachsler, & Puhse, 2016). In general, the improvement of cognitive functions could be attributed to the increase of cerebral circulation, alteration of the action of neurotransmitters, and the state of arousal (Kashihara, Maruyama, Murota, & Nakahara, 2009).

"Arousal" theory is one of the popular theories that explain the mechanism how acute exercise influences cognitive functions. Arousal is the physiological and psychological state of wakefulness or the sense organs stimulated to a point of perception, which is important in regulating attention and memory storage (Sharot & Phelps, 2004). The type and intensity of physical activity was found to be associated with states of arousal and cognitive performance (Lambourne & Tomporowski, 2010). Exercise-induced arousal involves the activation of the reticular-activating system, which regulates ascending projections to the prefrontal cortex in the brain (Iwanczuk & Guzniczak, 2015). An inverted-U hypothesis was proposed on the basis of "arousal" theory; this hypothesis predicts that cognitive task performance would increase to a peak level as exercise-induced arousal increases before declining with increased levels of physiological arousal (Mcmorris & Graydon, 2000). Most existing studies focused on the influence of moderate aerobic exercise on cognitive functions (Byun, et al., 2014; Lambourne & Tomporowski, 2010; Soga, et al., 2015). An interestingly popular research direction is whether different types of exercise (e.g., resistance and coordinative exercise) with moderate intensity have the same effects on the EF of children.

Several studies investigated the effects of resistance training on EF and interesting results were found in adults (Chang & Etnier, 2009; Tsai, et al., 2014) and adolescents (Harveson, et al., 2016) but not in children. Tsai et al. (2014) investigated the influence of resistance training with different levels of intensity (80% 1RM, 50% 1RM, and non-exercise) on EF in young adults and explored potential biochemical mechanisms. In the study, participants completed 40 minutes of resistance training on exercise machines including bench presses, biceps curls, triceps extensions, leg presses, vertical butterflies, and leg extensions. The serum levels in cortisol were significantly decreased after acute high-intensity and moderate intensity resistance training, and the changes of cortisol levels were found to be associated with the changes in electrophysiological performance in cognitive tasks. The results supported the beneficial effects of acute resistance training on EF but also indicated that the positive influence could be due to changes in arousal and possibly modulated by serum cortisol levels (Tsai, et al., 2014). A randomized controlled trial study in adults also provided research evidence that acute resistance training, which included 2 sets of 10 repetitions for 6 exercises, has positive effects on speed of processing and shifting of the habitual response, but no significant effects were found on inhibition (Chang & Etnier, 2009). Harveson et al. also compared the effects of 30-minute aerobic exercise and resistance exercise on cognitive function in 16-year-old high school students (Harveson, et al., 2016). The results showed that acute aerobic exercise (30 minutes of walking/jogging with 50%-60% maximum heart rate) and resistance exercise (2 sets of 15 repetitions in 6 exercises) could increase cognitive function. However, the positive acute effects of resistance exercise on EF found in adults and adolescents cannot be generalized across age groups due to the paucity of related studies on children.

Besides resistance training, another potentially appropriate exercise type for enhancing EF is that of coordinative exercises. Coordinative exercise refers to complicated exercise that requires the participation and cooperation of multiple body parts to realize specific goals. This form of exercise requires the nervous system to shift between activation and inhibition quickly to ensure accuracy and coordinative control of actions (Egan, Verheul, & Savelsbergh, 2007). Coordinative exercise is involved in the activation of the frontal lobe, which may influence attention and working memory (Budde, Voelckerrehage, Pietrabykkendziorra, Ribeiro, & Tidow, 2008; Courchesne, et al., 1994). The frontal lobe is the neuronal structure in charge of executive function and motor coordination (Hernandez, et al., 2002). Therefore, coordinative exercise could potentially improve the EF of children, given the likely similarity in the brain function for these activities. Studies further proved that teenagers show shorter reaction time (RT), higher accuracy rate (AR) (Chang, Tsai, Chen, & Hung, 2013) and higher attention level (Buddle, Voelcker-Rehage, Pietrassyk-Kendiziorra, & Ribeiro, 2008) in an EF test after coordinative training.

The third type of exercise of interest is that of comprehensive exercises. Comprehensive exercise items may have better or at least similar effects given that aerobic exercise and resistance training may influence EF in different pathways (Huang, Larsen, Riedlarsen, Moller, & Andersen, 2014; Tsai, et al., 2014). For example, soccer is a comprehensive exercise that involves aerobic exercise, muscular strength, and coordination (Egan, et al., 2007); different components are considered equally important in soccer (Stolen, Chamari, Castagna, & Wisloff, 2005). Teenagers who received six months of soccer training could achieve outstanding progresses in agility, working memory, attention, planning, and inhibition (Alesi, Bianco, Luppina, Palma, & Pepi, 2016). Another study reported that eight weeks of soccer training is beneficial to the EF development of teenagers (Jiang & Zeng, 2015). However, only a few studies reported the acute impacts of soccer exercise on the EF of teenagers. Thus, it is of interest to examine the effects of a comprehensive exercise like soccer in this scope of work.

In summary, existing studies showed that chronic and acute exercises have positive impacts on the EF of children (Chen, et al., 2014; Hillman, Kamijo, & Scudder, 2011; Soga, Masaki, Gerber, & Ludyga, 2018). However, whether resistance, coordinative, and comprehensive exercises training have positive influence on children's EF remain unclear due to inconsistent findings (Brush, Olson, Ehmann, Osovsky, & Alderman, 2016; Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009) and paucity of evidence (Soga, et al., 2018). Since exercise intensity was identified as a key factor that influences the effects of physical activity on EF, whether different types of exercise with similar intensity have the same effects on cognitive function remains unclear.

In the current study, it was hypothesized that there are differences in improvement in the IC and WM tests after acute resistance training, coordinative training, soccer training and sedentary behaviors.

Methods

Participants

Participants were recruited from a primary school through school propaganda and publicity materials sent to parents. In the advertisement, parents were informed of the purpose, content, and procedure of the research. Participating children and parents were required to sign a consent form and complete a questionnaire to report children's mental and physical health status. The study was approved by the ethics committee of the China Institute of Sport Science. The inclusion standards of participants were: 1) no cardiovascular, psychological, and nervous system disease; 2) no recent intake of drugs; 3) dextromanual; 4) normal vision and 5) able to accomplish moderate-intensity exercise. A total of 161 pupils participated in this study. Using computer-generated numbers, participants were randomly divided into soccer training (n=40), resistance training (n=41), coordinative training (n=40), and control groups (n=40). Data of 16 children were excluded due to incomplete data, poor training performance (e.g., did not reach the target exercise heart rate of 125–155 beats/min), or decision to drop out. Finally, the data of 145 pupils were included in the analysis, including 32 in soccer training (15 boys and 17 girls), 41 in resistance training (22 boys and 19 girls), 35 in coordinative training (17 boys and 18 girls), and 37 in the control group (20 boys and 17 girls) (Figure 1). The age of participants ranged from 10 to 12 years old. Participants had no significant differences in age, gender, and body mass index (BMI) (Table I).

Procedure

The pre-test of EF was conducted seven days before the intervention (exercise training or watching cartoon films). Participants were instructed not to participate in any moderate to high intensity exercises or refrain from taking any medication three days before the EF test. During the intervention, participants were required to complete 40 minutes of resistance training, coordinative training, soccer training or watch 40 minutes of cartoons in groups, according to random allocation.

After the intervention program, participants were given 15minutes to rest. The post-test of EF was conducted when the heart rates of participants recovered to the

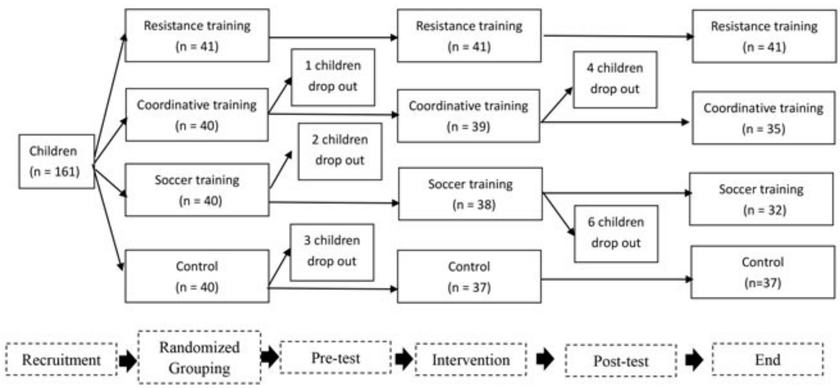

Fig. 1. Chart flow of research.

TABLE I
Descriptive Data Of Participants' Demographic Characteristics And Exercise Manipulation

	Control	Coordinative Training	Resistance Training	Soccer Training	Total	p
n	37	35	41	32	145	
Number of girls (%)	17 (45.9%)	18 (51.4%)	19 (46.3%)	17 (53.1%)	71(49.0%)	.93
Age (y)	10.9±0.4	10.9±0.3	11.0±0.31	10.9±0.30	10.9±0.3	.35
BMI[1] (kg/m^2)	18.1±0.8	17.9±0.4	17.8±0.3	17.9±0.2	17.9±0.5	.34
Resting HR	85.1±12.1	86.2±11.8	85.6±11.7	85.3±12.3	85.6±11.9	.68
Average HR during intervention	89.5±10.3$^{\#*\S}$	132.6±12.3$^{\#}$	135.2±11.7*	139.3±12.1§	123.1±11.6	.00
HR after intervention	87.3±11.8$^{\#*\S}$	121.1±7.8$^{\#}$	118.8±8.5*	122.3±8.2§	112.1±9.0	.00

Note: BMI: Body Mass Index;
$^{\#}$: significant difference between control and coordinative training groups
*: significant difference between control and resistance training groups
§: significant difference between control and soccer training groups

±10% range of their resting heart rate. Two trained testers performed EF measurements in pre and post-tests at 3:00 p.m. to 4:00 p.m.. The pre and post-tests were implemented in a quiet and bright classroom. Participants received pre-training before the formal test, wherein they were informed of the test procedures. They could also perform practices on sample test items under the guidance of researchers. The participants began to take the formal test once they fully understood the various tasks' requirements.

TABLE II
Comparison Of Reaction Time And Accuracy Rate In Go/Nogo And 2-Back Test

Task	**RT/Accuracy rate**	**Control**	**Resistance**	**Coordinative**	**Soccer**
Go/NoGo	Pre-RT (ms)	701.5±38.5	704.7±34.2	695.2±37.7	690.1±26.5
	Post-RT (ms)	694.3±104.4	710.3±55.9	681.5±55.3	716.2±84.6
	Pre-accuracy	$0.87±0.02^{\#*\S}$	$0.89±0.05^{*}$	$0.88±0.02^{\#}$	$0.87±0.06^{\S}$
	Post-accuracy	$0.90±0.11^{\#*\S}$	$0.95±0.08^{*}$	$0.97±0.06^{\#}$	$0.96±0.04^{\S}$
2-back Test	Pre-RT (ms)	$1054.7±247.6^{\#*\S}$	$1041.2±275.7^{*}$	$1073.3±252.3^{\#}$	$1043.7±364.5^{\S}$
	Post-RT (ms)	$909.4±192.7^{\#*\S}$	$821.8±266.3^{*}$	$788.5±180.7^{\#}$	$810.6±153.9^{\S}$
	Pre-accuracy	$0.78±0.03^{\#*\S}$	$0.81±0.08^{*}$	$0.78±0.10^{\#}$	$0.80±0.10^{\S}$
	Post-accuracy	$0.82±0.13^{\#*\S}$	$0.87±0.15^{*}$	$0.87±0.08^{\#}$	$0.89±0.1^{\S}$

Note: #: significant difference between control and coordinative training groups
*: significant difference between control and resistance training groups
§: significant difference between control and soccer training groups

MEASUREMENT TOOLS

Go/NoGo Task

The IC of participants were measured via Go/NoGo test with the vision used by Burden et al. (2011). Go/NoGo task is a classical IC test with a long history, which is widely applied in neuropsychological assessments in both children and adults (Drewe, 1975; Langenecker, Zubieta, Young, Akil, & Nielson, 2007; Nakata, et al., 2008). The task demonstrated modest validity and high test-retest reliability (Langenecker, et al., 2007). In the current test, participants were invited to watch a randomly sequenced presentation of English letters at the center of a computer screen.The participants were informed to press the space bar on a keyboard as quickly as possible when any letter other than the letter "X" (Go stimulus) appeared, but not make any response when the letter "X" (NoGo stimulus) appeared. There were 2 blocks of trials with 40 trials in the first block and 180 trials in the second block. The first block was the practice trials. Prior to the second block, more trials could be given until participants fully comprehended the task. In the second block, 126 trials (70%) were Go trials and the other 54 (30%) were NoGo trials. The total display time for each stimulus was set at 500ms, with random interstimulus intervals ranging from 1,200 to 1,400 ms. Errors of response towards Go stimulus are typically considered as an indicator of inattention to the task, while NoGo errors and RT to Go stimulus were found to be related to impulsivity (Halperin, Wolf, Greenblatt, & Young, 1991; Manly, Davison, Heutink, Galloway, & Robertson, 2000). Therefore, in the current study, the dependent variables are the AR of response towards NoGo stimulus and RT for each Go stimulus. The RT is the time from when Go stimulus appeared to the time participants pressed the button (both correct and incorrect trials were included) and AR is the percentage of correct items in total items towards NoGo stimulus. All responses occurring between 100 and 1900 ms post-stimulus onset were considered valid.

2-Back Task

The WM of participants were measured using 2-back task via the version applied by Perlstein et al. (2003). The n-back task is a classical WM paradigm frequently applied in children and adults (Forns, et al., 2014; Leon-Dominguez, Martin-Rodriguez, & Leon-Carrion, 2015b). In brief, the 2-back task requires participants to correctly recall the content shown two trials ago. Better performance at this task suggests better working memory capacity. The validity and reliability of n-back test (including 2-back test) for measuring WM measurement among children and adults are supported by substantial scientific evidence (Forns, et al., 2014; Jacola, et al., 2014; Kulikowski & Potaszkulikowska, 2016; Leon-Dominguez, Martin-Rodriguez, & Leon-Carrion, 2015a). In the 2-back test, English letters were displayed alternately in the center of a computer screen. The total display time for each stimulus was set at 500 ms with inter-stimulus interval of 2500 ms. Participants need to use their dominant hand to press "space" or "enter" buttons on keyboard denoting "target" and "nontarget". In the current test, the target was any letter that was identical to the one presented two trials back. In this test, 33% of the trials were targets. Participants need to complete 6 blocks of trials with each block consisting of 25 trials. 30 seconds between blocks were provided to allow participants to rest. The initial 2 blocks were practice trials with feedback on their performance. Prior to the formal 100-trial test, up to 75 practice trials could be provided until participants understood the task and their performance stabilized. Performance in 2-back task was assessed based on the RT and AR. The RT is the time from when "target" or "nontarget" appeared to the time participants pressed the button (both correct and incorrect trials were included). AR is the percentage of correct trials in total trials towards both "target" and "nontarget". All responses occurring between 100 and 3000 ms post-stimulus onset were considered valid.

Interventions

For consistency sake, the intervention duration was set at 40minutes for the soccer training (comprehensive exercise), resistance training, coordinative training and control groups.

Soccer Training (Comprehensive exercise)

Soccer is a comprehensive exercise, wherein strength, power, and endurance are equally important (Stolen, et al., 2005). The soccer training group was led by a coach. The routine included 5-minute warm-up exercises, 5-minute tackler exercise, 8-minute moving dribble, 2-minute rest, 8-minute moving passing and catching, 2-minute rest, 8-minute dribble shot, and 2-minute cooling-down exercises. Preliminary tests before the formal study with 15 children were conducted in which the heart rates of children were measured via the POLAR TEAM 2 heart rate monitoring system during and after the exercises. The average heart rates after soccer training was 122.3 beats/min.

Resistance Training

The resistance training included 5-minute warm-up exercises and three groups of combined resistance training. One group of combined resistance training is composed of five groups of medicine ball tossing (head forward and body forward), push-up (20 for boys and 12 for girls), and sit-up (30 for boys and 20 for girls). A 3-minute rest was set between every two groups of combined resistance training. A previously conducted preliminary test showed that the average heart rates after resistance training was 118.8 beats/min.

Coordinative Training

Rope skipping, which requires participation and cooperation of arms and legs, is widely applied for coordination training. Rope skipping positively influences the development of coordination (Ozer, Duzgun, Baltaci, Karacan, & Colakoglu, 2011; Trecroci, Cavaggioni, Caccia, & Alberti, 2015). Shuttlecock kicking, which is also called Jianzi, is a popular traditional Chinese sport. The game requires good coordination among players using various parts of their body except the hands to keep a heavy shuttlecock from touching the ground. In the current study, coordinative training included 5-minute warm-up exercises and six groups of comprehensive coordinative training (approximately 35 minutes). Each group covered 1-minute rope skipping, 2-minute rest, 1-minute shuttlecock, and 2-minute rest. The results of preliminary tests showed that the average heart rates after coordinative training was 121.1 beats/min.

Control Group

Participants in control group were required to watch 40 minutes of cartoons in groups. Their average heart rate after the activity was 87.3 beats/min.

Randomization and blinding

We outsourced a statistician to perform the randomization and allocation for the four groups after pre-testing of IC and WM. Two researchers who were blinded to group allocation measured IC and WM. Research organizers (XW and FW) were not involved in the measurement work. Children and their parents were familiar about the group allocation, but they were blinded to the research hypothesis.

Statistical analysis

Statistical analyses were conducted for RT and AR using 4 (group: coordinative, resistance, soccer and control) × 2 (time: pre-intervention and post-intervention) repeated measures ANOVA to determine whether the four groups have differences in IC and WM improvement. Bonferroni post-hoc analyses were conducted when significant difference occurred. Partial eta squared (η^2) was applied to determine the effect size of the executive function test. A significance level of p=.05 was set in all the analyses. According to Cohen (Cohen, 1988), the following standard was applied to determine the magnitude of the mean effect size: small effect size $\eta^2<0.06$, medium effect size 0.07 $\eta^2<0.14$, and large effect size η^2 0.14.

Results

Go/NoGo task

Figure 2A illustrates the data of RT to the Go/NoGo task among the three exercise training groups and the control group before and after intervention. The results of repeated ANOVA demonstrated no significant main effect of time (F[1, 141]=1.37, p=.26, η^2=0.02) and group (F[3, 141]=2.16, p=.09, η^2=0.04) on RT. The interaction of time × group (F[3,141]=2.22, p=.08, η^2=0.03) was also insignificant. The data suggested that there is no significant change in RT in Go/NoGo task among the four groups.The AR of the Go/NoGo task was analyzed as shown in Figure 2B. Significant main effect of group (F[3, 141]=3.95, p=.01, η^2=0.78) and significant time effect (F[1, 141]=15.09,p=.00, η^2=0.964) were observed. The significant effects of the interaction of time × group was also identified (F [3, 141]=4.52,p=.01, η^2=0.78). According to multiple comparison of inter-group differences based on Bonferroni method, the ARs of coordinative, soccer, and resistance training groups are significantly higher than that of the control group. However, no significant difference was found among the three intervention groups in post hoc analysis.

2-back task

As shown in Figure 3a, the effect of time (F[1, 141]= 53.22, p=.00, η^2=0.28), group (F[3, 141)]=4.59, p=.00, η^2=0.89), and interaction of time × group (F[3,141]=13.13, p=.00, η^2=0.22) were significant in the 2-back task. The coordinative, resistance, and soccer training groups have significantly

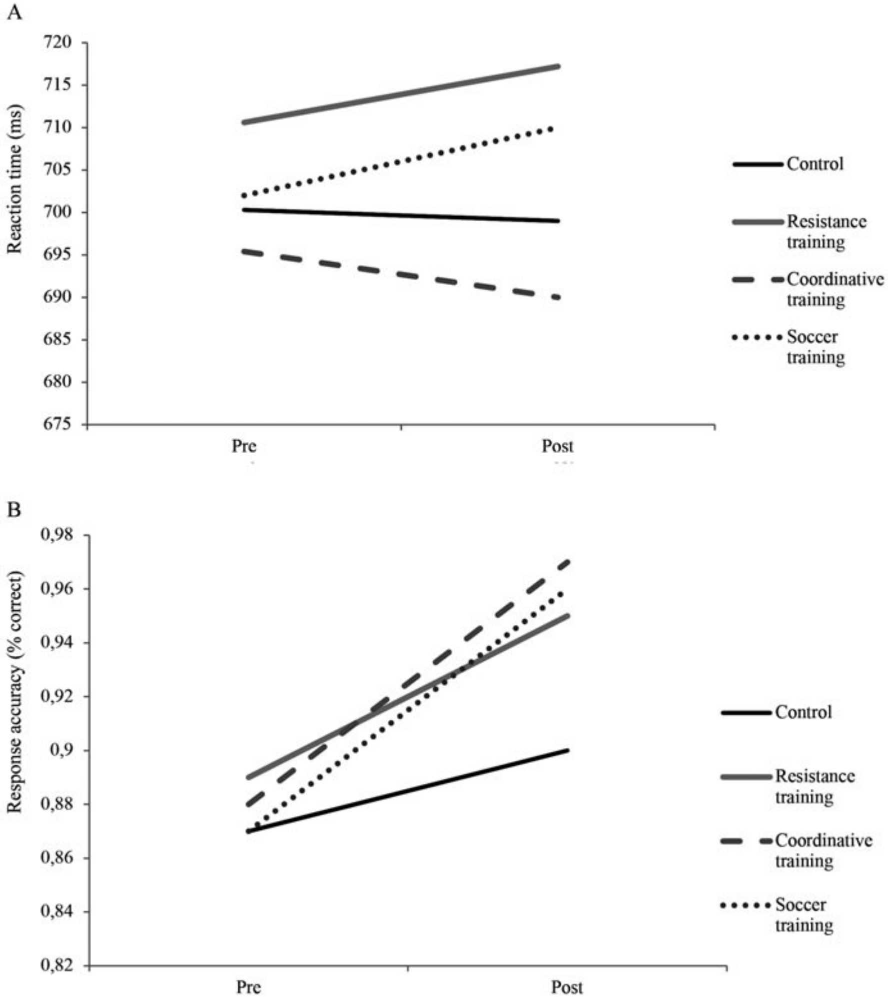

Fig. 2. Reaction time (A) and accuracy rate (B) for the Go/NoGo task before and after intervention in different groups

shorter RTcompared with the control group. However, no significant difference was observed among the three intervention groups. For the AR in n-back test (Figure 3b), the results of repeated measure ANOVA showed significant time effect ($F[1,141]=13.94$, $p=.00$, $\eta^2=0.09$) and interaction of time × group ($F[3,141]=6.67$, $p=.00$, $\eta^2=0.12$). The resistance, coordinative, and

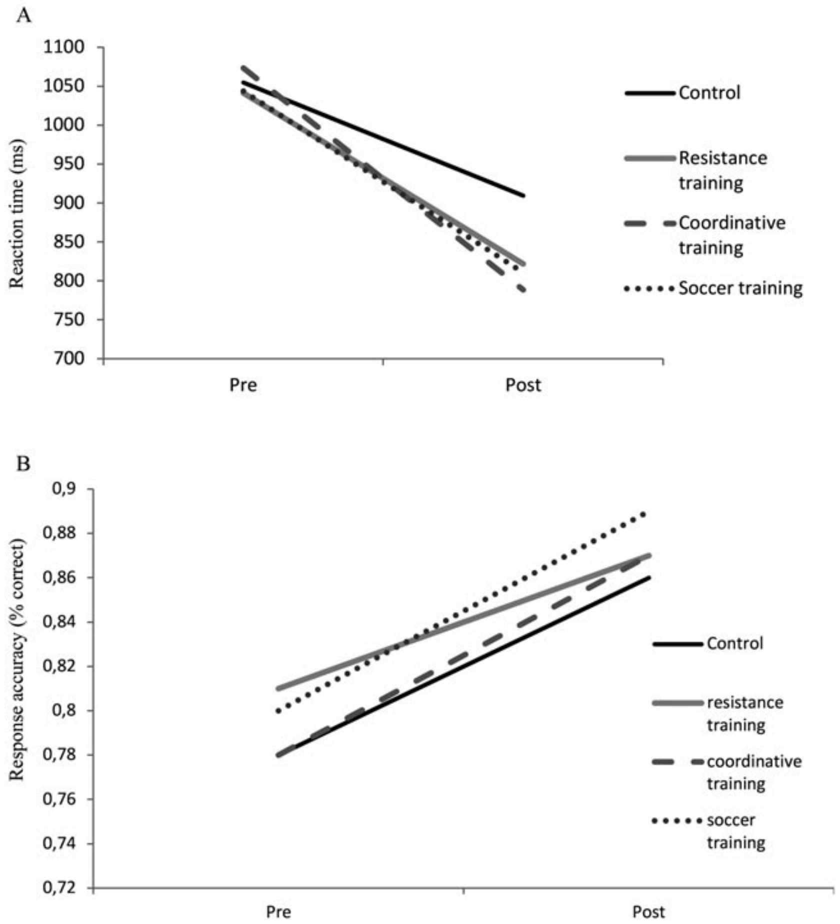

Fig. 3. Reaction time (A) and accuracy rate (B) for the 2-back task before and after intervention in different groups

soccer intervention groups have significantly higher AR than the control group. However, no significant difference was observed among the three intervention groups. The results of repeated measures ANOVA indicated that participants in the resistance, coordinative, and soccer training groups have shorter RT in the 2-back test and better AR in the Go/NoGo and 2-back test compared with participants in the control group. However, post hoc analysis revealed that no significant difference was found among the three exercise intervention groups in both RT and AR.

Discussion

In the current study, Go/NoGo task and 2-back task were applied to compared the effects of acute resistance, coordinative and soccer training with control group on IC and WM of children. In the Go/NoGo task, the NoGo errors are responses that occur when no response is needed, they are assumed to related to impulsivity (Halperin, et al., 1991). The RT towards Go trials were found to be negative correlated to NoGo errors because individuals who responded more quickly were more likely to make more errors (Manly, et al., 2000). In the 2-back task, better AR and faster RT means participants made less errors and had quicker processing speed in monitoring, updating, and manipulation of remembered information, which are core components of WM (Miller, Price, Okun, Montijo & Bowers, 2009; Owen, Mcmillan, Laird & Bullmore, 2010).

The results this study showed that children in the resistance, coordinative, soccer training groups had shorter RT in the 2-back test and better AR in Go/NoGo and 2-back tests than their counterparts in the control group. The results indicate that all three types of acute exercises have better impacts on IC and WM than watching cartoons among pupils. This finding supports the hypothesis that there are differences in improvement in the IC and WM tests between acute exercise exertions of moderate intensity and control groups. In 2009, Hillman et al. discovered that the AR of the Flanker task test increased, and the reading performance of children improved after they walked for 20 minutes at 60% of the maximum heart rate (Hillman, et al., 2009). Chang et al. also reported that EF improves after 30minutes of middle-to high-intensity bicycle exercises (Chang, et al., 2011). However, most research on exercise and EF focused on aerobic exercise. The present study further proves that acute resistance, coordinative, and soccer exercises with moderate intensity also have positive impacts on the IC and WM of children.

Rope skipping and kicking shuttlecock are common coordinative exercises in China, which are conducive to fitness improvement among children (Ha, Lonsdale, Ng, & Lubans, 2014). A study investigated the relationship between coordination and EF among adolescents and showed that coordination was associated with EF (Rigoli, Piek, Kane, & Oosterlaan, 2012). Chang et al. found that eight-week coordinative training can improve the EF of children (Chang, et al., 2013). The results of this study also support that acute coordinative exercise have positive impact on the EF of children. To play coordinative exercises, like rope skipping and kicking shuttlecock, children must observe position and movement tracks of the rope and shuttlecock, deliver information through the nervous system, make decisions, and accomplish the next action through the motor system. The entire process must be accomplished in a very short time. These series of actions require the coordination of different body parts, fast delivery and decision of the nervous system, and accurate coordinative control of multiple body parts. Research also indicated that coordinative exercise could pre-activate parts of the brain that are responsible for mediating functions like attention (Budde, et al., 2008; Courchesne, et al., 1994). These studies may help explain the mechanism why acute coordinative exercise has positive influence on EF.

Previous studies on physical activity and EF mainly concentrated at the influence of aerobic training, whereas only a few studies focused on the influences of acute resistance training on EF. Based on acute resistance exercise intervention of adults, resistance training was found to have positive impacts on EF (Chang & Etnier, 2009; Tsai, et al., 2014). However, Brush et al. discussed the dose–effect relationship between resistance exercise and EF; they found that resistance exercise has limited and task-specific impacts on EF (Brush, et al., 2016). The present study also finds that resistance training has a positive influence on AR of Go/NoGo and RT and AR of 2-back task. Moreover, it was reported that the effects of exercise training on EF are task-dependent (Alves, et al., 2012; Chun-Chih, et al., 2015; Etnier & Chang, 2009). IC maybe more sensitive to resistance training than other aspects of EF (Soga, et al., 2018). The results of current study showed that the effect size towards the 2-back task is larger than that to the Go/NoGo task. The results further confirmed that acute exercise does not equally affect the entire family of EF.

Another contribution to the literature is the examination of soccer training as a comprehensive exercise for enhancing children's EF. Soccer is a type of open and confrontational exercise that can improve children's aerobic capacity, muscular strength, and motor coordination comprehensively (Egan, et al., 2007). Studies found that long-term soccer training is in favor of EF development of children (Alesi, et al., 2016; Jiang & Zeng, 2015). It was also found that, after 6 months of soccer training the children in soccer training group had significant improvement in agility, visuo-spatial working memory, attention, planning and inhibition than their counterparts in sedentary group (Alesi, et al., 2016). However, few studies investigated the effects of acute soccer training on EF in children. The current results supported that acute soccer training could have favorable impact on IC and WM.

In the recent studies in endocrinology, skeletal muscle was identified as a secretory organ (Pedersen & Febbraio, 2012), which may help explain the mechanisms underlying the benefits for EF induced by resistance and comprehensive exercises. Muscle secretome consists of several hundred secreted peptides including Interleukin-6 and brain-derived neurotrophic factor, which may be beneficial to brain function (Pedersen & Febbraio, 2012). These proteins produced by skeletal muscle are dependent on contraction. Therefore, exercise training, especially resistance and comprehensive training, may influence IC and WM by enhancing skeletal muscle secretion.

This study is one of the few studies that compared the influences of resistance, coordinative, and soccer exercises on the EF of children. While the results of a previous study indicated that acute resistance training may not be as effective as aerobic exercise(Pontifex, et al., 2009), the present study showed that the soccer, resistance, and coordinative training groups achieve better performance in Go/NoGo and 2-back tasks after 40 minutes of exercises than the control group. However, these three exercise types with moderate intensity cause similar impacts on the IC and WM of children. Numerous studies proved that physical activity with moderate intensity have positive influence on EF (Kashihara, et al., 2009; Ludyga, et al., 2016). To this end, arousal theory may help explain such a mechanism. This theory hypothesized an inverted U-relationship between the activation level of the nervous system (cognitive function) and exercise intensity, and the optimal intensity of physical activity could be close to anaerobic threshold (Chmura, Krysztofiak, Ziemba, Nazar, & Kaciuba-Uscilko, 1997; Kashihara, et al., 2009). Furthermore, the exercise intensity of the three intervention groups indicated by heart rate were quite similar, thereby leading to similar effects on the IC and WM of children.

Determining the optimal exercise intensity has important implications for exercise intervention for improving cognitive functions in children and adolescents. Moderate exercise, excluding light or high intensity exercise, was associated with improved cognitive functions in an elderly, community-dwelling cohort (Albrektson, et al., 2015). The current study further verified the positive effects of moderate intensity exercise on EF. Moreover, the results of this study also indicated that the type of physical exercise may not be an important factor, but exercise intensity could play a key role in improving EF in children. However, more studies on dose–response relationship of physical activity and cognitive functions are still needed.

Several limitations should be acknowledged when interpreting the findings in this study. First, EF has three categories, but only two (IC and WM) were studied. An important reason is that teenagers are not able to complete the cognitive function test which takes too long. Future studies should further our understanding of the effects of different exercise on other cognitive functions, including task switching and planning. Second, the range of age of participants is narrow, which may limit the generalizability of results to other age groups.

Conclusion

Acute resistance, coordinative, and soccer training with moderate intensity have positive impacts on the IC and WM of children. However, no difference in EF improvement was found in the three types of exercises.

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