Improved executive functions in 6–12-year-old children following cognitively engaging tennis lessons

Toru Ishihara

Graduate School of Education, Hokkaido University

Shigemi Sugasawa and Yusuke Matsuda

Nagoya Green Tennis Club Group

Masao Mizuno

Faculty of Education, Hokkaido University

Author Note

Toru Ishihara, Graduate School of Education, Hokkaido University; Shigemi Sugasawa and Yusuke Matsuda, Nagoya Green Tennis Club Group; Masao Mizuno, Faculty of Education, Hokkaido University

No external funding was received for this research.

No conflicts of interest exist for any of the authors.

Correspondence concerning this paper should be addressed to Toru Ishihara, Graduate School of Education, Hokkaido University, Kita 11-jo, Nishi 7, Kita-ku, Sapporo, Hokkaido 060-0811, JAPAN, Tel: +81-11-706-7524, E-mail: t.ishihara@edu.hokudai.ac.jp

Abstract

The aim of this cross-sectional study was to evaluate the relationships between cognitively engaging exercise (i.e., game-based and coordination exercises), executive functions (i.e., inhibitory control and working memory), and physical fitness. Forty junior tennis players (6-12 years old), who regularly participated in tennis lessons (2.55 years, *SD* = 1.61) prior to the study, were investigated. All subjects completed evaluations of executive functions (inhibitory control and working memory) at rest. The duration of each of the lessons' instructional activities, including coordination training, game-based exercise, rallying, and non-physical activity (explanations and breaks) was recorded. Physical fitness was evaluated using the Tennis Field Test. A longer duration of game-based exercise was positively correlated with inhibitory control and physical fitness. Coordination training was associated with improved working memory. Non-physical activity was inversely correlated with inhibitory control, working memory, and physical fitness. The results suggest that game-based tennis lessons have beneficial effects on inhibitory control and physical-fitness levels, and a longer duration of coordination training is associated with better working memory. The present study indicates that shortened non-physical activity time within a sports setting is associated with the development of executive functions and physical fitness.

Keywords: sports activity, inhibitory control, working memory, game-based exercise, coordination training

Improved executive functions in 6–12-year-old children following cognitively engaging tennis lessons

There is growing apprehension that children are becoming physically inactive and less fit. Adequate levels of physical activity/fitness in childhood contribute to the development of healthy adult lifestyles, which ensures both physical and cognitive health (Donnelly et al., 2016; Hallal, Victora, Azevedo, & Wells, 2006; Hillman, Erickson, & Kramer, 2008). Several studies have shown that physical activity is positively associated with improved brain function and physical fitness during development (Hillman et al., 2014; Kamijo et al., 2011; Ruiz et al., 2006). Furthermore, improved childhood physical activity/fitness and brain functions predict improved health conditions among adults (Moffitt et al., 2011; Ortega, Silventoinen, Tynelius, & Rasmussen, 2012). Thus, it is important to monitor physical/brain development through physical activity during childhood.

Executive functions (i.e., the regulation of cognitive processes controlling goal-directed behavior) are critical for sports performance (Verburgh, Scherder, Van Lange, & Oosterlaan, 2014), school readiness, school success (Blair & Diamond, 2008), and academic achievement (Best, Miller, & Naglieri, 2011). Furthermore, increased childhood executive functions predict health, wealth, and public safety (Moffitt et al., 2011). Therefore, examinations of the relationships between physical activity/fitness and cognition are focused on executive functions (Best, 2010; Diamond, 2015; Hillman et al., 2014).

Inhibitory control and working memory are foundational components of executive function (Diamond, 2013; Miyake et al., 2000). Inhibitory control is the ability to control one's attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external lure. Working memory is the ability to hold information in the mind and work with it. The use of these components fosters the development of higher-order executive functions, such as reasoning, problem solving, and planning. These functions are present not only in adults but also in children (Huizinga, Dolan, & van der Molen, 2006; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003).

The tasks frequently used to examine inhibitory control and working memory are the Stroop Color and Word Test and N-back Task, respectively. The Stroop Color and Word Test is a well-known instrument for measuring cognitive functions, such as information-processing speed, attention, interference, and inhibitory control. In the Stroop Color and Word Test, participants are instructed to name the color of the incongruent color-word stimulus (e.g., Blue printed in green ink) (Stroop, 1935). Because word reading is a more automatic cognitive process than is color naming, participants are required to inhibit strong internal predispositions. In the N-back Task, participants are required to monitor a series of stimuli and respond whenever a stimulus is presented that is the same as the one presented in previous trials (Owen, McMillan, Laird, & Bullmore, 2005). This task requires the storage and active employment of information within the mind. Positive relationships have been reported between physical activity/fitness and performance of these types of tasks among children and adolescents (Buck, Hillman, & Castelli, 2008; Drollette et al., 2016; Scudder et al., 2014).

Type of exercise can affect the outcomes of physical training; therefore, it is important to develop effective training programs (Best, 2010; Diamond, 2015; Pesce, 2012). Cognitively engaging physical activity might be more beneficial for the improvement of executive functions than simpler exercise (Best, 2010; Pesce, 2012; Schmidt, Jaeger, Egger, Roebers, & Conzelmann, 2015). Computer games without physical activity improve executive functions of children (Karbach & Kray, 2009; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009); therefore, combining cognitive engagement with exercise should be beneficial for supporting the development of executive functions among children. One literature review by Best (2010) focused on studies examining the relationship between executive function and exercise type. Cognitively engaging exercise (e.g., group games, coordinative exercise) was found to have a stronger effect on children's executive functions than simpler exercise (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009; Schmidt et al., 2015). From these findings, it can be assumed that strategic play during group games, coordinative exercise, and non-automated exercise engage similar cognitive processes to those involved in executive function tasks (Best, 2010).

Sports activities using open skill (e.g., tennis) require cognitive activity and complex body movements; therefore, they should improve the development of executive functions (Crova et al., 2014; Ishihara, Sugasawa, Matsuda, & Mizuno, 2016; Schmidt et al., 2015). Tennis activity intervention and tennis experience have been shown to be associated with better executive functions among children, independent of physical fitness gain/level (Crova et al., 2014; Ishihara et al., 2016). These study findings suggest that the characteristics of exercise with cognitive engagement in tennis contribute to the development of children's executive functions.

Tennis lessons consist of various instructional activities, which include rallying, coordination training, game-based exercise, and non-physical activities (instructions and breaks). Game-based exercise and coordination training are highly cognitively engaging compared to rallying. Tennis games require cognitive engagement (e.g., superior reaction, goal-directed behavior, strategic behavior, decision making), while coordination training comprises unautomated skill requiring cognitive engagement (top-down cognitive processes). Rallying requires some cognitive engagement (e.g., superior reaction) but less higher-order cognition that taps into executive functions (goal-directed behavior, strategic behavior) than either game or coordination training. Therefore, these latter types of training would facilitate executive function to a greater extent than rallying.

An examination of the relationship between the lesson's instructional activities and executive functions (i.e., inhibitory control and working memory) and physical fitness among children is important for the development of effective training programs. However, few studies have examined the relationship between cognitively engaging exercise and executive functions. The purpose of this study is to gain a better understanding of this relationship. Specifically, this cross-sectional study evaluated the relationships between the cognitively engaging exercises of tennis lessons (coordination training and game-based exercise), executive functions (inhibitory control and working memory), and physical fitness levels of 6-12-year-old junior tennis players to suggest effective sports programs for supporting the development of executive functions and physical fitness.

Methods

Participants

Forty junior tennis players (6-12 years old, males = 23, females = 17) took part in this study. Prior to the study, the children regularly participated in tennis lessons (once a week, mean number of years = 2.55, *SD* = 1.61, range = 0.1-6.2). Participants were recruited from 13 classes consisting of four competitive levels and five different coaches. The rates of all the instructional activities for the participating children were controlled by each coach. Players who were enrolled in educational programs for cognitive or attention disorders were excluded from this study. All the participants and their parents provided written informed consent in accordance with the requirements of the institutional review board of Hokkaido University, which approved the study. Table 1 shows the participants' demographic characteristics.

Instructional activities

A courtside observer recorded the duration of time spent in each of the instructional activities (coordination training, games, rallying, collecting balls, and non-physical activity) that comprised the tennis lessons. Heart rates were measured in 1-second intervals using a heart rate (HR) monitor (RS400, Polar, Kempele, Finland).

Assessment of executive functions

Two executive functions were evaluated using the tasks outlined below, which were performed on a PC. The distance between the participants' eyes and the display was maintained at 50 cm.

Inhibitory control. Information-processing speed and inhibitory control were evaluated using the Stroop Color and Word Test (Stroop, 1935). The Stroop test consists of two trials: control and incongruent. First, participants were exposed to 16 practice stimuli, and then they completed the control and incongruent trials with a 1-min rest period between each trial. The stimuli used in the control trial were four patches of color (red, yellow, green, and blue). In the incongruent trial, the names of colors were presented; however, the color of the text did not match the named color (e.g., the word "red" was printed in green). The stimuli for each of these tasks were presented on a gray background. In each trial, 8 sets of 8 stimuli were presented, and were evenly distributed throughout the screen. We prepared a color-labeled keyboard for use with this task: the C-key was labeled red, the V-key yellow, the N-key green, and the M-key blue. The participants were required to press the key that corresponded to the color of the stimulus as quickly and as accurately as possible. The main dependent variables were the mean reaction time (RT) and the accuracy of each trial (control trial: processing speed and incongruent trial: inhibitory control), the interference score for the RT (RT [incongruent condition] - RT [control condition]), and the interference score for accuracy (accuracy [control condition] - accuracy [incongruent condition]).

Working memory. Working memory was evaluated using the 2-back task (Owen et al., 2005). In the 2-back task, participants compared the current stimulus with the two stimuli presented previously. They were instructed to push the right Ctrl key if the current stimulus differed from the two previous stimuli, and to push the left Ctrl key if the current stimulus was the same as the two previous stimuli. The stimuli consisted of nine numbers (i.e., 1–9). All stimuli were presented on a gray background for 2,000 ms each, and the stimulus-onset asynchrony was set at 3,000 ms. The stimulus configurations subtended a visual angle of 1.72° (1.5 cm × 1.5 cm). The participants performed 12 practice trials and then completed two blocks of 25 trials each, with a 1-min rest interval between the blocks. The main dependent variables were the mean RT and participants' accuracy.

Physical fitness

Tennis-related physical performance. Tennis-related physical performance was evaluated using the Tennis Field Test, which can be performed on a tennis court (Japan Tennis Association, 2005; Kuroda et al., 2015). The Tennis Field Test has been used for both junior and senior tennis players (Japan Tennis Association, 2005; Kuroda et al., 2015). It consists of six measures: the number of sit-ups performed in a 30-s period (an index of muscular endurance), the distance (in cm) jumped in a standing long jump (an index of leg power), the time taken to complete a spider run (an index of agility), the time taken to sprint 10 m (an index of high-power output), the time taken to complete a shuttle-run test (an index of speed), and the distance run in three min (an index of whole-body endurance).

Statistical analysis

Statistical analyses were performed using IBM SPSS statistical package, ver. 21.0 (IBM Inc., Tokyo, Japan). Prior to the analysis, we assessed the normality of variables using the Kolmogorov-Smirnov test. All variables were normally distributed ($p > .10$). Participants' total scores on the Tennis Field Test were analyzed using principal components factor analysis. Correlation analyses were conducted to assess the relationships between age, sex (dummy coded with male = 1 and female = 0), BMI, tennis experience, physical fitness (score on the Tennis Field Test), and executive functions. Instructional activities, executive functions, and physical fitness level were correlated with age, sex, BMI, and tennis experience (Table 2); therefore, the relationships between executive functions, physical fitness levels, and instructional activities were analyzed using partial correlations after controlling for age, sex, BMI, and tennis experience. Significance levels were set at $p < .05$.

Results

Instructional activities

The breakdown of lessons by time spent performing various activities was as follows: 27.00% (12.58–46.19%) non-activity time (i.e., explanations and breaks), 39.22% (8.22–63.08%) games, 23.92% (5.18–41.57%) rallies, 4.81% (0.00–17.79%) coordination training, and 4.98% (0.00–10.39%) collecting balls. Heart rate data were collected for 32 subjects. Mean heart rate was 144.04 bpm (127.08 to 162.12 bpm). The exercise intensity was 68.40% of the predicted maximal heart rate (61.18 to 77.36%). Games included cognitively engaging gaming such as following and playing using one side stroke (only forehand or backhand). In this case, the players aimed at either their opponent's unpermitted or permitted side, if there was an open space. If they finished with a volley, the players got two points; therefore, the players strategically developed their net play or intercepted their opponent's net play. Rallying also contained various restrictions (e.g., using only forehand or backhand); however, the player constantly aimed at the permitted side to keep up the rallying. Therefore, rallying requires less cognitive engagement than does gaming. Coordination training consists of unautomated skills requiring top-down cognitive processes such as following, self-rallying with the non-dominant hand, self-rallying behind the back or under the leg, and playing catch using two balls.

Factor analyses results for the tennis field test

Principal components factor analysis for all the participants' scores on the Tennis

Field Test (sit-ups, standing long jump, spider run, 10-m sprint, shuttle run, and 3-min distance run) revealed a single factor that accounted for 70.87% of the variance (weights: sit-up = .81, standing long jump = .76, spider run = -.92, 10-m sprint = -.80, and shuttle run = -.93, 3-min distance run = .82).

Relationships between instructional activities and executive functions

The correlations between the instructional activities and executive functions, after controlling for age, sex, BMI, and tennis experience are presented in Table 3. Game time was inversely associated with interference RT (pr = -.34, p = .04) (Figure 1A). This finding indicates that a longer duration of game-based exercise is related to better inhibitory control. The duration of non-physical activity was positively correlated with participants' RTs for the incongruent condition and interference (incongruent condition RT: pr =.35, p = .04, interference RT: pr = .38, p = .02) (Figure1B). These correlations indicate that a longer duration of non-physical activity is associated with worse inhibitory control. Coordination training was positively correlated with participants' accuracy on the 2-back task (pr =.42, p = .01) (Figure 1C). This finding indicates that a longer duration of coordination training is related to better working memory. The duration of non-physical activity was inversely correlated with their accuracy on the 2-back task (pr = -.38, p = .02) (Figure 1D). These correlations indicate that a longer duration of non-physical activity is associated with poorer working memory. No other significant correlations were found.

Relationships between instructional activities and physical fitness level

The correlations between the instructional activities and physical fitness level, after controlling for age, sex, BMI, and tennis experience are presented in Table 4. Game-based exercise was positively correlated with participants' performance on the standing long jump (pr =.46, p < .01) and their total scores (pr = .45, p < .01) on the Tennis Field Test; however, they were inversely correlated with performance on the spider run (pr = -.43, p < .01) and shuttle run (*pr* = -.48, $p < .01$). These findings indicate that a longer duration of game-based exercise is related to a higher level of physical fitness.

Rallying was positively correlated with the shuttle run (*pr* =.38, $p = .02$) and was inversely correlated with performance on the standing long jump (*pr* = -.38, $p = .02$), 3-min distance run (*pr* = -.36, $p = .03$), and the total scores on the Tennis Field Test (*pr* = -.46, $p < .01$). The duration of non-physical activity was positively correlated with performance on the spider run (*pr* = .46, $p < .01$) and shuttle run (*pr* = .58, $p < .01$), and it was inversely correlated with sit-ups (*pr* = -.37, $p = .03$). These findings indicate that longer times spent rallying and doing non-physical activity are related to a lower level of physical fitness. No other significant correlations were found.

Discussion

This study examined the relationships between cognitively engaging activities (i.e., coordination and game-based activities), executive functions (i.e., inhibitory control and working memory), and physical fitness level in children. The main findings of this study were as follows: (1) longer durations of non-physical activities were associated with less efficient executive functions and lower levels of physical fitness, (2) game-based exercise was related to better inhibitory control and physical fitness, and (3) coordination training was associated with better working memory among children. These findings suggest that exercise programs consisting of game-based activities and coordination training are beneficial for the development of executive functions and physical fitness in children.

Some research has shown that higher levels of physical activity/fitness are related to better executive function (Hillman et al., 2014; Ishihara et al., 2016; Kamijo et al., 2011; Scudder et al., 2014). In this study, longer durations of non-physical activities were negatively correlated with inhibitory control and working memory. These results indicate that higher physical activity levels in sports settings are associated with better executive functions, suggesting that sports programs containing less non-physical activity time (e.g., reduced explanation) better support the development of executive functions.

In this study, exercise intensity in tennis lesson was 68.40% of the predicted maximal heart rate (61.18 to 77.36%). Previous study reported that acute exercise with 60 to75% of the predicted maximal heart rate improves cognition in children (Hillman et al., 2009; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). Therefore, in our sample, tennis lessons appeared to be suitable exercise intensity for improvement of executive function.

Non-physical activity time and rallying were negatively correlated with physical fitness, and game-based tennis training was positively associated with physical fitness. These results suggest that longer physical activity times support physical fitness improvements, and the rates of games used in physical activity situations are important for overall fitness development. Children are more highly motivated to play games in which they can win points than to engage in rallying. Games influence physical fitness more than rallying because stronger motivational factors are involved. Therefore, game-based exercise might improve physical fitness to a greater extent in children.

This study provides evidence for the relationship between cognitively engaging exercise (i.e., game-based tennis training and coordinative exercise) and improved executive functions among children. Furthermore, game-based tennis training was associated with higher physical fitness level. Previous studies have suggested that cognitively engaging exercise improves cognitive functions to a greater extent than does less cognitively engaging exercise (i.e., circuit training, normal physical education class) among children and adolescents (Budde et al., 2008; Pesce et al., 2009; Schmidt et al., 2015), and this study's results support this premise. The game of tennis and other coordinative exercises require cognitive engagement (strategic behavior, superior reactivity, anticipation, and decision-making capacities, top-down cognitive process) (Fernandez-Fernandez, Sanz-Rivas, & Mendez-Villanueva, 2009). These skills may contribute to improved inhibitory control and working memory.

Our findings suggest that cognitively engaging exercise is more strongly associated with inhibitory control and working memory than with processing speed. Cognitively engaging exercise was associated with better performance on the Stroop Color and Word Test incongruent trial, interference score, and the 2-back task. However, no significant correlations were found between performance on the Stroop Color and Word Test control trial and the instructional activities. Previous studies have suggested that executive functions are more sensitive to the effects of physical exercise than are other cognitive functions (Best, 2010; Colcombe & Kramer, 2003; Hillman et al., 2014). Hillman et al. (2014) reported that in a randomized control study, 9 months of a physical-activity intervention in an after-school program improved cognitive task performance among elementary school children. Furthermore, the effect was found for cognitive tasks requiring executive functions (i.e., inhibitory control and cognitive flexibility), but not for tasks requiring lower-order cognitive functions.

The participants in this study had been regularly participating in tennis lessons only one time per week. In spite of this, the revealed relationships between the cognitive engaging exercise and their cognitive/physical development are intriguing. The dose-response relationships between cognitively engaging exercise (i.e., game-based exercise and coordination training) and executive function (i.e., inhibitory control and working memory) were detected in our sample, and the effect size were moderate to large (pr = .34, pr = .42, respectively). The dose-response relationships between game-based exercise and physical fitness was also detected, and the effect size was moderate to large (pr = .43 to .48). These results indicate the importance of developing a sports program that supports cognitive/physical development. Our findings suggest that even engaging in highly cognitively engaging sports activities no more than once per week may be associated with improved executive functions and physical fitness.

Although the present study demonstrated relationships between cognitively engaging sports activity, executive functions (i.e. inhibitory control and working memory), and physical fitness levels, several limitations should be acknowledged. First, this study used a cross-sectional design; therefore, we could not confirm the causal effects. Second, this study did not measure intelligence, with which executive functions have reportedly been associated (Ardila, Pineda, & Rosselli, 2000). Longitudinal studies or intervention designs and more diverse measures (e.g., intelligence assessments) are needed to confirm that cognitively engaging exercise is a useful tool for supporting the development of executive functions in children.

In summary, this study suggests that longer durations of game-based and coordinative exercise in sports activities are associated with improved inhibitory control and working memory, respectively. Furthermore, longer durations of game-based exercise are associated with improved physical fitness. The benefits of cognitively engaging exercise appear to follow a dose–response relationship, as an increase in the duration of the cognitively engaging activities in this tennis program was associated with better executive functions and higher levels of physical fitness among the children. Further research is needed to investigate the relationships between exercise type, development of executive functions, and fitness levels.

Acknowledgments

The authors wish to thank all of the children, their parents, and the staff at Nagoya Green Tennis Club Group for participating in this study. This study did not receive grants from any funding agency in the public, commercial, or not-for-profit sectors. The authors have no financial disclosures or conflicts of interest to declare.

References

Ardila, A., Pineda, D., & Rosselli, M. (2000). Correlation between intelligence test scores and executive function measures. *Archives of Clinical Neuropsychology*, *15*(1), 31–36.

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review*, *30*(4), 331–351.

Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences*, *21*(4), 327–336.

Blair, C., & Diamond, A. (2008). Biological processes in prevention and intervention: the promotion of self-regulation as a means of preventing school failure. *Development and Psychopathology*, *20*(3), 899–911.

Buck, S. M., Hillman, C. H., & Castelli, D. M. (2008). The relation of aerobic fitness to stroop task performance in preadolescent children. *Medicine & Science in Sports & Exercise*, *40*(1), 166–172.

Budde, H., Voelcker-Rehage, C., Pietraßyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters*, *441*(2), 219–223.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychological Science*, *14*(2), 125–130.

Crova, C., Struzzolino, I., Marchetti, R., Masci, I., Vannozzi, G., Forte, R., & Pesce, C. (2014). Cognitively challenging physical activity benefits executive function in overweight children. *Journal of Sports Sciences*, *32*(3), 201–211.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168.

Diamond, A. (2015). Effects of Physical Exercise on Executive Functions: Going beyond Simply Moving to Moving with Thought. *Annals of Sports Medicine and Research*, *2*(1), 1011.

Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., … Szabo-Reed, A. N. (2016). Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review. *Medicine & Science in Sports & Exercise*, *48*(6), 1197–1222.

Drollette, E. S., Scudder, M. R., Raine, L. B., Davis Moore, R., Pontifex, M. B., Erickson, K. I., & Hillman, C. H. (2016). The sexual dimorphic association of cardiorespiratory fitness to working memory in children. *Developmental Science*, *19*(1), 90–108.

Fernandez-Fernandez, J., Sanz-Rivas, D., & Mendez-Villanueva, A. (2009). A Review of the Activity Profile and Physiological Demands of Tennis Match Play. *Strength and Conditioning Journal*, *31*(4), 15–26.

Hallal, P. C., Victora, C. G., Azevedo, M. R., & Wells, J. C. (2006). Adolescent physical activity and health. *Sports Medicine, 36*(12), 1019-1030.

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Neuroscience*, *9*(1.), 58–65.

Hillman, C. H., Pontifex, M. B., Castelli, D. M., Khan, N. A., Raine, L. B., Scudder, M. R., … Kamijo, K. (2014). Effects of the FITKids Randomized Controlled Trial on Executive Control and Brain Function. *Pediatrics*, *134*(4), e1063–1071.

Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience*, *159*(3), 1044–1054.

Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia*, *44*(11), 2017–2036.

Ishihara, T., Sugasawa, S., Matsuda, Y., & Mizuno, M. (2016). Relationship Between Tennis

Experience and Executive Function in Male Children, Independent of Physical Fitness Level. *Medicine & Science in Sports & Exercise*, *48*(5 Suppl 1), 930.

Japan Tennis Association. (2005). *Shinban Tenisu Shidou Kyouhon* [New Version of Tennis Instruction Book], Taishukan Shoten.

Kamijo, K., Pontifex, M. B., O'Leary, K. C., Scudder, M. R., Wu, C. T., Castelli, D. M., & Hillman, C. H. (2011). The effects of an afterschool physical activity program on working memory in preadolescent children. *Developmental Science*, *14*(5), 1046–1058.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science*, *12*(6), 978–990.

Kuroda, Y., Suzuki, N., Dei, A., Umebayashi, K., Takizawa, K., & Mizuno, M. (2015). A comparison of the physical fitness, athletic performance and competitive achievements of junior and senior tennis players. *Movement, Health & Exercise*, *4*(1), 39–50.

Lehto, J. E., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology*, *21*(1), 59–80.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100.

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., … Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(7), 2693–2698.

Ortega, F. B., Silventoinen, K., Tynelius, P., & Rasmussen, F. (2012). Muscular strength in male adolescents and premature death: cohort study of one million participants. *BMJ*, *345*, e7279.

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N - back working memory paradigm: A meta - analysis of normative functional neuroimaging studies. *Human Brain Mapping, 25*(1), 46-59.

Pesce, C. (2012). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of Sport & Exercise Psychology*, *34*(6), 766–786.

Pesce, C., Crova, C., Cereatti, L., Casella, R., & Bellucci, M. (2009). Physical activity and mental performance in preadolescents: Effects of acute exercise on free-recall memory. *Mental Health and Physical Activity*, *2*(1), 16–22.

Pontifex, M. B., Saliba, B. J., Raine, L. B., Picchietti, D. L., & Hillman, C. H. (2013). Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder. *Journal of Pediatrics*, *162*(3), 543–551.

Ruiz, J. R., Rizzo, N. S., Hurtig-Wennlöf, A., Ortega, F. B., Wärnberg, J., & Sjöström, M. (2006). Relations of total physical activity and intensity to fitness and fatness in children: The European Youth Heart Study. *American Journal of Clinical Nutrition*, *84*(2), 299–303.

Schmidt, M., Jaeger, K., Egger, F., Roebers, C. M., & Conzelmann, A. (2015). Cognitively Engaging Chronic Physical Activity, But Not Aerobic Exercise, Affects Executive Functions in Primary School Children: A Group-Randomized Controlled Trial. *Journal of Sport & Exercise Psychology*, *37*(6), 575–591.

Scudder, M. R., Lambourne, K., Drollette, E. S., Herrmann, S. D., Washburn, R. A., Donnelly, J. E., & Hillman, C. H. (2014). Aerobic capacity and cognitive control in elementary school-age children. *Medicine & Science in Sports & Exercise*, *46*(5), 1025–1035.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662.

Thorell, L. B., Lindqvist, S., Nutley, S. B., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science*, *12*(1), 106–113.

Verburgh, L., Scherder, E. J. A., Van Lange, P. A. M., & Oosterlaan, J. (2014). Executive functioning in highly talented soccer players. *PLoS ONE*, *9*(3), e91254.

Table 1

Participant characteristics

Variables	*N* or Mean (*SD*)	Range
N	40	
Males/Females	23/17	
Age (years old)	9.6 (1.7)	6.4-12.4
Height (cm)	133.2 (10.8)	109.0-153.2
Weight (kg)	29.5 (7.2)	17.5-49.3
BMI (kg/m^2)	16.4 (2.00)	13.0-22.6
Tennis experience (years)	2.6 (1.6)	0.1-6.2

Note: BMI = body mass index.

Table 2

Correlations between participants' characteristics, instructional activities, and executive functions

Variables	Age		Sex		BMI		Tennis experience	
Sex	-.09		-					
BMI	.44	**	.01		-			
Tennis experience	.36	*	-.01		.58	**	-	
Instructional activities								
Coordination training	-.40	*	.06		-.31	*	-.01	
Rallying	-.07		-.15		-.41	**	-.24	
Game	.40	*	.01		.49	**	.24	
Collecting balls	-.43	**	-.20		-.37	*	-.07	
Non-activity time	-.21		.20		-.07		-.14	
Stroop Color and Word Test								
Control RT	-.73	**	.19		-.38	*	-.30	#
Incongruent RT	-.64	**	.27	#	-.38	*	-.23	
Interference RT	-.16		.26		-.18		.00	
Control accuracy	.17		.11		.08		.17	
Incongruent accuracy	-.14		.17		.17		-.14	
Interference accuracy	.22		-.03		-.05		.22	
2-back task								
RT	-.50	**	-.02		-.16		-.17	
Accuracy	.46	**	-.06		.11		.12	
Tennis field test								
Sit-ups	.61	**	-.08		.46	**	.22	
Standing long jump	.67	**	.10		.18		.30	#
Spider run	-.76	**	-.04		-.36	*	-.19	
10-m sprint	-.61	**	.13		-.17		-.20	
Shuttle run	-.74	**	.00		-.35	*	-.22	
3-min distance run	.71	**	.08		.28	#	.26	
Total score	.80	**	-.08		.31	#	.31	#

Note: BMI = body mass index. RT = reaction time. * $p < .05$, ** $p < .01$, # $p < .10$

Table 3

Correlations between instructional activities and executive functions, after controlling for age, sex, body mass index, and tennis experience, presented as Pearson's correlation coefficient (95% confidence interval)

Variables	Instructional Activities (%)									
	Coordination training		Rally		Game		Collecting ball		Non-physical activity	
Stroop Color and Word Test										
Control RT	-.01	(-.33 - .32)	.01	(-.32 - .34)	-.05	(-.37 - .28)	-.29	(-.57 - .04)	.17	(-.17 - .47)
Incongruent RT	-.10	(-.42 - .24)	.14	(-.20 - .45)	-.24	(-.53 - .10)	-.17	(-.48 - .16)	.35*	(.02 - .61)
Interference RT	-.16	(-.47 - .18)	.22	(-.12 - .51)	-.34*	(-.60 - -.02)	.06	(-.28 - .38)	.38*	(.06 - .63)
Control accuracy	.09	(-.24 - .41)	.06	(-.28 - .38)	-.11	(-.43 - .22)	-.08	(-.40 - .25)	.10	(-.24 - .42)
Incongruent accuracy	.08	(-.26 - .40)	-.16	(-.46 - .18)	.25	(-.09 - .53)	-.03	(-.36 - .30)	-.26	(-.54 - .08)
Interference accuracy	.03	(-.30 - .35)	.15	(-.19 - .45)	-.25	(-.54 - .08)	-.05	(-.37 - .29)	.25	(-.09 - .53)
2-back Task										
RT	-.04	(-.36 - .29)	.16	(-.17 - .47)	-.26	(-.54 - .08)	-.05	(-.38 - .28)	.27	(-.06 - .55)
Accuracy	.42*	(.11 - .66)	.05	(-.29 - .37)	.05	(-.28 - .37)	.05	(-.28 - .37)	-.38*	(-.63 - -.05)

Note: RT = reaction time. * $p < .05$, ** $p < .01$

Table 4

Correlations between instructional activities and physical fitness after controlling for age, sex, body mass index, and tennis experience, presented as Pearson's correlation coefficient (95% confidence interval)

Variables	Instructional Activities (%)				
	Coordination training	Rally	Game	Collecting ball	Non-physical activity
Tennis field test					
Sit-ups	.11 (-.23 - .42)	-.04 (-.37 - .29)	.24 (-.09 - .53)	-.09 (-.40 - .25)	-.37* (-.62 - -.04)
Standing long jump	-.16 (-.46 - .18)	-.38* (-.63 - -.06)	.46** (.15 - .68)	.17 (-.17 - .47)	-.30 (-.57 - .03)
Spider run	-.13 (-.44 - .21)	.29 (-.05 - .56)	-.43** (-.66 - -.12)	-.02 (-.35 - .31)	.46** (.15 - .68)
10-m sprint	.28 (-.06 - .56)	.07 (-.26 - .39)	-.31 (-.58 - .02)	-.14 (-.45 - .20)	.30 (-.03 - .57)
Shuttle run	-.27 (-.55 - .07)	.38* (.05 - .63)	-.48** (-.70 - -.18)	-.19 (-.49 - .15)	.58** (.32 - .77)
3-min distance run	.17 (-.17 - .47)	-.36* (-.61 - -.03)	.26 (-.07 - .54)	-.16 (-.46 - .18)	-.09 (-.40 - .25)
Total score	.10 (-.42 - .23)	-.46** (.16 - .69)	.45** (-.68 - -.14)	-.07 (-.27 - .39)	-.26 (-.08 - .54)

Note: * $p < .05$, ** $p < .01$

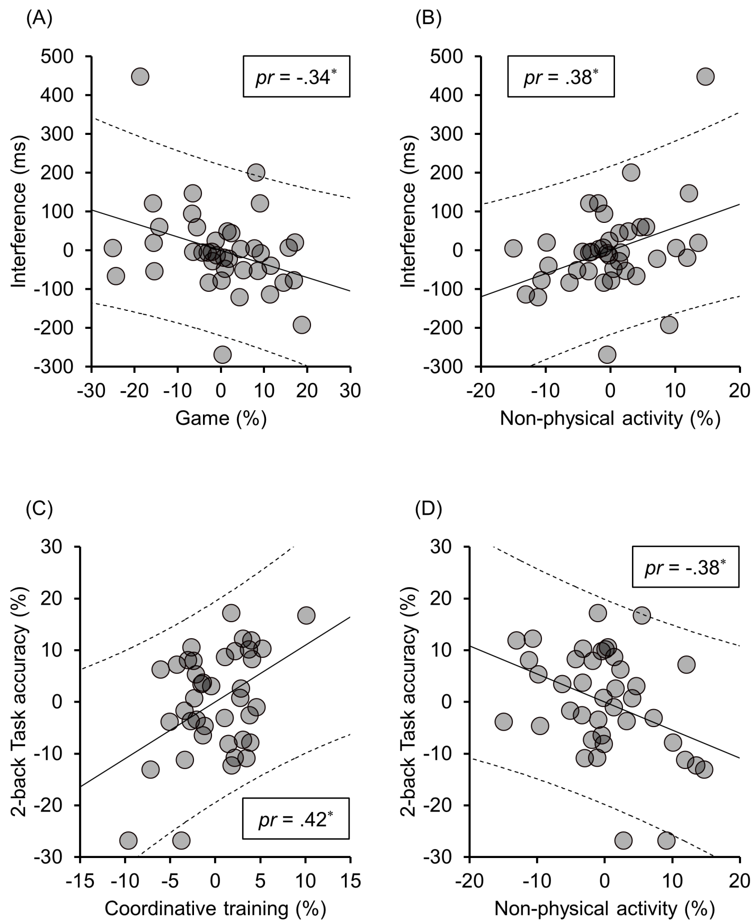

Figure 1. Correlations between instructional activities and executive functions after controlling for age, sex, body mass index, and tennis experience. *Note*: (A) Correlations between game and interference on reaction time; (B) Correlations between non-physical activity and interference on reaction time; (C) Correlations between coordination training and reaction time on the 2-back Task; (D) Correlations between non-physical activity and reaction time on the 2-back Task; solid line, regression line; dashed line, 95% confidence interval, * $p < .05$.