國立體育大學 102 學年度研究所博士班入學考試試題

系所：競技與教練科學研究所　　組別：教練科學組

科目：運動心理學文獻評論（本試題共 18 頁）

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請由下列二篇文獻任選一篇作以下問題之論述 (中英文答題均可)

Chang, Y. K., Ku, P. W., Tomporowski, P. D., Chen, F. T., & Huang, C. C. (2012). The effects of acute resistance exercise on late-middle-aged adults' goal planning. *Medicine and Science in Sports and Exercise, 44*(9), 1773-1779.

Chang, Y. K., Tsai, Y. J., Chen, T. T., & Hung, T. M. (2013). The Impacts of coordinative exercise on executive function in kindergarten children: An ERP study. *Experimental Brain Research, 225*(2), 187-196.

1. List the operational definitions of the main variables (independent and dependent variables). (10%)
2. What is the specific purpose of the research? (10%)
3. What is the main rationale that provides for presenting the relationship among the variables (20%) ? How is it derived, and supported? (20%)
4. What are the main results and significant advantages of the research? (20%).
5. How do these findings implicate related conditions in the real world? (20%)

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RESEARCH ARTICLE

The impacts of coordinative exercise on executive function in kindergarten children: an ERP study

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Abstract This study examined the behavioral and neuroelectrical impacts of a coordinative exercise intervention with different exercise intensities on executive function in kindergarten children. Participants underwent the Eriksen flanker test before and after an exercise program that involved 35-min sessions twice per week for 8 weeks, with either low or moderate intensity. Our findings revealed that exercise intervention, regardless of intensity, resulted in shorter reaction times and higher response accuracy in both congruent and incongruent trials, with incongruent trials receiving a larger benefit from exercise compared with congruent trials. Additionally, neuroelectrical activation demonstrated greater P3 amplitude and shorter P3 latency following exercise in both trials. These results suggest that coordinative exercise may specifically benefit prefrontal-dependent tasks in the immature brain state of kindergarten children by increasing the allocation of attentional resources and enhancing the efficiency of neurocognitive processing.

Keywords Executive control · Fitness · Inhibition · P3 · Physical activity

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Introduction

Research is accumulating that provides evidence linking physical exercise with the enhancement of different aspects of cognitive function. These positive results have been found not only in cross-sectional studies comparing high fitness and low fitness groups but also in longitudinal studies that examine changes in cognitive function after a long-term exercise intervention, where facilitative effects on cognition were generally observed in groups with higher fitness levels or those receiving exercise intervention (Hillman et al. 2008; Smith et al. 2010). However, the effects of exercise on cognition have been primarily studied in college-aged or older adults, and relatively few studies have investigated the effects in adolescents or younger children (Tomporowski et al. 2008).

It is reasonable to suppose that children might receive profound influences from exercise because both the environment and individual experiences can affect the sensitive developing brain during this immature stage. Indeed, a meta-analysis of exercise and cognition demonstrated a larger positive magnitude in children (effect size, ES = 0.32) (Sibley and Etnier 2003) than in younger or older adults (ES ranged from 0.12 to 0.16) (Smith et al. 2010). Nevertheless, previous studies were limited by initial cross-sectional design, insubstantial systematic exercise programs, and inadequately validated cognitive measures, which lead to challenges in demonstrating causation (Sibley and Etnier 2003; Tomporowski et al. 2008). To address these concerns, Davis et al. (2007) employed a rigorous aerobic fitness-enhanced exercise program with moderate to vigorous exercise intensity (heart rate >150 beat per min, bpm) for 15 months in overweight children and found that the exercise group with 40 min per session performed better on a standard cognitive assessment system test than those in either the exercise group with 20-min sessions or the control groups, suggesting that the positive relationship between exercise and cognition was moderated by exercise duration.

In addition to aerobic exercise, recent studies have proposed a possible link between coordinative exercise and cognition (Kwok et al. 2011; Hotting et al. 2012). Coordination exercise is characterized by complex motor movements involving multiple degrees of freedom and interaction with body parts for goal-directed behaviors (Newell 1985; Egan et al. 2007). The adaptation of coordination exercise improves the neuromotor abilities in both the peripheral (e.g., neuromuscular ability) and central (e.g., brain neurocircuit) nervous systems, which might provide a constructive basis for improved cognitive performances. Indeed, coordinative exercise that requires motor coordination has been positively associated with cognitive performance in children (Planinsec 2002). The beneficial effects may be attributed to the activation of the cerebellum and to the neurobehavioral systems elicited by the exercise mode (Budde et al. 2008). However, the effects of long-term coordinative exercise with simultaneous manipulation of other exercise features (e.g., intensity) on cognition in children have yet to be determined.

According to the executive function hypothesis, executive function, which is controlled by the prefrontal cortex and encompasses multiple cognitive processes for goal-directed behavior, receives disproportional benefits from exercise (Tomporowski et al. 2008). Additionally, Best (2010) proposed a potential link between exercise and childhood executive function; participating in exercise requires executive effort, and executing complex motor activity in turn enhances the neural circuitry relevant to executive function, suggesting a reciprocal relationship. A recent functional magnetic resonance imaging (fMRI) study demonstrated that long-term exercise improved not only the planning aspects of executive function but also enhanced bilateral prefrontal cortex activation (Davis et al. 2011). It should be noted that executive function consists of several distinct components, and few of these constructs have been investigated within the domain of exercise and cognition.

Several recent studies have examined the effects of fitness on executive function using event-related potential (ERP), which reads patterns of neuroelectrical activity in response to internal or external events. Compared with preadolescents with low fitness levels, those in the high fitness group exhibited superior performance in a visual discrimination task (Hillman et al. 2005) and the Eriksen flanker task (Stroth et al. 2009; Pontifex et al. 2011), which manipulates the inhibitory aspect of executive function (Eriksen and Eriksen 1974). The high fitness group also demonstrated different P3 profiles (a positive-proceeding waveform occurring between 300 and 800 ms following the stimulus) in which superior cognitive indexes such as larger P3 amplitude and shorter P3 latency of the ERP components were observed (Stroth et al. 2009; Pontifex et al. 2011). Although these ERP studies have provided advanced information at a high temporal resolution on how exercise influences cognition at the neural level, it is still unknown whether aerobic exercise-induced ERP activation related to specific aspects of executive function would occur in coordinative exercise in kindergarten children.

The purpose of the present study was to investigate the effects of a long-term coordinative exercise training program on cognitive performance in kindergarten children. Specifically, we examined whether exercise training at two intensities would improve the inhibitory aspect of executive function or influence the P3 index of ERP measurements elicited by a flanker test paradigm. We hypothesized that both exercise training groups would experience executive control performance benefits, both behaviorally and neuroelectrically, while training with moderate intensity would result in greater facilitative impact.

Methods

Participants

Twenty-six healthy kindergarten children aged 6–7.5 years (15 boys, mean age $= 7.2 \pm 0.3$; 13 girls, mean age $= 7.0 \pm 0.34$) were voluntarily recruited via presentations and flyers distributed within a local kindergarten in Taipei. To participate in the study, the following inclusion criteria were required: (a) subjects could not take medication; (b) subjects had to be free of cardiovascular-related disease, psychiatric disorders, and neurological abnormalities; (c) subjects must be able to perform physical exercise; (d) subjects must have normal or corrected-to-normal vision; and (e) subjects were required to display right hand dominance. These inclusion criteria were determined by both children and parents through a modified heath screening questionnaire recommended by the American College of Sports Medicine (ACSM) exercise guidelines (American College of Sports Medicine 2010). Eligible children were randomly assigned into either low- or moderate-exercise-intensity training groups. All children and parents read and completed written informed consent forms approved by the Institutional Review Board at the Taipei Physical Education College.

Physical fitness measures

Five tests, including a 60-s crunch curl up session, standing long jump, standing on one leg with eyes closed, sit-and-reach, and body mass index, were applied to determine the physical fitness capacities of muscular endurance, power, balance, flexibility, and body composition, respectively. These tests were specifically selected because the norms of these measures have been established and are considered to be standard in the Preschool Children Fitness Program (PCFP) by the Department of Education of the Taipei City Government. The testing procedure was administered by a trained examiner following PCFP guidelines.

Materials

The present study used a modified Eriksen flanker task paradigm that has been widely employed to examine the inhibitory aspect of executive function (Eriksen and Eriksen 1974). The flanker task consisted of two trial types, with either congruent or incongruent visual stimuli. The congruent trial was a horizontally arranged array of arrows presented in the same direction (e.g., <<<<< or >>>>>). The incongruent trial had a similar array of arrows, but the middle arrow, the target, was displayed in the opposite direction (e.g., <<><< or >><>>). Participants were asked to respond to the direction of the target arrow within the array of arrows by pressing the corresponding right or left finger button (e.g., right finger pressing L for <<><<; left finger pressing A for >><>>) as quickly and accurately as possible. The presentation of the trials was controlled by Neuroscan Stim software (2.0 version). A fixation cross was displayed on the center of the computer screen for 1,000 ms, followed by an imperative stimulus with a 200 ms presentation time. The interstimulus interval (ISI) was 2,000 ms, and failure to respond within 1,000 ms or pressing the wrong button was considered an incorrect response. The sizes of the fixation cross and stimulus were 0.6 cm and 2 × 10 cm, respectively, and they appeared on a black background on a 32 × 29 cm computer screen. At a viewing distance of 70 cm, the vertical and horizontal visual angles were 2° and 8°, respectively. A total of 208 response trials were divided into 4 blocks of 52 trials each, in which the order of congruent and incongruent trials was randomized with the same probability. Each block included a 1-min resting interval, and the total task duration was approximately 10 min. The accuracy percentage and reaction times of correct responses on both congruent and incongruent trials were identified as metrics of behavioral cognitive performance.

Experimental procedure

Children were asked to undergo three separate sessions. In session I, participants, along with their parents, were asked to come to a specific and quiet room provided by the kindergarten to report their demographic background and complete the prescreening processes to determine eligibility for participation. Those who met the inclusion criteria were instructed to sit in a comfortable chair, and pre-test cognitive data were collected with the flanker task after performing a block of 20 practice trials. Next, pre-test physical fitness data were collected from each participant by completing the 60-s crunch curl up session, a standing long jump test, standing on one leg with their eyes closed, a sit-and-reach test, and a body mass index measurement. Examinations of cognitive and physical fitness testing were obtained during the weekday afternoon, and no stimulating food or soft drink was provided by the kindergarten prior to testing.

Session II was the soccer exercise program. Soccer was emphasized because kicking a moving ball constitutes a high level of movement that requires prospective control, perceptual skill, and motor coordination. In particular, its execution requires the interaction of agonist and antagonist muscles (Manolopoulos et al. 2006; Egan et al. 2007). The modified children's program consisted of a soccer exercise program with courses of either low- or moderate-exercise intensity in 35-min sessions, twice per week, for 8 weeks. The course was designed to provide coordinative exercise with an instructional, fun, and enjoyable approach, rather than focusing on competition or skill enhancement. Each session involved the following stages: warm up for 5 min, perform the main exercises for 25 min, and cool down for 5 min. The warm up stage included a 4-min stretch and 1-min vertical knee raise exercise, with a frequency of 1 s per raise. The main exercise stage was designed to reach different exercise intensity loads, in which low and moderate intensities were separately identified as 40–50 % or 60–70 % of maximal heart rate, respectively (the average heart rates were 103.7 ± 8.33 bpm and 140.2 ± 9.53 bpm, respectively), based on ACSM exercise guidelines (American College of Sports Medicine 2010). Specifically, the main exercises in the low-exercise intensity group emphasized soccer's coordination movement in the lower extremities, and with continuous walking (e.g., dribble while walking, circular passing while walking, or kicking the ball against the wall), while exercises in the moderate-intensity group targeted similar soccer actions constituting lower extremity movements coordinated with continuous running (e.g., dribble with jogging or sprinting, circular passing game with jogging, or long shots). Seven heart rate monitors (Sport Tester PE 3000, Polar Electro Oy, Kempele, Finland) were randomly attached to participants in each exercise program to verify the intensity manipulation during the main exercise stage. The cool-down stages consisted of stretching exercises while discussing the main course themes. The exercise program was instructed by a soccer-certified physical education teacher.

During session III, participants performed both the flanker task and the physical fitness tests as in session I to collect post-test data. Participants and parents who completed the three sessions were compensated by receiving a toy and an explanation of the aim of the experiment.

ERP recording and data reduction

Electroencephalography (EEG) was measured in a quiet, sound-attenuated room. EEG was recorded with an elastic cap containing 30 equidistantly spaced Ag/AgCl electrodes (Neuroscan Quick-cap, Neuroscan Inc, Virginia, USA) at the scalp sites F3, Fz, F4, T3, C3, Cz, C4, T4, P3, Pz, P4, O1, Oz, and O2 according to the international 10–20 system. The average of the right and left mastoids served as a reference, while the Fpz site was used as a ground electrode. Eye movements were recorded as vertical and horizontal electro-oculograms (EOG) via bipolar external electrodes above the left pupil (VEOG) and at the outer corners of both eyes (HEOG), respectively. All electrode impedances were kept below 5 kΩ. Amplified EEG data were acquired with a band pass filter at 0.1–30 Hz, a continuous sampling rate of 500 Hz, and a 60-Hz notch filter using a Neuroscan Synamps2 amplifier (Scan 4.3, Neurosoft Labs, Inc.).

The EEG data from each condition were corrected offline by an ocular artifact algorithm (Semlitsch et al. 1986). EEG epochs were then segmented from 100 ms before to 1,000 ms after trial onset, with the 100 ms pre-stimulus period used as a baseline correction. In addition, waveform excursions that exceeded ±100 µV were excluded. The filtered EEG epochs were averaged, and the ERP components were identified. The P3 component was determined as the maximum positively proceeding peak within 300–800 ms after trial onset in which the P3 amplitude and latency were identified in Fz, Cz, and Pz (Hillman et al. 2005; Kamijo et al. 2007). The numbers of averaged correct and artifact-free trials for congruent and incongruent conditions were 70.75 ± 1.50 and 54.75 ± 7.63, respectively.

Statistical analysis

The present study applied a quasi-experimental structure with between-subject design. An independent t test was initially conducted between the low- and moderate-intensity training groups to examine the homogeneity of the demographic backgrounds. A paired t test was further applied to separately investigate the time effects in the low- and moderate-exercise-intensity groups. A 2 (group: low-exercise intensity vs moderate intensity) × 2 (times: pre-test vs post-test) × 2 (condition: congruent vs incongruent) × 3 (site: Fz, Cz, vs Pz) mixed repeated measures ANOVA was further utilized to evaluate the flanker test performance and P3 measures. Multiple comparisons were performed, when appropriate, following any simple main effects. All ANOVAs were evaluated by adjusting the Greenhouse–Geisser correction to avoid violation of the sphericity assumption.

Results

The two groups had no significant demographic differences in age, gender, height, weight, parental education, family social economic status, or soccer experience. Additionally, no significant effects were found in the five physical fitness tests (t's > -7.26, $p > .05$) (see Table 1). These results suggest a homogeneous initial status between the groups.

Physical fitness measures

Paired t tests revealed significant differences in the 60-s crunch curl up session, sit-and-reach test, and BMI in the moderate training group (t's > 1.57, p's $< .05$), while only a difference in BMI was found in the low-exercise-intensity group ($t = 2.79$, $p < .01$). No difference was found in the level of satisfaction with the soccer exercise course between the groups (see Table 2).

Table 1 Descriptive data for participant demographic characteristics

Variable	Low intensity ($N = 13$)	Moderate intensity ($N = 13$)	All ($N = 26$)
Age (year)	7.18 ± 0.30	6.98 ± 0.34	7.10 ± 0.33
Gender (girl)	6	7	13
Height (cm)	1.17 ± 0.045	1.16 ± 0.052	1.16 ± 0.047
Weight (kg)	22.77 ± 3.96	22.23 ± 4.07	22.5 ± 3.94
BMI (kg/m^2)	16.67 ± 2.04	16.39 ± 1.94	16.5 ± 1.5
Parental education (years)	17 ± 2	17.25 ± 1.5	17.13 ± 1.64
Family social economic status	3 ± 0	3.5 ± 0.7	3.25 ± 0.5
Soccer experiences (yes %)	50 %	50 %	50 %

Table 2 Means and standard deviation in each experimental condition

Variable	Low intensity		Moderate intensity	
	Pre-test	Post-test	Pre-test	Post-test
60-s crunch curl up	8.85 ± 7.41	9.52 ± 6.78	5.23 ± 5.54	9.96 ± 6.94*
Sit-and-reach test	27.46 ± 5.17	27.92 ± 7.92	26.53 ± 7.89	30.23 ± 7.69*
Standing long jump (cm)	94.46 ± 14.47	90.53 ± 16.55	87.45 ± 12.51	94.63 ± 14.63
Standing on one leg with eyes closed (second)	4.29 ± 2.90	5.73 ± 6.56	3.01 ± 1.96	6.37 ± 8.60
BMI	16.67 ± 2.04	16.22 ± 2.11*	16.39 ± 1.94	16.02 ± 2.03*
Satisfaction of soccer course	–	3.67 ± 5.12	–	4.00 ± 8.95

Satisfaction of soccer curse ranged from 1 to 5, higher score represent higher satisfaction. * Represents the significant difference between pre- and post-test

Behavioral performance

Regarding the accuracy rate, a three-way ANOVA revealed main effects of time and condition (F's > 24.05, p's < .001) and an interaction of time and condition ($F = 12.19$, $p < .001$). A post hoc comparison indicated that the post-test period had a higher accuracy rate in both congruent (93.34 % ± 9.91) and incongruent (90.55 % ± 7.15) trials compared with those in the pre-test period (87.4 % ± 12.71 and 75.36 % ± 7.15, respectively), in which the congruent condition had higher accuracy than the incongruent condition (see Fig. 1a). Tests following the simple main effect revealed that, although the congruent condition had higher accuracy rates than the incongruent conditions in pre- and post-test measures, the differences between post- and pre-test in the incongruent condition were larger (ES = 5.60) than those in the congruent condition (ES = 2.65) (see Fig. 1b).

In terms of reaction time, a three-way ANOVA revealed only main effects for time and condition (F's > 15.88, p's < .001). A subsequent post hoc comparison indicated that reaction times in the post-test period for both congruent (551.03 ± 94.58 ms) and incongruent (590.60 ± 97.25 ms) trials had shorter durations compared with those in the pre-test condition (604.52 ± 98.03 ms and 661.32 ± 116.79 ms, respectively), in which the incongruent condition had longer durations than the congruent condition (see Fig. 2).

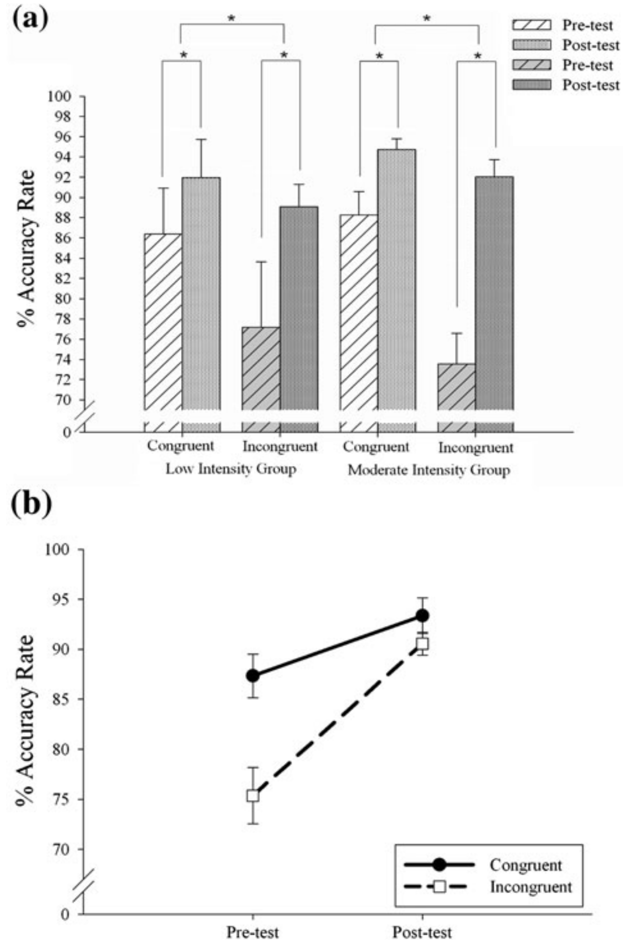

Fig. 1 **a** Accuracy rate to flanker trials and times between two exercise intensity groups. **b** Interaction of flanker trails and times assessed in accuracy rate. Data are mean ± SEM. *$p < .05$

ERP results

For the P3 amplitude, a four-way ANOVA revealed main effects of time ($F = 30.98$, $p < .001$, $ç^2 = -.56$) and site ($F = 13.59, p < .001, ç^2 = .36$). In addition, an interaction of time × condition × site was also found ($F = 4.16$, $p < .005$, $ç^2 = -.15$). When controlling the time factor, decomposition of the condition and site yielded significance in site (F's > 8.23, $p < .01$, $ç^2 > .24$), where larger amplitudes were found in Cz, Pz, and Fz in both pre- and post-tests (t's > −4.03, $p < .01$). When controlling the condition factor, the decomposition of time and site yielded significance in site ($F = 6.30$, $p < .05$) in the congruent condition and in time (F = 31.12, $p < .01$, $p = .000$, $ç^2 = .56$) and site (F = 12.660, $p < .001$, $ç^2 = .34$) in the incongruent condition. Generally, P3 amplitude in the post-

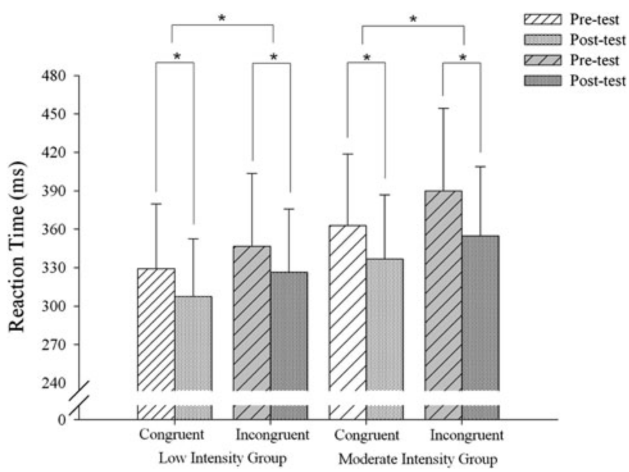

Fig. 2 Reaction time to flanker trials and times between two exercise intensity groups. Data are mean ± SEM. *$p < .05$

test was larger than those in the pre-test in both conditions, where larger P3 amplitudes were found in Pz and Cz compared to those in Fz (t's > 2.34, $p < .01$). When controlling the site factor, decomposition of the interaction of time and condition yields significant time effects in Fz, where the P3 amplitude in the post-test was larger than those in pre-test ($t = -6.02$, $p < .01$). The other two sites showed larger amplitudes in the incongruent condition than those in congruent condition, particularly in Pz and Cz (F's $> .58$, $p < .01$, $ç^2 = .17$) in both the pre- and post-test.

Regarding P3 latency, a four-way ANOVA demonstrated a main effect of time ($F = 41.06$, $p < .001$), in which both the congruent (503.87 ± 47.73 ms) and incongruent (501.82 ± 61.69 ms) conditions in the post-test period had shorter latency than those conditions during the pre-test (565.27 ± 86.21 ms and 565.44 ± 96.81 ms, respectively) (see Fig. 3). No other main effects or interactions across factors were observed.

Discussion

To our knowledge, this is the first study to behaviorally and neuroelectrically examine the effects of long-term coordinative exercise on the inhibitory aspect of executive function performance in kindergarten children. Children in the moderate-intensity group demonstrated improved fitness capabilities, including muscular endurance, flexibility, and body composition, while the low-intensity group only showed decreased body composition.

The behavioral results partially support our hypothesis, in which children had higher accuracy and faster reaction times in an inhibitory task following the coordinative exercise intervention. However, no significant differences were found between the low- and moderate-intensity groups, suggesting that exercise itself, regardless of intensity, facilitates improvement in executive function. Although the results were limited by the lack of a control group, these behavioral findings are in line with previous studies displaying correlations between motor ability and cognition (Planinsec 2002; Uhrich and Swalm 2007). These findings are also similar to studies comparing fitness effects on cognition in preadolescent children, in which high aerobic fitness groups show more response accuracy (Hillman et al. 2009a; Pontifex et al. 2011; Wu et al. 2011) and less response variability (Wu et al. 2011) compared to low aerobic fitness groups on a modified flanker test. Our results extend the knowledge base on coordinative exercise in kindergarten children.

Although performance in both trial types improved after the intervening exercise program, incongruent trial performance improved more dramatically, suggesting that executive function may have improved more in an adaptive capacity following exercise. This selective effect on incongruent trial performance corresponds with the executive function hypothesis. A theory-based classical meta-analysis observed that long-term aerobic exercise improved all types of cognition (e.g., speed, spatial, and executive control) in older adults, but executive control received the largest benefit (Colcombe and Kramer 2003). Given that executive function is robustly associated with the neural circuitry of the prefrontal cortex (Best and Miller 2010), it is plausible that exercise alters the prefrontal cortex, which in turn influences its function. Indeed, Weinstein et al. (2012) recently observed that aerobic fitness is correlated with gray matter density in multiple brain regions, including the dorsolateral prefrontal cortex, where the gray matter of the right inferior frontal gyrus and precentral gyrus mediates the relationship between fitness and inhibition of the Stroop test. This study supports the view that exercise-induced changes in the prefrontal cortex fulfill a crucial role in influencing executive function. Taken together, our observation of a beneficial exercise effect on executive function demonstrates that exercise could be an effective stimulus for prefrontal cortex development in young children.

Notably, the present study found that the central and parietal cortices demonstrated larger P3 amplitude compared to the frontal cortex, suggesting that brain development is different for children. Compared to the brain regions responsible for attention, sensorimotor processing, and speed and language development, the prefrontal cortex develops later during the adolescent period (O' Hare and Sowell 2008). Our results were consistent with longitudinal structural MRI studies, which indicate that the central cortices involving the motor and sensory systems mature earliest, followed by the parietal cortices related to spatial attention; the prefrontal cortices associated with higher-

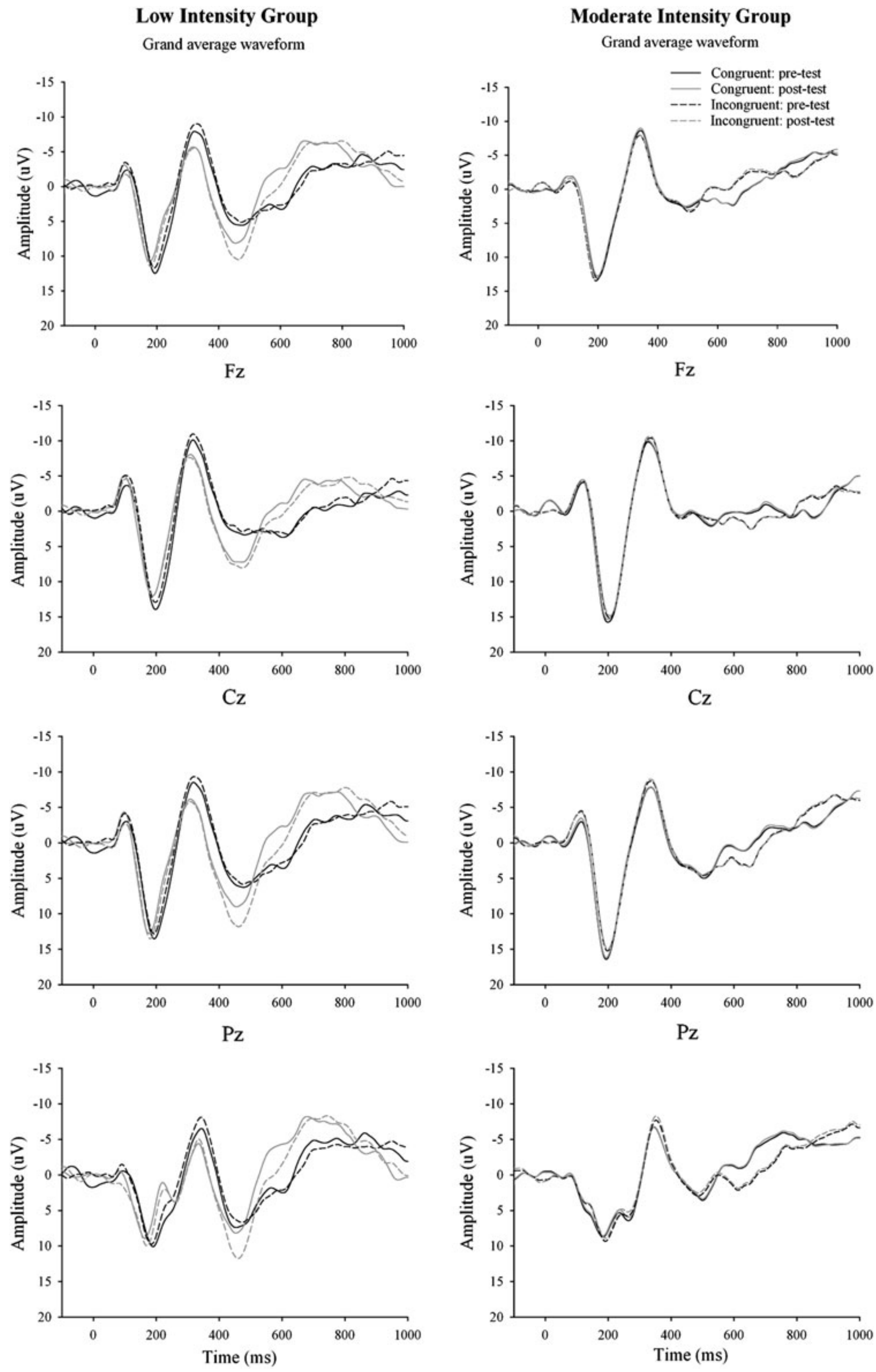

Fig. 3 Grand average waveforms elicited by two flanker trials and time assessed at average and selected electrodes in each exercise intensity group

order cognition mature last (Sowell et al. 2003; Giedd 2004; Gogtay et al. 2004; Sowell et al. 2004). Similar differential maturation in the frontal and parietal cortices was also identified by fMRI where neuropsychological task-induced parietal activation was observed in adolescence and task-induced prefrontal activation was found in adults (Adleman et al. 2002), reflecting the differences in maturation of brain regions. The development of the prefrontal cortex is nonlinear and involves both progressive (e.g., neurogenesis and synaptogenesis) and regressive (e.g., synaptic pruning) processes (Gogtay et al. 2004). Gray matter augmentation occurs dramatically in early childhood but diminishes in the frontal cortex, with expanding myelination and connectivity continuing after 7 years of age (Sowell et al. 2004). The protracted maturation of the prefrontal cortex corresponds with processing speed in executive function tasks (Amso and Casey 2006). It is worth noting that mature processing is shaped in part by both the environment and individual experiences and is therefore susceptible to change in its immature stages (Best 2010; Best and Miller 2010).

As expected, the ERP results showed an augmented P3 amplitude and faster P3 latency following the exercise intervention. Corroborating these results, preadolescents with high fitness levels display a pattern of increased P3 amplitude and shortened P3 latency compared to those with low fitness levels (Hillman et al. 2009a; Pontifex et al. 2011). Given that P3 amplitude is recognized as reflecting the amount of attentional resources allocated for context updating in working memory or oddball tasks (Polich 2007), while P3 latency represents the efficiency of stimulus identification and classification speed (Kamijo et al. 2007), long-term coordinative exercise might improve executive function by increasing the allocation of attentional resources and accelerating neurocognitive processing. It is intriguing that kindergarten children could exhibit this neurocognitive pattern following exposure to exercise.

Beyond the prefrontal cortex, recent studies have indicated that other sub-cortical areas may be involved in the interaction between exercise and cognition. As noted by Erickson et al. (2009), fitness levels in older adults were positively correlated with right and left hippocampal volumes after adjusting for other confounding factors (e.g., age and sex), and a fitness-related increase in the hippocampal volume responsible for spatial memory was also observed. A similar finding was observed in preadolescent children (Chaddock et al. 2010a). A recent study also proposed that fitness leads to adaptive changes in the basal ganglia, a group of nuclei associated with voluntary motor control, motor integration, cognitive flexibility, and executive function. Chaddock et al. (2010b) observed that highly fit preadolescent children not only perform better in flanker tasks but also have larger sub-components of the basal ganglia, including the caudate nucleus, putamen, and globus pallidus. Exercise-induced modification of the basal ganglia provides a particularly important approach to further elucidate the relationship between coordinative exercise and cognition. Indeed, a recent meta-analysis demonstrated that participants who regularly participated in interceptive sports show the largest effects on cognitive function assessed in the laboratory (Voss et al. 2010), suggesting a prominent role of coordinative exercise. Clearly, the integration of coordinative exercise, executive function, and subcortical cortex using MRI techniques would provide valuable perspectives in advancing knowledge of the brain mechanisms underlying this effect and is therefore worth considering for future research.

The strength of this study was that it used ERP to explore a longitudinal coordinative exercise effect on executive function in kindergarten children. However, based upon its pilot status, the study suffered from a lack of a control group, which limited the interpretation of the current findings. Specifically, the study cannot rule out the possibility of interactions between exercise, learning, and maturation effects. Another limitation is the type of executive function emphasized. Given that multiple distinct factors are involved in executive function (for instance, Miyake et al. (2000) indicated that executive function involves three latent constructs, i.e., shifting, inhibition, and updating), our findings cannot appropriately generalize to global aspects. Indeed, whether exercise generally or selectively impacts executive function is still controversial (Etnier and Chang 2009; Smith et al. 2010). Additionally, while the present studies emphasize P3, which has been consistently examined in fitness-cognition research (Hillman et al. 2005; Pontifex et al. 2011), and extensively applied when using flanker task (Kamijo et al. 2007; Hillman et al. 2009b; Kamijo et al. 2009), other stimulus-locked and response-locked ERP components (e.g., N1, N2, error-related negativity) have also been examined and resulted in ambiguous findings (Hillman et al. 2005; Themanson and Hillman 2006; Pontifex et al. 2011). Obviously, further research is required to replicate these findings with a control group, to compare other aspects of executive function, and to examine other neuroelectrical indices in order to advance our understanding. Accordingly, despite the fact that we provided a relatively rigorous exercise regimen considering intensity, duration, frequency, and length, our protocol was unable to meet the ACSM exercise recommendations for children (i.e., 60 min of moderate to vigorous intensity exercise, preferably daily). Furthermore, compared to younger and older adult populations, only a few studies have examined the relationship between exercise duration and specific aspects of executive function in children (Davis et al. 2007; Davis et al. 2011). Along with Tomporowski et al. (2008), we believe that research applying appropriate exercise load (e.g., meeting the recommended amount of exercise for children) and investigating the effects of specific exercise features (e.g., intensity, frequency, duration, length) on cognition in children could be informative. It should also be noted that our study was limited to examining one type of exercise and its effect on cognition. Several recent studies have indicated that exercise modes other than aerobic exercise would benefit cognition across the lifespan, such as resistance exercise (Chang et al. 2012a; Chang et al. 2012b) and Tai Chi Chuan (Chang et al. 2010) for older adults and a martial arts courses (known to be a form of exercise that involves coordinative characteristics and discipline) for children (Diamond and Lee 2011). As such, future research might also consider a comparison of exercise modality effects on cognition.

In conclusion, our behavioral and ERP findings support a beneficial effect of coordinative exercise on cognitive function in kindergarten children, particularly in a task involving executive function. Exercise with both low and moderate intensities could increase the allocation of attentional resources and shorten the time needed for neurocognitive processing. Our data tentatively suggest that coordinative exercise alters the brain at both the cortical and sub-cortical levels, which in turn influences cognition. Given that executive function in early childhood is a critical foundation for classroom behavior and emotional self-regulation (Best 2010), these findings could inform teachers and physical education-related administrators that coordinative exercise involving coordinated movements of the lower extremities at low or moderate intensity, twice per week, in 35-min sessions for 8 weeks might serve as a useful intervention to improve cognition for kindergarten children.

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Effects of Acute Resistance Exercise on Late-Middle-Age Adults' Goal Planning

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[1]Graduate Institute of Athletics and Coaching Science, National Taiwan Sport University, Taoyuan County, Taiwan, REPUBLIC OF CHINA; [2]Graduate Institute of Sports and Health, National Changhua University of Education, Changhua City, Taiwan, REPUBLIC OF CHINA; [3]Department of Kinesiology, College of Education, University of Georgia, Athens, GA; and [4]Graduate Institute of Sports Science, National Taiwan Sport University, Taoyuan County, Taiwan, REPUBLIC OF CHINA

ABSTRACT

CHANG, Y.-K., P.-W. KU, P. D. TOMPOROWSKI, F.-T. CHEN, and C.-C. HUANG. Effects of Acute Resistance Exercise on Late-Middle-Age Adults' Goal Planning. *Med. Sci. Sports Exerc.*, Vol. 44, No. 9, pp. 1773–1779, 2012. **Purpose**: We investigated the effects of an acute bout of resistance exercise on the planning component of executive function in late-middle-age adults. **Methods**: With a within-subjects design, 30 community-dwelling adults (mean age = 57.20 ± 2.93 yr, 16 females) experienced both resistance exercise and control treatment conditions. The exercise condition involved two sets of 10 repetitions of 70% of 10-repetition maximum of seven exercises, whereas the control condition consisted of reading. Planning was assessed before and immediately after each treatment via the Tower of London task. **Results**: Acute resistance exercise facilitated Tower of London performances in terms of less total move scores, more total correct scores, and a longer total initial time compared with control and baseline. **Conclusions**: Our results expand the existing literature by demonstrating that resistance exercise has a positive effect on cognition and contributes to improved quality of planning, working memory, and inhibition aspects of executive function. **Key Words:** ACUTE EXERCISE, COGNITION, EXECUTIVE FUNCTION, INHIBITION, WORKING MEMORY

Executive function refers to a dynamic system that interconnects multiple components of mental processes that are involved in goal-directed behaviors, especially in nonroutine situations. The components of executive function include planning, scheduling, inhibition, and working memory (16). Executive function organizes various subcomponents of cognition that are essential for everyday living.

Older adults evidence diverse executive impairments (11), and researchers have evaluated the effects of exercise training as a means of remediating aspects of executive function. The majority of experiments have used chronic aerobic exercise training programs designed to improve participants' cardiorespiratory fitness. In general, exercise training leads to older adults' improved executive function (21,24).

Recently, there has been interest in the effects of acute single bouts of exercise on executive function. Acute exercise has been shown to facilitate response inhibition (6,12), working memory (4,13,29,34), and cognitive flexibility (17,31). Two recent studies have examined the effects of acute aerobic exercise on planning, a main component of executive function. Cordova et al. (18) investigated the effects of a 25-min bout of ergometer cycling on older adults' cognitive performance. Compared with a control group, cycling at 90% ventilatory threshold was found to result in improvements of planning assessed by one measure of the Tower of Hanoi, cognitive flexibility assessed by the Trail Making Test, and frontal performance assessed by verbal fluency. Similar results were obtained by Chang et al. (15), who found that a single bout of moderate-to-vigorous ergometer cycling facilitated the total move and total correct scores of the Tower of London (TOL) in young adults. These studies suggest that the processes involved in planning improve immediately after a bout of acute exercise. Planning is essential for functioning successfully in daily life, and the underlying processes of planning involve modeling and anticipating the consequences of actions before their execution (26). Specifically, successful planning involves the mental representation of both initial and goal situations and creation of the sequential operations of actions required (36).

Recently, researchers have begun to examine the effects of resistance exercise on cognition. Similar to aerobic exercise, it is plausible that resistance exercise can induce physiological and metabolic activations that may positively affect cognition (12,13). Chang and Etnier (12) found that acute resistance exercise with two sets executed at 75%

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of 10-repetition maximum (10RM) benefits middle-age adults' speed of processing assessed by the Stroop Color and Word Tests and reduces interference as assessed by the Stroop Color–Word Test. In addition, Chang and Etnier (13) randomly assigned college-age participants into control and 40%-, 70%-, and 100%-of-10RM groups and assessed their Stroop Test and Paced Auditory Serial Addition Test performances before and after the treatments. The results supported a dose–response relationship between exercise intensity and cognitive performance: a linear relationship was found between exercise intensity and information processing speed assessed by the color and word components of the Stroop Tests, and a quadratic relationship was found between exercise intensity and executive function assessed by the color–word component of the Stroop Test and the accuracy of the Paced Auditory Serial Addition Test. In contrast, Pontifex et al. (34) compared the effects of resistance exercise (three sets of 8 to 12 repetitions at 80% of one-repetition maximum), aerobic exercise (60%–70% $\dot{V}O_{2max}$), and control conditions on young adults' working memory. They found that working memory performance improved immediately and 30 min after an acute aerobic exercise condition, compared with baseline; however, resistance exercise did not alter cognitive performance. The lack of agreement between these studies may be due to differences in the resistance training protocols or cognitive tests used.

Resistance exercise has been seen as particularly important for middle-age and older adults to counter sarcopenia, an aging-related degenerative loss in skeletal muscle mass and strength (39). Indeed, resistance exercise has been advised as the main modality of exercise recommendation from American College of Sports Medicine (ACSM) and American Heart Association viewpoints (30). Although acute resistance exercise has been found to benefit adults' speed of processing and working memory and reduce interference (12,13), the effects on planning are unknown. The present study, therefore, was designed to extend these findings by measuring the effects of acute whole-body resistance exercise on late-middle-age adults' performance on the TOL task, which provides a sensitive measure of the planning. The acute bout of exercise was hypothesized to benefit the planning aspect of executive function in the specific population.

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METHODS

Participants

Thirty late-middle-age and young older-age community-dwelling adults age 57.20 ± 2.93 yr (range = 55–70 yr) were recruited. Participants completed a demographic questionnaire, the Physical Activity Readiness Questionnaire (PAR-Q), the International Physical Activity Questionnaire (IPAQ), and the Mini-Mental State Examination (MMSE). Following the guidelines of ACSM (2), participants who were selected met the criteria of PAR-Q to ensure there were no potential risk factors for the participant to perform a single bout of exercise. In addition, only participants who received MMSE scores of more than 26, which were classified as normal cognitive function, were included. IPAQ, an international surveillance questionnaire, was used to assess the amount of physical activity by METs (7). The number of participants was determined based upon a power analysis using a 2 × 2 mixed design with an effect size of f = 0.31 (12). The protocol was approved by the National Taiwan Sport University institutional review board. Table 1 presents descriptive data for the participants.

Exercise-Related Measures

HR. An HR monitor (HR monitor, model S610i; Polar Electro, Kempele, Finland) was used to assess HR throughout the treatment session. The HR data received from the HR monitor were based upon 5-s HR averages.

RPE. The RPE developed by Borg (10) provided a subjective rating of each individual's perception of effort during exercise. The original Borg scale ranging from 6 to 20 was used. The examiner recorded RPE at 2-min intervals during the exercise.

TOL Task

The TOL task is a neuropsychological assessment used extensively to measure planning in the clinical and research settings (22,32). Performing the TOL effectively requires determining goals and subgoals before starting (33) and monitoring sequences of operations (e.g., selected, executed, evaluated, and accepted or withdrawn) (20). The TOL-Drexel second edition was used. The TOL equipment consisted of two identical wooden boards (30 × 7 × 10 cm) and two sets of three colored balls (blue, green, and red). Each board had three posts with differing heights, where the tallest post can match three balls, the middle post can match two balls, and the shortest post can place only one ball. One wooden board was controlled by the examiner and used to show the completion configuration, and the other board

TABLE 1. Descriptive data for participant demographic and physiological characteristics (mean ± 1 SD).

Variable	Male (*n* = 14)	Female (*n* = 16)	All (*N* = 30)
Age (yr)	58.43 ± 2.71	56.13 ± 2.75	57.20 ± 2.93
Education (yr)	3.64 ± 1.28	3.13 ± 1.26	3.37 ± 1.27
Height (cm)	168.14 ± 6.36	156.97 ± 6.68	162.18 ± 8.57
Weight (kg)	69.86 ± 7.85	57.88 ± 10.20	63.47 ± 10.88
BMI (kg·m^{-2})	24.72 ± 2.57	23.40 ± 3.21	24.02 ± 2.96
IPAQ (METs)	834.86 ± 507.75	876.38 ± 703.27	857.00 ± 609.78
Resting HR (bpm)	64.93 ± 10.17	68.13 ± 9.22	66.63 ± 9.64
MMSE	28.14 ± 1.46	28.63 ± 1.45	28.40 ± 1.45
10RM			
Right bicep curl (lb)	25.71 ± 5.30	15.38 ± 3.42	20.20 ± 6.80
Left bicep curl (lb)	24.86 ± 5.78	16.59 ± 4.76	20.45 ± 6.65
Back latissimus pulldown (lb)	82.29 ± 10.31	56.13 ± 10.36	68.80 ± 17.12
Chest press (lb)	87.79 ± 21.15	56.06 ± 18.69	70.87 ± 25.11
Chest fly (lb)	50.50 ± 9.16	28.37 ± 7.40	38.70 ± 13.86
Leg curl (lb)	64.07 ± 16.16	47.06 ± 11.96	55.00 ± 16.29
Leg press (lb)	152.86 ± 24.03	129.69 ± 21.25	140.50 ± 25.11

BMI, body mass index; resting HR, resting HR assessed in session.

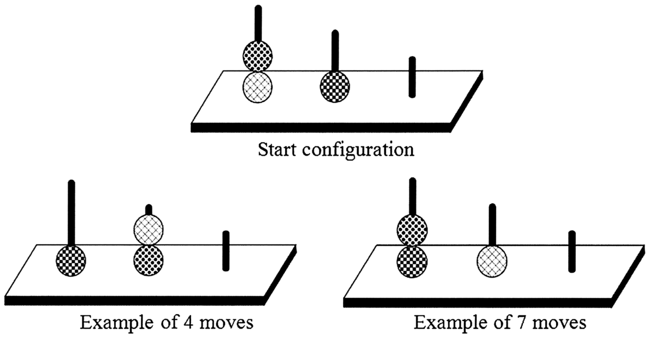

FIGURE 1—Start and goal configurations of the TOL task.

was controlled by the participant. The adult version of the TOL consisted of 10 standard problems with increasing complexity (requiring a minimum number from two to seven moves). Participants were asked to rearrange the balls from a standard starting configuration to the specific completion configuration in the fewest moves without violating TOL Task rules (Fig. 1). The total administration time of the TOL is approximately 15 to 25 min. Seven TOL scores were derived as described by the TOL technical manual (19). The total move score was the sum of differences between the number of actual ball moves and the minimum number of moves for each problem. The total correct score was the number of problems solved where the criteria of the minimum number of moves was reached. Rule violation scores were of two types: a) placing or trying to place more balls on a peg than it can physically support and b) removing two balls from the peg at the same time. Time violation scores were counted if the participants failed to finish a problem under 1 min. Total initial time was the time between presentation of the goal configuration by the examiner to the participant's lifting the first ball off a post. Total execution time was the duration from the first ball being lifted to the successful completion of a given problem. Total planning–solving time was computed by summing the total initial time and the total execution time.

Experimental Procedures

Each participant was asked to attend three laboratory sessions, separated by at least 48 h. The first session consisted of baseline assessments. The participant was presented with a brief introduction to the experiment and completed an informed consent and then completed the PAR-Q, health history, demographic, MMSE, and IPAQ questionnaires. After completing the questionnaires, participants who met the inclusion criteria were instructed to attach the HR monitor and to sit quietly in a comfortable chair in a dimly lit room for 15 min. At the conclusion of the 15-min period, resting HR was assessed. Then, the participant's 10RM of each of seven exercises was determined after a testing protocol developed by Baechle and Earle (5). All of the seven exercises were assessed by experienced experimenters using dumbbells (Bowflex SelectTech; Nautilus, Inc., Vancouver, BC) or a multistation machine (2100 × 3060 × 2200 mm; Sunpro Company, Brookpark, OH).10RM is the maximum weight one can lift in 10 repetitions for a given exercise. The exercises included right bicep curl, left bicep curl, back latissimus pulldown, chest press, chest fly, leg curl, and leg press.

Sessions 2 and 3 consisted of four stages: cognitive instruction, cognitive pretest, treatment, and cognitive posttest. In session 2, the participant was first given instructions on the TOL Task and then performed 10 prescribed TOL problems as a pretest. When assigned to the exercise condition, the participant performed a resistance exercise protocol that included a 10-min warm-up and two sets of 10 repetitions of 70% of 10RM of each of the seven exercises. The rest between sets and each exercise was 30 and 60 s apart, respectively. The protocol was designed on the basis of our previous studies (12,13). Exercise duration was approximately 20 min. When assigned to the rest condition, the participant was asked to read materials related to physical activity and mental health for 20 min. Then, the participant completed the same TOL again as a posttest, within 3 min after the treatment. Sessions 2 and 3 were counterbalanced to minimize the potential order and practice effects.

HR was assessed immediately before the TOL pretest as pretest HR, at the end of each of the seven exercises (or every 2 min in the reading condition) with the average as treatment HR, and after exercise or rest and immediately before performing the TOL posttest as posttest HR. Exercise intensity was measured using HR reserve (HRR) where percentage of intensity was calculated by the formula (treatment HR − resting HR)/maximal HR − resting HR (2). RPE was also reported at the end of each of the seven exercises and then averaged as treatment RPE. After completion of the three sessions, participants were given a fee for compensation and briefed on the purpose of the experiment.

Statistical Analyses

A two-way counterbalanced design was used with condition and time as independent variables. To analyze TOL scores, two-way repeated-measures multivariate ANOVA (MANOVA) were separately conducted for move-related scores (total move and total correct), violation-related scores (rule violation and time violations), and time-related scores (total initial time, total executive time, and total planning–solving time). The Wilks Λ statistic was used. To test the exercise intensity manipulation, a two-way repeated-measures 2 (condition: control vs exercise) × 3 (time: pretest HR, treatment HR, posttest HR) ANOVA was used to determine the effects of exercise intensity on HR. Greenhouse–Geisser correction was used when the Mauchly test of sphericity was violated. Simple main-effects analyses and/or *post hoc* tests were further performed when necessary interactions were reached significantly. Estimates of effect size using the Cohen d and partial eta square (η^2) were reported to present

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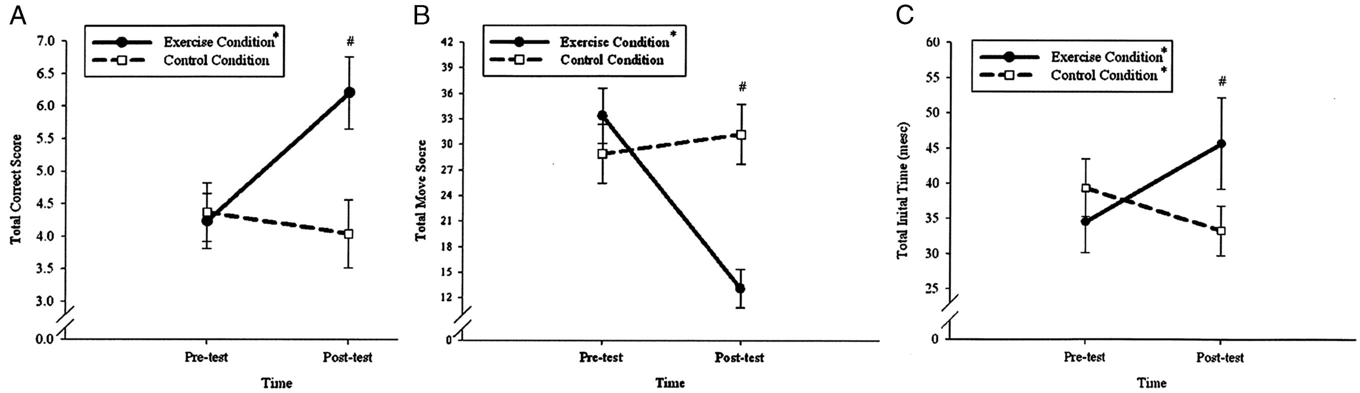

FIGURE 2—TOL task scores (mean ± 1 SE) as a function of time and condition total correct score (A), total move score (B), and total initial time (C). Note that more total correct scores, less total move scores, and longer initial time present better performances. *Significant difference between pretest and posttest for this condition; #significant difference between the exercise and control conditions.

the magnitude. An α of 0.05 was used for all statistical analyses.

RESULTS

TOL Performances

Total correct score and total move score. Two-way repeated-measures MANOVA revealed a significant main effect of time, as well as an interaction of condition and time (P's < 0.001, partial $\eta^2 > 0.39$), but no effect of condition was observed. Follow-up univariate ANOVA revealed main effects for condition, time, and their interaction in total correct score (P's < 0.05, partial $\eta^2 > 0.13$). A simple main effect further demonstrated significant effects for exercise condition (pretest vs posttest) and posttest (exercise vs control condition) (P's < 0.001, partial $\eta^2 > 0.33$), where the posttest in the exercise condition had more correct scores than the pretest in the exercise condition and the posttest score in the control condition. In contrast, no difference between pretest and posttest in the control condition was found. Similarly, no difference between exercise and control conditions in pretest was found (Fig. 2A).

Regarding total move scores, there were a main effect for time and an interaction of condition and time (P's < 0.001, partial $\eta^2 > 0.37$). Simple main effects further demonstrated significant effects for exercise condition (pretest vs posttest) and posttest (exercise vs control condition) (P's < 0.001, partial $\eta^2 > 0.51$), where posttest in the exercise condition had less move scores. No other differences were found (Fig. 2B). Table 2 summarizes the descriptive statistics for TOL scores.

Rule violation score and time violation score. Two-way repeated-measures MANOVA revealed a significant main effect of time ($P < 0.01$, partial $\eta^2 = 0.28$), where posttest had less violation scores than pretest. No main effect of condition and interaction of condition and time were found.

Total initial time, total executive time, and total planning–solving time scores. Two-way repeated-measures MANOVA revealed a main effect of time and an interaction of time and condition ($P < 0.05$, partial $\eta^2 = 0.25$), whereas no effect of condition was found. Concerning total initial time, follow-up univariate ANOVA revealed that there was a significant interaction of condition and time ($P < 0.05$, partial $\eta^2 = 0.18$). The simple main effect further demonstrated that there were differences between posttest and pretest in both conditions (P's < 0.05, partial $\eta^2 > 0.13$), where posttest in the control condition showed shorter time than pretest. In contrast, posttest in the exercise condition showed longer time than pretest (Fig. 2C).

Regarding total executive time and total planning–solving time, the follow-up univariate ANOVA revealed a main effect of time (P's < 0.01, partial $\eta^2 > 0.20$), where posttest had a shorter time than pretest for both conditions. No main

TABLE 2. Means (±1 SD) and effect sizes of TOL scores in each experimental condition.

	Control Condition			Exercise Condition		
Sources	Pretest	Posttest	ES	Pretest	Posttest	ES
Total correct score[a]	4.37 ± 2.47	4.03 ± 2.85	−0.13	4.23 ± 2.33	6.20 ± 3.02[b,c]	0.73
Total move score	28.90 ± 18.95	31.20 ± 19.32	0.12	33.37 ± 17.70	13.10 ± 12.39[b,c]	−1.33
Time violation score	0.47 ± 1.14	0.17 ± 0.46	−0.35	0.50 ± 0.94	0.10 ± 0.31	−0.57
Rule violation score	0.53 ± 1.07	0.07 ± 0.25	−0.59	0.33 ± 0.61	0.03 ± 0.18	−0.67
Total initial time[a]	39.38 ± 22.44	33.27 ± 19.30[b]	−0.29	34.56 ± 24.26	45.65 ± 35.61[c]	0.36
Total execution time	193.26 ± 101.93	163.81 ± 80.05	−0.32	187.05 ± 93.28	186.19 ± 55.15	−0.01
Total planning–solving time	232.30 ± 101.28	196.75 ± 81.95	−0.39	221.54 ± 102.39	139.21 ± 67.30	−0.95

Effect size (ES) is calculated by Cohen *d*.
[a] Higher values present better performance.
[b] Significant difference between pretest and posttest for this condition.
[c] Significant difference between the exercise and control conditions.

TABLE 3. Descriptive data for exercise manipulation check (mean ± 1 SD).

Variable	Control Condition	Exercise Condition
Pretest HR	75.43 ± 10.57	74.53 ± 10.1
Treatment HR	69.46 ± 8.23	108.86 ± 17.80[a]
Posttest HR	74.87 ± 9.05	98.83 ± 13.36[a]
HRR (%)	2.93	42.24
RPE	—	14.81 ± 1.35

HRR was computed based upon the formula from ACSM (1).
[a] Significant difference between exercise and control conditions.
Pretest HR and posttest HR, average HRs assessed before the cognitive pretest and posttest, respectively; treatment HR, average HR assessed during the treatment; RPE, average RPE assessed during the experimental treatment.

effects of condition and interaction of condition and time were found.

Exercise Manipulation Check

Results of the 2 × 3 repeated-measure ANOVA for HR revealed that there were main effects for condition ($P < 0.001$, partial $\eta^2 = 0.84$), time ($P < 0.001$, partial $\eta^2 = 0.78$), and interaction of condition and time ($P < 0.001$, partial $\eta^2 = 0.86$). The simple effect analyses revealed that there were exercise and control effects (P's < 0.001, partial $\eta^2 > 0.48$), where treatment HR was significantly higher than posttest HR, which was also significantly higher than pretest HR in the exercise condition, whereas treatment HR was significantly lower than both pretest and posttest HRs in the control condition. Alternatively, there were time effects for treatment HR and posttest HR (P's < 0.001, partial $\eta^2 > 0.87$) but not for pretest HR. HRR was 42.24% for the exercise condition and 2.93% for the control condition, reflecting that the exercise intensity is moderate. For the exercise condition, average RPE was 14.81, which was classified as effort of moderate intensity (from somewhat hard to hard). Table 3 presents detail descriptive statistics for the exercise manipulation check.

DISCUSSION

The study assessed the effects of a single bout of resistance exercise on the planning component of executive function in late-middle-age adults. The effects of a 20-min whole-body resistance exercise regimen on TOL performance were assessed. As predicted, after exercise, the total correct score improved relative to the pretest and control conditions. Facilitative effects were also found in terms of less total move scores and longer total initial time after the exercise. The total move score is believed to reflect the quality and efficiency of planning (9,35), and the processes underlying the total move score include operations such as visuospatial analysis, anticipation, mental manipulation, online maintenance, rule supervision, and process evaluation (35). Unterrainer et al. (37) indicated that good planning performers spend longer initial time than poor performers, suggesting that more time is given to develop problem-solving strategies. Longer total initial time has been linked to better response inhibition and the capacity to suppress inappropriate response before conducting behavior to a given task (3). The present finding of longer total initial time but no effect on total execution time suggests that resistance exercise influences the central more than the peripheral component of movement control processes. These findings corroborate those of Cordova et al. (18), who found that acute aerobic exercise improved older adults' move scores on the Tower of Hanoi test. Taken together, it seems that resistance exercise influences many components of executive function.

Working memory has been linked to total correct score on the TOL (19). One must temporarily hold mental repetitions of previous moves while contemplating conditions for a successful move. The facilitating effect of resistance exercise on working memory observed in the present study differs from those reported by Pontifex et al. (34), who found that working memory improved after aerobic but not resistance exercise and control conditions. There are several explanations for the discrepancy. The exercise intensity used in the present study was considerably less than that used by Pontifex et al. The participants in the present study were late-middle-age adults, whereas those targeted by Pontifex et al. were college-age adults. The cognitive tests selected differ, and the mental processes required to perform the TOL differed from the modified Sternberg task used by Pontifex et al. Recently, Etnier and Chang (22) postulated that effects of exercise might be disproportionally sensitive to specific components of executive function that are dictated by task demands. It will be important for researchers to isolate factors that moderate the effects of resistance exercise on specific executive function and its related task.

Rule violation and other time-related indices of TOL performance were not influenced by resistance exercise. These findings are similar to those reported by Chang et al. (15), who evaluated the effects of aerobic exercise on late-middle-age adults' TOL performance. These findings support the consensus that people with intact cognitive ability rarely violate TOL rules (19).

The underlying mechanisms of resistance exercise on planning are hypothesized to be similar to those of aerobic exercise. Recent neuroelectric studies using measures of P3 of event-related potential and contingent negative variation (CNV) provide the evidence that acute aerobic exercise optimizes arousal and attention for receiving cues during the performance. P3 and CNV are time-locked neuroelectrical activations of event-related potential that are associated with different aspects of cognitive processes (i.e., attention). Hillman et al. (25) found that after acute aerobic exercise, the P3 component showed a larger amplitude and shorter latency, reflecting that acute exercise benefits cognitive performance via increasing attentional resource allocation and efficiency of information processing. Likewise, Kamijo et al. (28) reported that aerobic exercise alters participants' arousal level and corresponding larger early and late CNV amplitudes. Given that CNVs are associated with arousal and reflect the orienting response to involuntary cues and either anticipation of the response stimulus or motor preparation (23), the results of the present study suggest that exercise alters arousal and improves cognitive performance by influencing orienting, anticipation, and motor preparation.

It is also possible that the effects of resistance exercise on planning are specifically due to insulin-like growth factor-1 (IGF-1), which is a polypeptide hormone that promotes tissue growth (14). IGF-1 has the ability to transport across the blood–brain barrier and has been linked to cognition (1). Furthermore, serum levels of IGF-1 have been found to associate with cognition measured by several neuropsychological assessments (8,27). Kalmijn et al. (27) indicated that IGF-1 level in serum was correlated to older adults' global cognitive performance. Recently, Bellar et al. (8) reported that serum IGF-1 is associated with working memory and executive function in healthy older adults. Given that acute resistance exercise elevates IGF-1 (38), it may serve as a mediator between the exercise and executive functions.

The interpretations of the results of the present study are limited by several factors. Given that the main purpose of the study targeted resistance exercise, planning, and late-middle-age adults, variables including aerobic exercise group, younger and older participants, or other components of executive function were not included in the design. As such, differences in biological, physiological, and psychological aspects among different populations limit generalization of the results to other populations. In addition, although the sample size was chosen based upon power analysis, caution of small sample sizes that affect the outcome should be proposed.

In conclusion, this study demonstrated that acute resistance exercise has a positive effect on many components of executive function in late-middle-age adults. In particular, the pattern of TOL performance suggests that resistance exercise improves the quality of planning. Neurohormonal mechanisms such as IGF-1 may explain the effects of resistance exercise on the populations' cognition, but additional research on the issue will be required.

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