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

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Highlights

- We examined the effects of tennis play on executive functions (EFs) in children.
- A single 50-minute 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.

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-minute 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.

Keywords: sports activity; cognitive engaging exercise; inhibitory control; working memory; cognitive flexibility

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, stationary biking) [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 and 0.32 (Cohen's *d*) [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].

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 is 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.

Material and methods

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.

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 minutes. 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 minutes. In our country, tennis clubs generally comprise 45- to 60-minute programs for children. Our sample typically took part in 50-minute tennis lessons, so we set the lesson duration at 50 minutes. During this time, their heart rates were measured in 1-second 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 minutes after the 50 minutes 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.

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 four stages and used age appropriate tennis rackets. By using the age appropriate equipment, instruction of P+S was focused on playing the game.

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. Details of these tasks are presented in the supplementary material. The main dependent variables of these tasks were mean reaction time (RT) and accuracy.

Statistical Analysis

We assessed the normality of variables using the Kolmogorov-Smirnov test. The accuracy data for the three EFs tasks and HR data did not show a normal distribution; therefore, accuracy and HR were globally ranked before performing the ANCOVA [23]. One-way ANCOVAs were conducted to examine the significance of the differences in demographic data, cardiorespiratory fitness, mean HR (at pre-test, during programs, and at post-test), and EF task performance data at pre-test adjusted for age and gender. Principal components analyses were conducted to obtain the overall score for EFs (RT and accuracy of the SCWT incongruent trial, 2-back Task, LGT switching condition) and basic processing speed/accuracy (requiring less executive aspects of cognition; RT and accuracy of the SCWT control trial, LGT repetitive condition). The mean RT and accuracy data obtained during the

three tasks were analyzed using 3 (group: CONT, TBA, P+S) \times 2 (time: pre-test or post-test) two-way ANCOVAs that were adjusted for age and gender (coded as 0 = girl, 1 = boy) to determine time dependent change. Previous research suggested that the effects of acute exercise on EFs might have individual differences [4]. In this study, improvement of RT was affected by RT at pre-test [Δ RTs was significantly correlated with RTs at pre-test in all tasks ($r < -.33$, $p < .01$, data not shown); i.e., lower performer(s) at pre-test showed greater improvement than higher performer(s)], therefore, we conducted one-way ANCOVAs on Δ RT that adjusted for age, gender, and score at pre-test. Significant main effects of group were further analyzed via Scheffé's post hoc tests.

Results

Participants' Characteristics

Descriptive data regarding the participants' demographic characteristics are presented in Table 1. No significant differences in gender ($\chi^2 = 2.13$, $p = .35$) and other variables ($F < 2.42$, $p > .09$, partial $\eta^2 < .06$) were detected between the groups.

Lesson Type

The breakdown of TBA lessons by time spent performing various activities was as follows: 32% non-activity time (i.e., explanations and breaks), 5% games, 19% rallies, 27% ball feeding, 5% coordination training, and 12% collecting balls. For the P+S lessons, the breakdown was as follows: 26% non-activity time, 40% games, 24% rallies, 0% ball feeding, 5% coordination training, and 5% collecting balls. All of the lessons ended in a game.

Heart Rates

HR data were collected for 60 subjects, due to a limited number of HR monitors. During the programs, participants in the TBA and P+S groups showed a higher mean HR than did those in the CONT group ($F = 36.31$, $p < .01$, partial $\eta^2 = .57$; $t > 8.04$, $p < .01$, $d > 3.82$).

No significant difference was observed between the TBA and P+S groups ($t = 0.10, p = .92, d = 0.03$). We noted no group differences at either pre- or post-test ($F < 1.47, p > .23$, partial $\eta^2 < .06$) (Table 1).

Executive Functions

Results of principal components factor analysis, task performance data, and summary of ANCOVA results on EFs task performance are provided in the supplementary material (Supplementary Table 1-4).

No significant group difference was detected for EF task performance at pre-test ($F < 12.62, p > .07$, partial $\eta^2 < .07$). There were no main effects of group, time, and group \times time interaction on accuracy for any EF task.

There were significant main effects of time on RT for all tasks ($F > 5.12, p < .03$, partial $\eta^2 > .06$). Post-hoc testing demonstrated the subjects' post-test RTs were shorter than were their pre-test RTs for all tasks. No main effect of group on reaction time was observed for any of the tasks ($F < 1.58, p > .21$, partial $\eta^2 < .05$).

Group \times time interaction on RT for overall EFs, SCWT incongruent trial, and 2-back Task was observed ($F > 4.25, p < .02$, partial $\eta^2 > .10$) (Figure 1A). The RTs of the P+S group were shorter than they had been at pre-test on the three measures ($t > 4.71, p < .01, d > .63$). The RTs of the TBA group were shorter than they had been at pre-test on the overall EFs and SCWT incongruent trial ($t > 2.81, p < .01, d > .38$), but not 2-back Task ($t = 1.86, p = .07, d = 0.28$). No time point differences were observed on the three measures in the CONT group ($t < 1.96, p > .05, d < .48$). No group differences were observed at pre- and post-test ($t < 1.86, p > .07, d < 1.00$). There was no significant group \times time interaction on RTs for other tasks.

One-way ANCOVA revealed a significant main effect of group on \angle RT for overall EFs after controlling for the RT at pre-test ($F = 7.62, p < .01$, partial $\eta^2 = .18$). Post hoc analysis on \angle RT for overall EFs showed there was greater facilitation of RT in the P+S

group than in the CONT and the TBA groups (versus CONT: $t = 3.68, p < .01, d = 1.37$; versus TBA: $t = 2.27, p = .03, d = 0.58$). In addition, the TBA group showed greater improvements than in the CONT group ($t = 2.02, p = .05, d = 0.79$) (Figure 1B).

One-way ANCOVA revealed a significant main effect of group on Δ RT at post-test for the SCWT incongruent trial after controlling for the RT at pre-test ($F = 3.25, p = .04$, partial $\eta^2 = .08$). Post hoc analysis on Δ RT for the SCWT incongruent trial showed there was only marginally greater facilitation of RT in the P+S group than in the CONT and TBA groups ($t > 1.71, p < .10, d > 0.58$) (Figure 1B).

One-way ANCOVA revealed a significant main effect of group on Δ RT for the 2-back Task after controlling for the RT at pre-test ($F = 5.18, p < .01$, partial $\eta^2 = .13$). Post hoc analysis on Δ RT for the 2-back Task showed there was greater facilitation of RT in the TBA and the P+S groups than in the CONT group ($t > 2.13, p < .04, d > 0.83$) (Figure 1B).

Discussion

This study examined the effects of two types of tennis lessons—a technique-based approach (TBA) and a game-based approach (PLAY+STAY [P+S])—on the executive functions (EFs) of junior tennis players. We found that one TBA or P+S lesson resulted in greater immediate improvement in EFs as compared to watching a TV program (CONT); the P+S lessons might be especially beneficial for promoting EFs given that this group improved the most on the EF composite index. Our results expand previous knowledge on the effects of an acute bout of exercise on cognition found in laboratory settings toward real world applications.

The present study suggests that both the TBA and P+S lessons improve EFs. Following both types of tennis lessons, participants' overall RT for EFs was shortened to a greater extent than following watching TV. Inhibitory control was facilitated after both types

of tennis lessons, while it was unchanged after watching TV. Our findings are in accord with those of previous studies that demonstrated the positive effect of acute exercise on EFs in children [4–8]. In this study, TBA and P+S demonstrated larger effect sizes than reported in recent meta-analyses (Cohen's $d = 0.32$ or 0.52)[2,3]. Our findings suggest that sports activity (i.e., tennis) may be a useful tool for facilitating EFs in children.

Participants' RT in overall EFs was shortened to a greater extent by P+S lessons than TBA lessons. However, those who started off with worse (i.e., longer) RTs always improved more than those who started off with better RTs regardless of condition, and P+S participants started off with slower RTs than TBA participants[§]. [[§]Footnote: Indeed, one reviewer suggested that we might simply be seeing variation around a common mean. The simple-exercisers started out with a good RT of 1052 ms and ended up improving a little to 943 ms. The game-players started out with a longer mean RT (1090 ms) and ended up improving more to 916 ms. The mean RT across both time points on the EF-composite index was 998 ms for the simple exercisers and 1003 ms for the game-players (both of which round to 1000 ms). Thus, the reviewer suggested this might be normal variation around a common mean for both groups.] Furthermore, working memory was facilitated in the P+S group, while it was maintained after the TBA and CONT groups. These results suggest that P+S might be more beneficial than TBA for facilitating EFs. Recent studies using a longitudinal design have suggested that chronic cognitive engaging exercise has beneficial effects on EFs of children [24–26]. Further research using longitudinal design is needed to examine whether chronic game-based tennis lessons (P+S) enhance EFs more than technique-based tennis lessons in children.

The present study could not elucidate the mechanisms behind the greater improvement of EFs following the P+S lesson than the TBA lesson. One possible explanation is that games in tennis lessons require more effortful cognitive processing with top-down

cognitive control and the ability to override automatic behavior and bodily movement. As mentioned previously, tennis games require cooperation with other children, strategic behavior, the coordination of complex bodily movements, and adaptation to continually changing task demands, whereas repetitive exercises (i.e., ball feeding) require less such cognitive activities. Thus, the P+S lesson may require more EF activity and therefore should lead to greater improvements in EFs than a TBA lesson. The more one practices a skill (such as EFs) and the more the skill is challenged, the more the skill improves [17,27]. Many functional magnetic resonance imaging studies reported that more effortful processing imposes greater demands on EFs-related circuitry, as highlighted by greater frontal activation [28–30].

Given the children who participated in this study were tennis players, it might be inappropriate to apply the results to children not involved in competitive sports such as tennis. Considering length of competition history of participants (tennis experience = 0.1 to 7.3 years), there were no significant correlations between tennis experience and change in EF task performances after controlling for age, gender, and group ($|r| < .20$, $p > .09$, data not shown). This finding indicates that the effects of acute bout of tennis lessons on EFs were irrespective of tennis experience. As such, we believe the present study can apply to children other than those who are tennis players.

Contrary to the findings of a recent study that reported a positive effect of acute exercise on cognitive flexibility [7] and accuracy data [5], we found no group difference for cognitive flexibility and accuracy data. Furthermore, on the individual EFs tasks, there were no significant differences between the two tennis groups. This inconsistency might have been due to the tasks lacking sufficient sensitivity. The Local-global Task and Stroop Color and Word Test were conducted in a way that minimized their difficulty; therefore, our sample

showed high accuracy at pre-test (94.30% and 96.16%) and there might have been ceiling effects.

This study has several limitations that should be acknowledged. The participants in this study were highly heterogeneous in terms of age and sample size and were not randomly allocated to the three groups; it is possible that our results might have been biased by these factors. Another study is needed using a randomized controlled trial or crossover design. The several limitations noted in this study are listed below: not randomly assigned; ceiling effects on our EF tasks (otherwise might have found stronger effects); no group differences on any individual EF measure; were post-test differences on the EF composite meaningful?; only examined benefits that dissipate quickly (benefits from a single session disappear within minutes).

Conclusion

The current study suggests that a single tennis lesson of either technique-based approach (TBA) or game-based approach (PLAY+STAY [P+S]) improves EFs immediately afterward to a greater extent than does watching TV. Furthermore, P+S lessons might be more beneficial than TBA lessons for facilitation of EFs. Further research is needed to determine whether chronic game-based exercise enhances EFs more than simple exercise in children. Moreover, there is a need to evaluate the role of enhanced EF performance (ability to concentration and pay attention, stay on task, complete assignments, follow multi-step instructions, see things from multiple perspectives) immediately after the exercise session on school performance.

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Figure Legends

Figure 1. (A) Mean (SEM) RTs for each group and condition at pre- and post-test after controlling for age and gender, illustrating the group \times time interaction. (B) Δ RTs after controlling for age, gender, and RTs at pre-test.

Note: RT, reaction time; CONT, control group (i.e., watching TV); TBA, technique-based approach; P+S, PLAY+STAY (game-based approach); SCWT, Stroop Color and Word Test,

** $p < .01$, * $p < .05$, $\dagger p < .10$.

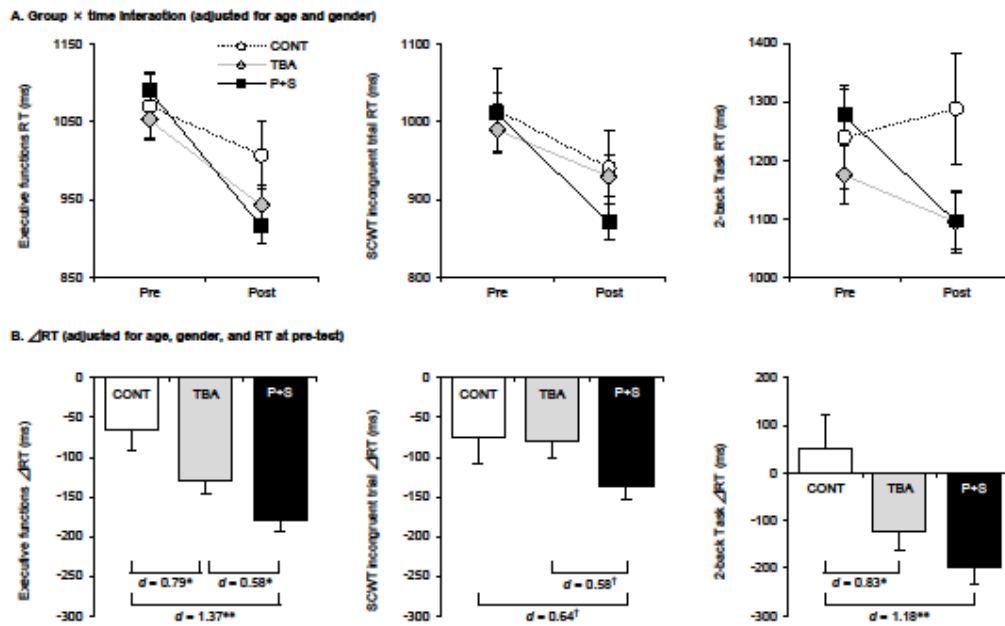


Table 1
Descriptive characteristics of the study participants

Variables	CONT	TBA	P+S
<i>N</i>	10	32	39
Gender			
Males	6	12	20
Females	4	20	19
Age (years)	9.1 (0.5)	9.7 (0.3)	9.8 (0.2)
Height (cm)	134.2 (3.0)	133.2 (1.7)	134.7 (1.5)
Weight (kg)	30.8 (2.0)	28.7 (1.1)	30.1 (1.0)
Body mass index (kg/m ²)	16.9 (0.6)	16.1 (0.3)	16.4 (0.3)
Tennis experience	1.4 (0.2)	2.2 (0.3)	2.6 (0.3)
Shuttle stamina test (m) ^a	404.57 (20.02)	427.33 (9.67)	429.78 (8.71)
Mean heart rate ^b			
During pre-test (bpm)	101.59 (4.29)	91.50 (2.15)	94.50 (1.92)
During programs (bpm)	94.88 (2.04)	142.39 (3.56) **	142.77 (1.78) **
During post-test (bpm)	94.85 (3.48)	94.80 (2.61)	97.29 (1.70)

Note: Values presented as *N* or mean (SEM), CONT = control group (i.e., watching TV), TBA = technique-based approach, P+S = PLAY+STAY (game-based approach), ** versus CONT, $p < .01$, ^a *N* = 74 (CONT = 7, TBA = 30, P+S = 37), ^b *N* = 60 (CONT = 6, TBA = 24, P+S = 30).