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Research article

The beneficial effects of game-based exercise using age-appropriate tennis lessons on the executive functions of 6–12-year-old children

Toru Ishihara [a,*], Shigemi Sugasawa [b], Yusuke Matsuda [b], Masao Mizuno [c]

[a] Department of Physical Fitness Science, Graduate School of Education, Hokkaido University, Japan
[b] Nagoya Green Tennis Club Group, Japan
[c] Faculty of Education, Hokkaido University, Japan

HIGHLIGHTS

- We examined the effects of tennis play on executive functions (EFs) in children.
- A single 50 min session of tennis play improved EFs of children.
- A single session of game-based exercise improved EFs more than repetitive exercise.
- The short-term EF benefit might be useful for the class immediately after exercise.
- Perhaps more extended practice playing tennis might be useful for EF development.

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ABSTRACT

This study evaluated the effects of two different types of tennis lessons—those involving a technique-based approach (TBA) and those involving a game-based approach (PLAY + STAY [P + S])—on the executive functions (EFs) of junior tennis players. Eighty-one tennis players (6–12 years old) were recruited and assigned to one of three groups: TBA, P + S, or watching TV (CONT). Subjects completed evaluations of EFs (inhibitory control, working memory, and cognitive flexibility) before and after 50 min programs. The overall score for EFs improved significantly for both the P + S and TBA groups but not for the CONT group; indeed the CONT group showed no improvement in overall EFs. Furthermore, the overall EF score improved more for P + S participants than for those in TBA. Looking at components of EFs, the pattern for inhibitory control reflected the pattern for the overall EF index: Improvement in the P + S and TBA groups but not in the CONT group. Only the P + S group improved in working memory. Thus, playing tennis and practicing isolated tennis skills both improved EFs of junior players more than did watching TV, and game-based tennis lessons seem to hold more promise for improving EFs than drills of tennis skills.

1. Introduction

A single (i.e., acute) bout of physical exercise is useful for facilitating cognition, which is expected to support learning in children immediately afterward [1–3]. The benefits of acute exercise for cognitive functions in children have been demonstrated in laboratory settings (e.g., treadmill walking) [4,5] as well as school settings (e.g., group jogging, group games) [6–8]. Further confirmation comes from two meta-analyses, which showed that acute exercise improves cognitive function in children, with effect sizes of 0.52 (Cohen's *d*) and 0.37 (Hedge's *g*) [2,3].

An acute bout of exercise improves perception and basic processing speed, as well as higher-order cognitive function (i.e., executive functions: EFs) in children [5,9]. The EFs are comprehensive functions governing goal-directed behavior and comprise three essential components: inhibitory control, working memory, and cognitive flexibility [10]. These three features are seen in both adults and children [10]. Relationships have been found between EFs and healthy food intake (greater fruit/vegetable and less junk food intake) [11], academic achievement and outcomes (school readiness and school success) [12], and performance in other settings such as sports [13]. Furthermore, acceptable levels of EFs in children have been found to predict better health and wealth and a reduced likelihood of having a criminal record [14].

* Corresponding author at: Graduate School of Education, Hokkaido University, Kita 11-jo, Nishi 7, Kita-ku, Sapporo, Hokkaido 060-0811, Japan.
E-mail address: t.ishihara@edu.hokudai.ac.jp (T. Ishihara).

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The utility of such exercises may depend on the sensorimotor learning and the degree of cognitive activity they involve (e.g., use of strategic behavior, coordination of complex bodily movements, and adaptation to continually changing task demands) [9,15,16]. Acute exercise involving cognitive activity (e.g., group games, coordinative training) may lead to greater improvements in EFs than simpler exercises (e.g., circuit training) [6,8]. Aerobic games require cooperation with other children, strategic behavior, coordination of complex bodily movements, and adaptation to continually changing task demands. It has been suggested that the differences in the EFs demands between game-based/complex and simpler exercises mean that the game-based/complex exercises facilitate EFs development to a greater extent than do simpler exercises [9,16,17]. Thus, it appears important to develop cognitively demanding exercise programs that can be implemented during the school day just prior to an academic class to encourage optimal performance in that class, and to test other possible real world applications of the acute effect of complex physical activity on EFs.

Playing tennis requires more top-down cognitive control and the ability to override automatic behavior than repetitive tennis training (e.g., ball feeding), which might lead to the facilitation of EFs in children. However, usually the same equipment (balls, courts) as adults are used in tennis lessons for children, and repetitive training (i.e., ball feeding) comprises a large proportion of the lessons because their motor and cognitive skills may be too immature to play games with the same equipment as adults.

In February 2007, the International Tennis Federation created a program targeting young children called PLAY + STAY (P + S), which modifies conventional tennis lessons (i.e., those using the technique-based approach; TBA) to better-fit children's needs. P + S tennis lessons focus on games with age-appropriate court sizes and equipment to help children play more strategically. Using the age appropriate equipment, players are able to serve, rally, and score from their first lesson [18]. In contrast, in TBA lessons, ball feeding comprises a large proportion of the lesson because children use the same balls and courts as adults do. Given the P + S program's focus on games and rallying, which requires substantial top-down cognitive control and the ability to override automatic behavior rather than repetitive exercise (i.e., ball feeding), we hypothesized that it would have greater benefits for the EFs (i.e., inhibitory control, cognitive flexibility, and working memory) of junior tennis players than would the TBA. Most previous studies that demonstrated the effects of acute exercise on cognitive function focused on aerobic exercise in laboratory settings. Thus, we evaluated the beneficial effects of P + S tennis lessons as compared to TBA on the EFs of tennis players aged 6–12 years old, and expand previous knowledge toward real world applications.

2. Material and methods

2.1. Participants

Eighty-one junior tennis players (6–12 years old, 38 boys, 43 girls, tennis experience: 0.1–7.3 years) participated in this study. We recruited participants from three tennis clubs. The tennis groups were classified based on the tennis lessons in which they usually participated [TBA (n = 32), P + S (n = 39)], because unfamiliar lesson programs were expected to influence the experimental results. We recruited a control group from among players who had recently changed from TBA lessons to P + S lessons (CONT; n = 10), who watched TV instead of undergoing the tennis lesson. Children who were receiving special needs education due to disorders of cognitive function or attention were excluded. Participants provided written assent and their parents provided written informed consent in accordance with the requirements of the Ethical Committee of Faculty of Education, Hokkaido University.

2.2. Procedure

Testing was completed over 2 days that included a cardiorespiratory fitness assessment and experimental session. Cardiorespiratory fitness was evaluated before the lesson by the use of the shuttle stamina test [19]. Seven participants could not participate in the cardiorespiratory fitness assessment due to a conflict with their parents' schedule; therefore, cardiorespiratory fitness data were collected for 74 participants. In the experimental session, participants entered a computer room and rested for 5 min. Participants were then instructed to complete the EFs tasks (pre-test assessment). Next, participants underwent a tennis lesson or watched a TV program (a popular animated cartoon) for 50 min. In our country, tennis clubs generally comprise 45–60 min programs for children. Our sample typically took part in 50 min tennis lessons, so we set the lesson duration at 50 min. During this time, their heart rates were measured in 1 s intervals using a heart rate (HR) monitor (RS400, Polar, Kempele, Finland). The contents of each tennis lesson and the time spent on each activity during the lesson were recorded. After the programs, participants were taken back to the same room and completed the same cognitive tasks at post-test 15 min after the 50 min of tennis lesson or watching TV. Participants were required to refrain from caffeine and exercise on the day of the experiment. All experiments were conducted between 13:30 and 17:30.

2.3. Differences in equipment and typical examples of instruction in tennis lessons

Equipment and typical examples of instruction in both tennis lessons are presented in Supplementary material. In P + S tennis lessons, junior players used various types of equipment separated into three stages and used age appropriate tennis rackets. By using the age appropriate equipment, instruction of P + S was focused on playing the game.

2.4. Assessment of executive functions

Three EFs were evaluated using the Stroop Color and Word Test (SCWT), 2-back Task, and Local-global Task (LGT). The details of the assessment of executive function are listed in Supplementary material. The SCWT is a well-known instrument for measuring inhibitory control [20]. Participants are instructed to name the color of the incongruent color-word stimulus (e.g., blue printed in green ink). Because word reading is a more automatic cognitive process than is color naming, participants are required to inhibit strong internal predispositions. In the 2-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 [21]. During the 2-back Task, participants are required to hold the information and update it (working memory). In the LGT, a geometric figure called a Navon figure [22], comprising a "global" stimuli composed of much smaller, or "local" stimuli, was randomly presented on the computer screen. The target stimuli were equally likely to appear at the global and local levels, whereas neutral stimuli appeared at the opposite level of the target stimuli. When the level of the target stimuli was alternated, i.e., "local" trials were followed by "global" trials and vice versa, participants are required to use cognitive flexibility. The main dependent variables of these tasks were mean reaction time (RT) and accuracy.