Kamijo, K., Hayashi, Y., Sakai, T., Yahiro, T., Tanaka, K., & Nishihira, Y. (2009). Acute effects of aerobic exercise on cognitive function in older adults. *Journal of Gerontology: Psychological Sciences, 64B(3)*, 356–363, doi:10.1093/geronb/gbp030, Advance Access publication on April 10, 2009

Acute Effects of Aerobic Exercise on Cognitive Function in Older Adults

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The present study investigated the effects of acute aerobic exercise on cognitive brain functions of older adults. Twenty-four males (12 older and 12 younger adults) performed a modified flanker task during a baseline session (no exercise) and after light and moderate cycling exercise in counterbalanced order on different days while measures of task performance and the P3 component of an event-related brain potential were collected. The results indicated that, for both age groups, reaction time following moderate exercise was shorter relative to the other sessions, and P3 latencies following both light and moderate exercise were shorter compared with the baseline session. In contrast, P3 amplitude increased only following moderate exercise in younger adults. These findings suggest that light and moderate exercises improve cognitive function across the adult lifespan, although the mechanisms underlying the effects of observed acute aerobic exercise on cognitive function may be age dependent.

Key Words: Acute aerobic exercise—Cognitive function—Event-related brain potentials (ERPs)—Older adults—P3.

COGNITIVE decline is almost universal in older adults and increases with age (Park, O'Connell, & Thomson, 2003). However, certain lifestyle factors may ameliorate or protect against cognitive aging. Recent human epidemiology studies have suggested that regular physical activity is associated with better cognitive functioning and less cognitive decline in later life (see Kramer, Erickson, & Colcombe, 2006, for a review).

Over the past several decades, a growing number of researchers have investigated the effects of both acute and chronic exercise on cognitive function in young and older adults. Research on chronic exercise has demonstrated cognitive improvements resulting from regular physical activity in older adults (see Colcombe & Kramer, 2003; Hillman, Erickson, & Kramer, 2008 for reviews). For example, neuroimaging studies have indicated that aerobic exercise training for 6 months increased volume in both gray and white matter primarily located in the prefrontal cortex (Colcombe et al., 2006), which is particularly vulnerable to the effects of aging (see Tisserand & Jolles, 2003 for a review). Furthermore, the effect of regular physical activity was larger for particular executive control processes (Hillman, Kramer, Belopolsky, & Smith, 2006; Kramer et al., 1999). The term "executive control" is used to describe a subset of cognitive functions involving working memory, mental flexibility, and inhibitory control. The prefrontal cortex is considered to be an important structure for executive control (Funahashi, 2001). Thus, the prefrontal cortex, which is susceptible to aging, and the processes mediated by it (i.e., executive control) are likely to be sensitive to the beneficial effects of chronic exercise.

In contrast to chronic exercise, less research has focused on the effects of acute exercise on cognitive functions in older adults. Molloy, Beerschoten, Borrie, Crilly, and Cape (1988) found that cognitive functions, as measured by the Mini-Mental State Examination (MMSE) and logical memory test, improved after 45 min of moderate intensity exercise (including both aerobic exercise and strengthening) in older adults (*M* = 66 years). Emery, Honn, Frid, Lebowitz, and Diaz (2001) investigated the effects of acute aerobic exercise for 35 min (20 min maximal cycling exercise + 15 min cooling down) on cognitive functions in both healthy older adults (*M* = 69 years) and older patients (*M* = 68 years) with chronic obstructive pulmonary disease (COPD). They found that acute exercise was associated with improved performance on the Verbal Fluency Test, a measure of verbal processing, only in the COPD patients. Thus, a consensus has not been reached regarding the relationship between acute exercise and cognitive functions in healthy older adults. The discrepancy may result from differences in the exercise intensity or in the specific cognitive functions evaluated, in a similar manner to differences reported for younger adults (Hillman, Snook, & Jerome, 2003; Kamijo et al., 2004b; Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007).

Electrophysiological studies using event-related brain potentials (ERPs) have been conducted during the last decade, and they have resulted in a deeper understanding of the relationship between acute exercise and cognitive functions. The advantage of the ERP approach is that it can provide information regarding the discrete cognitive processes between stimulus evaluation and response execution that

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are selectively influenced by acute exercise. ERP studies, particularly those that have investigated the effects of acute exercise in young adults on the P3 component, have found evidence of changes in cognitive function (see Kamijo, in press, for a review). The P3 is an endogenous component of an ERP occurring approximately 300–800 ms after stimulus onset and is believed to represent the updating of memory once sensory information has been analyzed (Donchin, 1981). The amplitude of this component is proportional to the amount of attentional resources devoted to a given task (Kramer & Strayer, 1988; Wickens, Kramer, Vanasse, & Donchin, 1983), and the latency is considered to be a measure of stimulus classification speed or stimulus evaluation time (Kutas, McCarthy, & Donchin, 1977).

Several previous P3 studies have used the flanker task to investigate the effects of acute exercise on the executive control of cognitive functions (Hillman et al., 2003; Kamijo et al., 2007). The flanker task requires variable amounts of inhibitory control and consists of two types of stimuli whose central target letter is flanked by noise letters (e.g., HHHHH for congruent stimulus and SSHSS for incongruent stimulus). Congruent stimuli elicit faster and more accurate responses and incongruent stimuli decrease response speed and accuracy (Eriksen & Schultz, 1979). The incongruent condition requires greater amounts of executive control due to activation of the incorrect response (elicited by the flanker stimuli) before evaluation is completed (Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Kramer & Jacobson, 1991). The frontal lobe hypothesis of aging suggests that a pronounced cognitive decline is observed in executive control processes as a function of aging (West, 1996). Therefore, it has been suggested that interference effect during the flanker task (i.e., differences in task performance between the congruent and incongruent condition) should be larger in older adults compared with the younger adults. According to this hypothesis, interference control required during the flanker task is age sensitive in general (e.g., Zeef & Kok, 1993; Zeef, Sonke, Kok, Buiten, & Kenemans, 1996), although

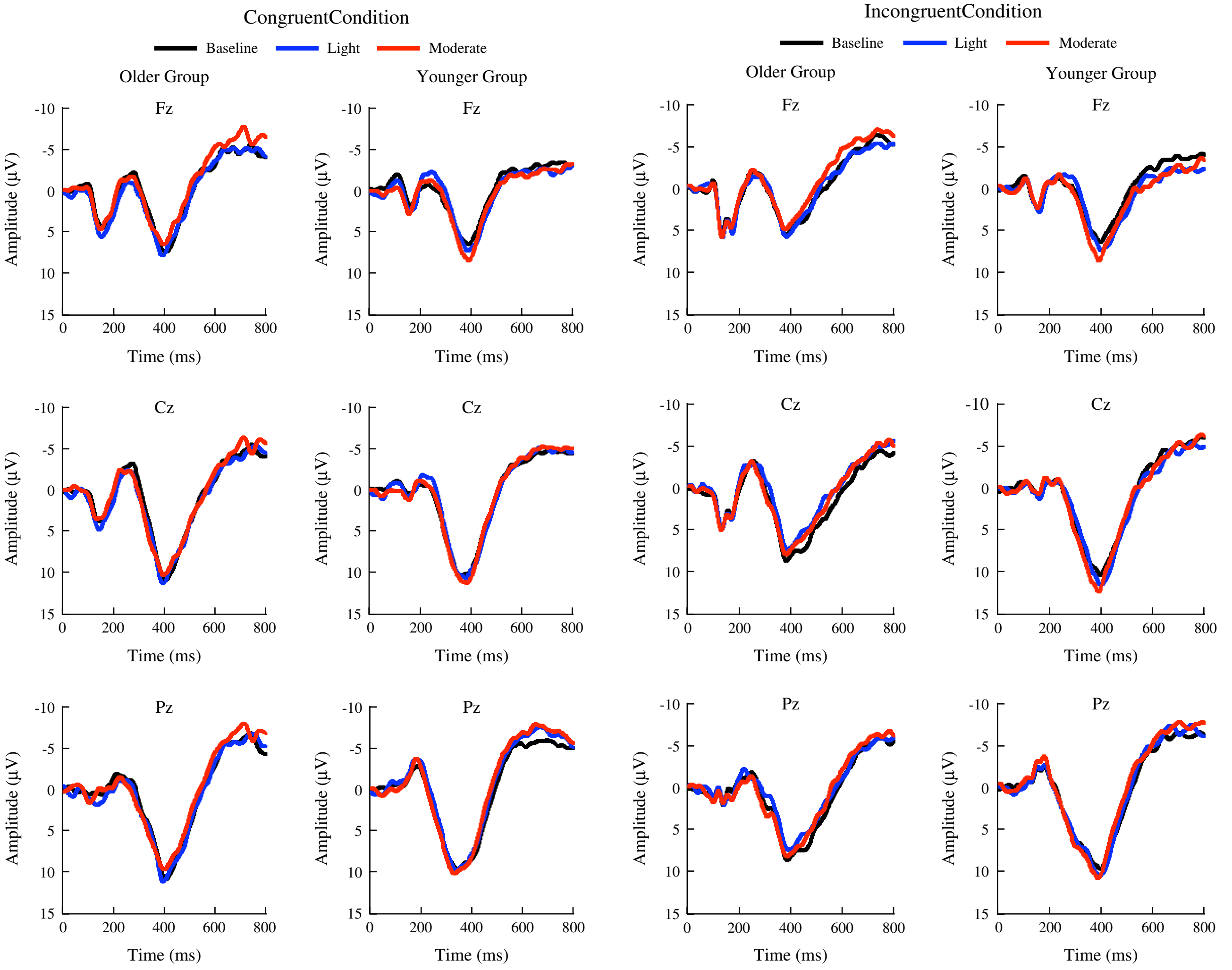

Figure 1. Grand averaged stimulus-locked event-related brain potential waveforms across groups (older, younger) and task conditions (congruent, incongruent) from Fz, Cz, and Pz.

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Table 1. Group Means for Participant Characteristics

	Older	Younger
Age (years)*	65.5 ± 1.5	21.8 ± 0.6
Height (cm)	163.3 ± 1.6	169.2 ± 2.4
Weight (kg)	64.9 ± 2.5	60.7 ± 1.5
Years of education (years)	12.5 ± 0.7	13.3 ± 0.6
MMSE*	29.0 ± 0.3	29.9 ± 0.1
BDI	3.6 ± 1.1	6.0 ± 1.1
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)*	32.4 ± 1.3	52.2 ± 2.1
HR_{max} (beat/min)*	154.9 ± 5.3	182.5 ± 5.1
IPAQ Total Physical Activity Score (kcal/day)	450.4 ± 70.3	324.5 ± 82.2

Notes: Values are mean ± *SE*. The maximum obtainable score on the MMSE is 30 and on the BDI is 63. MMSE = Mini-Mental State Examination; BDI = Beck Depression Inventory; IPAQ = International Physical Activity Questionnaire.

* Significant difference, unpaired Student's *t* test between groups, $p < .05$.

some exceptions to this have been reported (e.g., Wild-Wall, Falkenstein, & Hohnsbein, 2008).

Using a modified flanker task, Hillman and colleagues (2003) and Kamijo and colleagues (2007) indicated that the effects of acute aerobic exercise on P3 latency were observed only during incongruent trials in young adults, suggesting that acute aerobic exercise is beneficial for cognitive processing speed during tasks requiring greater amounts of executive control. These effects of acute exercise have similar properties to the effects observed from chronic exercise, indicating a possible connection between the effects of acute and chronic exercise. However, these previous ERP studies have been focused on young adults. It is unclear whether acute aerobic exercise exerts the same effect during older adulthood. In the present study, we examined this effect in older adults using the P3 component and behavioral measures during the flanker task.

To better examine the relationship between acute exercise and cognitive function in older adults, we also tested younger adults as a comparison. Furthermore, participants were assessed at two intensities (light and moderate) of cycling exercise and during a non-exercise condition. We tested several hypotheses in the present study. First, we examined whether acute aerobic exercise exerts the same effect during older adulthood as with younger adults. As mentioned earlier, Molloy and colleagues (1988) found that older adults demonstrated cognitive improvement after moderate intensity exercise, whereas Emery and colleagues (2001) reported that no effect of acute exercise was observed in healthy older adults after high intensity exercise. It is considered that this effect of exercise intensity in older adults is similar to the effect reported for younger adults (Kamijo et al., 2004b, 2007). Therefore, we expected that the effects of acute aerobic exercise would be similar between the older and younger group. Second, we expected that the beneficial effects of acute exercise would be larger following moderate exercise than light exercise in accordance with our previous studies indicating a curvilinear (inverted U shaped) relationship between exercise intensity and cognitive function (Kamijo et al., 2004b, 2007). Finally, based on previous ERP studies using the flanker task (Hillman et al., 2003; Kamijo et al., 2007), we predicted that the effects would be larger in the incongruent flanker condition that requires greater amounts of executive control. This is the process that appears to be the most sensitive to the effect of acute aerobic exercise.

MATERIALS AND METHODS

Participants

Thirty healthy males were recruited and classified into two groups based on age (older and younger adults). Data from six participants (three participants in each group) were discarded due to excessive noise in the electroencephalogram (EEG) signal. Thus, all analyses were conducted on the data from 24 participants (12 older adults aged 60–74 years and 12 younger adults aged 19–25 years). The characteristics of both age groups are summarized in Table 1. None of the participants exhibited signs of dementia (i.e., all MMSE scores >23, with a maximum score of 30) or depression (i.e., all Beck Depression Inventory [BDI] scores <13, with a maximum score of 63). All participants reported being free of neurological disorders, cardiovascular disease, and any medication that influence central nervous system function and had corrected-to-normal or normal vision. This study was reviewed and approved by the Research Ethics Committee, Graduate School of Comprehensive Human Sciences at the University of Tsukuba, and participants gave their informed consent to participate in the experiment.

Procedure

This experiment consisted of a baseline session and light intensity and moderate intensity exercise sessions. Each session was conducted at the same time on a different day (*M* = 12.5 ± 1.2 days between sessions). The order of sessions was nearly counterbalanced among the participants to minimize potential practice effects. Nearly counterbalanced because the counter-balancing order was conducted with all 30 participants in the study and not with the 24 participants who were included in the data analyses.

The baseline session consisted of measuring participants' ERPs and behavioral responses during a modified flanker task. On the day of the baseline session, participants completed the MMSE, Beck Depression Inventory, and International Physical Activity Questionnaire. Participants were then seated in a comfortable chair and prepared for neuroelectric measurement in accordance with the Society for Psychophysiological Research guidelines (Picton et al., 2000). The EEG was measured from the following nine sites of the international 10–20 system using an electro cap (Electro-Cap International, Inc., Eaton, OH): F3, Fz, F4, C3, Cz, C4,

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P3, Pz, P4, and referenced to linked earlobes with AFz as the ground electrode. The impedances were kept below 5 kΩ. To monitor possible artifacts due to eye movement, an electrooculogram was recorded using electrodes placed above and below the right eye. The participants were given the task instructions and allowed 32 practice trials. After the practice trials, they performed 160 trials of the modified flanker task.

In the exercise sessions, the participants exercised at the assigned intensity on each day using a cycling ergometer (828E, Monark Inc., Varberg, Sweden). They were prepared for neuroelectric measurement in the same manner as the baseline session and allowed 32 practice trials before the cycling exercise. Impedances were checked after exercise to determine that they did not rise from the pre-exercise levels. Less than 2 min after exercise, the participants began the modified flanker task.

Modified Flanker Task

A modified flanker task consisting of five arrowheads was used because Japanese older adults are unfamiliar with letters of the alphabet. The participants were instructed to press a button with their thumbs as quickly as possible corresponding to the direction of the centrally presented target arrowhead (left or right). The target arrowhead was surrounded by flanker arrowheads that either pointed in the same direction (congruent condition: < < < < < or > > > > >) or the opposite direction (incongruent condition: > > < > > or < < > < <). The arrowheads were presented for 200 ms with a 3000-ms interstimulus interval. The stimuli consisted of white arrowheads on a black background. The viewing distance was 100 cm. The arrowheads subtended a vertical visual angle of 4.3° and a horizontal visual angle between the two outside positions of 12.8°. Experimental trials consisted of 80 congruent and 80 incongruent conditions with left and right target arrowheads occurring with equal probability. The total task duration was approximately 8.5 min.

Exercise

Graded exercise test.—Before the experiment, the participants underwent a graded exercise test (GXT). Maximal oxygen uptake (VO_{2max}) for each participant was determined during the GXT with a cycling ergometer. The saddle height of the cycling ergometer was adjusted based on the height of the participant. The heart rate (HR) and rating of perceived exertion (RPE) were recorded every minute. HR was recorded using a Polar HR monitor (Polar Electro, Inc., Oula, Finland). The participants were asked to provide their RPE every minute during exercise using the 15-point Borg (1973) scale. The RPE allows participants to rate their perceived physical effort on a numerical scale ranging from 6 to 20 (7 = *very very light*, 9 = *very light*, 11 = *fairly light*, 13 = *somewhat hard*, 15 = *hard*, 17 = *very hard*, 19 = *very very hard*). The revolutions during the GXT were maintained at 60 rpm. Following a 2-min warm-up exercise with no load, the power output was set at 15 watts and then increased 15 watts every minute until the participants informed of the limit of the GXT to the examiner. VO_{2max} was chosen as the highest VO_2 value in the series of minute-by-minute VO_2 values or the value that complied with the criteria from Tanaka, Takeshima, Kato, Niihata, and Ueda (1990).

Acute exercise intervention.—The work rate corresponding to 30% (light exercise) and 50% VO_{2max} (moderate exercise) on the GXT was kept for 20 min in each exercise session. Following a 5-min warm-up at half the work rate of the exercise session, the participants performed exercise at each work rate with a 60 rpm pedaling rate. During the cycling exercise, VO_2, HR, and RPE were recorded every 5 min.

Data Reduction

EEG activity was amplified with a time constant of 1 s and a high-cut filter of 30 Hz. EEG data were converted from 100-ms prestimulus to 1500-ms poststimulus at a sampling rate of 500 Hz. Trials with eye blinks, eye movements (rejection levels: ±80 μV), and response errors were excluded from analysis. Based on visual inspection, trials were rejected due to artifacts during off-line analysis, in addition to the automatic rejection. On average, about 40% of trials were discarded due to artifact. The P3 component was measured relative to a 100-ms prestimulus baseline. P3 was defined as the most positive-going peak occurring within a 300- to 750-ms latency window, and it was analyzed at three midline electrode sites (Fz, Cz, and Pz).

Statistical Analysis

The between-groups factor was Age (older, younger). The within-groups factors were Exercise (baseline, light, moderate), Task (congruent, incongruent), and Region (frontal, central, parietal). The amplitudes and latencies of the P3 were analyzed using a four-factor (Age × Exercise × Task × Region) mixed-model analysis of variance (ANOVA). Reaction time (RT) and response accuracy were analyzed using a three-factor (Age × Exercise × Task) mixed-model ANOVA. The mean $\%VO_{2max}$, $\%HR_{max}$, and RPE for 20 min were analyzed using a two-factor (Age × Exercise) mixed-model ANOVA. Angular transformation was applied to the percentage data (i.e., response accuracy, $\%VO_{2max}$, and $\%HR_{max}$) before the analyses. Post hoc comparisons were conducted using univariate ANOVA and Tukey's honestly significant difference (HSD) post hoc multiple comparison test. Participant characteristics, shown in Table 1, were analyzed using unpaired Student's *t* tests. The significance level was set at 0.05.

RESULTS

Given the number of variables included in the study design, not all significant findings are shown in the *Results* section. Only those findings that involve the factors of Age, Exercise, and Task are presented.

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Table 2. Mean $\%VO_{2max}$, $\%HR_{max}$, and RPE for 20 min at Each Intensity Exercise Across Groups

	Older Adults		Younger Adults	
	Light Exercise	Moderate Exercise	Light Exercise	Moderate Exercise
%VO2max	36.6 ± 1.3	57.8 ± 2.0	32.4 ± 1.1	55.9 ± 2.4
$\%HR_{max}$	55.2 ± 1.1	74.1 ± 1.6	55.1 ± 0.5	74.6 ± 1.9
RPE score	10.9 ± 0.5	13.1 ± 0.6	9.7 ± 0.4	12.9 ± 0.3

Note: Values are mean ± *SE*. RPE = rating of perceived exertion.

Exercise

As expected, the VO_{2max} and HR_{max} were significantly different based on age, *t* values (1, 22) ≥ 2.56, $p \leq .025$, (see Table 1). However, we considered that the differences in VO_{2max} and HR_{max} between groups did not significantly contribute to an effect of acute exercise on cognitive function because relative exercise intensities (i.e., 30% and 50% VO_{2max}), rather than absolute intensities, were used in the present study.

The mean $\%VO_{2max}$, $\%HR_{max}$, and RPE for 20 min at each exercise intensity across both groups are presented in Table 2. The analyses for $\%VO_{2max}$, $\%HR_{max}$, and RPE revealed significant main effects for Exercise, $F(1, 22) = 190.70$, $p < .001$; $F(1, 22) = 225.11$, $p < .001$; $F(1, 22) = 113.55$, $p < .001$, respectively, with the results indicating that these measures were higher following moderate exercise compared with light exercise. No significant main effect or interaction involving Age was observed. These results indicate that differences in these measures as a function of exercise intensities were confirmed across groups, and the relative exercise intensity was considered equal across groups.

Behavioral Measures

The mean RTs and response accuracy across groups and exercise intensities are presented in Table 3. The RT analysis revealed a significant main effect for Exercise, $F(2, 44) = 4.36$, $p = .019$. Post hoc analyses indicated that across groups, the RT following moderate exercise was shorter than the RT following light exercise, $t(1, 23) = 2.83$, $p = .02$, and there was a marginally significant difference following moderate exercise compared with the baseline session, $t(1, 23) = 2.65$, $p = .057$. Significant main effects for Age, $F(1, 22) = 15.15$, $p = .001$, and Task, $F(1, 22) = 82.24$, $p < .001$, were also observed. The results indicated that younger adults responded faster than older adults, and all participants responded faster during the congruent compared with the incongruent condition. There were no significant interactions among the three factors.

The response accuracy analysis revealed a significant main effect for Task, $F(1, 22) = 61.80$, $p < .001$, indicating greater accuracy during the congruent condition compared with the incongruent condition. No significant main effects or interactions involving Age or Exercise were observed.

P3

P3 amplitude analysis revealed an Age × Exercise interaction, $F(2, 44) = 6.28$, $p = .004$, with follow-up tests indicating that a significant main effect for Exercise was observed only for the younger group, $F(2, 22) = 6.78$, $p = .005$. Tukey's HSD post hoc analysis indicated that P3 amplitude following moderate exercise was larger than during the baseline session for the younger group, $t(1, 11) = 4.63$, $p = .004$, (see Fig. 2). No such effect was observed for the older group. A main effect for Task was also observed, $F(1, 22) = 6.25$, $p = .020$, with results indicating that P3 amplitude during the congruent condition was larger than during the incongruent condition. However, this main effect was modified by an Age × Task interaction, $F(1, 22) = 10.29$, $p = .004$, with follow-up tests indicating that P3 amplitude during the congruent condition was larger than during the incongruent condition only for the older group, $t(1, 11) = 6.09$, $p < .001$. No such effect was observed for the younger group.

P3 latency analysis revealed a significant main effect for Exercise, $F(2, 44) = 5.12$, $p = .01$, with follow-up Tukey's HSD post hoc analysis indicating that across groups the P3 latencies following light ($M = 389.7 \pm 5.3$) and moderate exercise ($M = 390.3 \pm 5.1$) were shorter than during the baseline session ($M = 397.8 \pm 5.3$), *t* values (1, 23) ≥ 2.62, $p \leq 0.026$. An Age × Task interaction was also observed, $F(1, 22) = 12.46$, $p = .002$, with follow-up tests indicating that P3 latency during the congruent condition was shorter than during the incongruent condition only for the younger

Table 3. Mean RT (ms) and Response Accuracy (%) Across Groups and Exercise Intensities

	Older Adults			Younger Adults		
	Baseline	Light Exercise	Moderate Exercise	Baseline	Light Exercise	Moderate Exercise
RT (ms)						
Congruent condition	425.8 ± 15. 0	423.5 ± 13.9	411.8 ± 15.5	352.5 ± 12.2	355.0 ± 11.7	344.1 ± 10.7
Incongruent condition	473.8 ± 16.7	480.9 ± 20.4	462.2 ± 17.0	397.4 ± 13.5	398.0 ± 12.2	387.8 ± 12.4
Response accuracy						
Congruent condition	99.7 ± 0.2	99.3 ± 0.4	99.9 ± 0.1	99.7 ± 0.2	98.5 ± 1.3	99.7 ± 0.2
Incongruent condition	94.8 ± 1.2	96.1 ± 1.1	94.7 ± 1.3	96.3 ± 0.8	95.2 ± 1.8	94.9 ± 2.3

Note: RT = reaction time.

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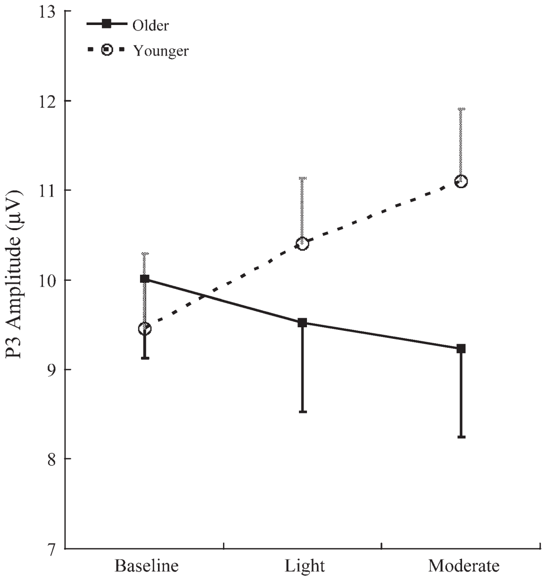

Figure 2. Mean P3 amplitude (μV) at all sessions across both age groups. Error bars indicate standard errors.

group, $t(1, 11) = 3.18$, $p = .009$. No such effect was observed for the older group. Furthermore, an Age × Region interaction was also observed, $F(2, 44) = 7.75$, $p = .001$, with follow-up tests indicating that the P3 latency for the younger group was shorter than for the older group only at the parietal region, $t(1, 22) = 2.42$, $p = .025$.

DISCUSSION

In the present study, the effects of acute aerobic exercise on human cognitive function in both older and younger adults were investigated using neuroelectric and behavioral measures. The main findings were that RTs were shorter following moderate exercise, compared with the baseline and light exercise sessions, for both age groups. Furthermore, P3 latencies following both light and moderate exercise were shorter than during the baseline session for both age groups. P3 amplitude following moderate exercise was larger than the baseline only for the younger group. These exercise-induced changes were observed across both task conditions.

As expected, younger adults exhibited shorter RT and P3 latency and larger P3 amplitude following moderate exercise. These findings corroborate our previous findings, indicating a curvilinear (inverted U shaped) relationship between exercise intensity and cognitive function (Kamijo et al., 2004b, 2007). However, even though RT following light exercise was not significantly different relative to the baseline session and RT was longer relative to the moderate exercise session, the P3 latency following light exercise was shorter than during the baseline session. RT encompasses multiple components of the stimulus–response relationship such as stimulus evaluation, response selection, and response execution (Doucet & Stelmack, 1999), whereas P3 latency is thought to reflect stimulus evaluation time and is generally unrelated to response processes (McCarthy & Donchin, 1981). Accordingly, the current findings suggest that moderate exercise might facilitate both stimulus evaluation processes (reflected by P3 latency) and response processes, whereas light exercise appeared to improve only the former. These findings support the previous P3 studies, indicating that neuroelectric measures are more sensitive than behavioral measures to the effects of acute aerobic exercise (Hillman et al., 2003; Kamijo et al., 2007).

As predicted, older adults demonstrated similar effects of acute aerobic exercise on RT and P3 latency to those exhibited by the younger adults, with the noted exception of the P3 amplitude. This finding indicates that the effects of acute aerobic exercise are similar across the adult lifespan. The differences in mean P3 latency between baseline and exercise sessions were small (about 10 ms). In aging studies, for instance, it has been reported that P3 latency increases with age at a rate of 1–2 ms every year (Polich, 1996). From this perspective, the differences in P3 latency identified in the present study are significant.

It is important to note that these changes were observed across task conditions, although previous studies using the flanker task indicated that the effects are larger in the incongruent flanker condition requiring greater amounts of executive control (Hillman et al., 2003; Kamijo et al., 2007). The mechanisms responsible for acute exercise effects on cognitive function remain unclear. Two possible mechanisms have been suggested in previous studies on the basis of the curvilinear (inverted U shaped) relationship as a function of differential exercise intensities. In a previous study by the author (Kamijo et al., 2004a), the influence of exercise intensity on arousal level was investigated using contingent negative variation (CNV), which is a slow negative ERP shift reflective of arousal level (Tecce, Savignano-Bowman, & Meinbresse, 1976). This study suggested that differences in exercise intensity influenced arousal level through changes in CNV amplitudes showing a curvilinear (inverted U shaped) behavior (Kamijo et al., 2004a). Second, Chmura, Nazar, and Kaciuba-Uscilko (1994) have investigated the relationship between plasma catecholamine and cognitive performance during a GXT, suggesting that the relationship between response speed and plasma catecholamine may be described by a curvilinear distribution. These changes in arousal level and plasma catecholamine resulting from exercise intensity appear similar to changes in RTs and P3 latencies found in the present study. If changes in arousal level and/or plasma catecholamine were associated with the effects of acute exercise on cognitive function, general nonselective effects (i.e., analogous effects on both congruent and incongruent condition), rather than selective effects, would have been observed similar to the present study. However, for reasons not clearly understood, the general nonselective effects were inconsistent with the previous

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study, indicating selective acute exercise effects on P3 latency (Hillman et al., 2003; Kamijo et al., 2007). Thus, we cannot yet conclude whether acute aerobic exercise selectively influences the executive control processes.

To the best of our knowledge, the effects of acute aerobic exercise on executive control have been investigated only using the flanker task (Hillman et al., 2003; Kamijo et al., 2007). Thus, ERP studies have investigated only one aspect of executive control (i.e., interference control). Future research should employ several classical executive control tasks with variable demands to not only better determine the effect of acute aerobic exercise on executive control but also to tap various executive control functions (e.g., attentional control, working memory, mental set shifting) to gain a broader understanding of this relationship.

With regard to P3 amplitude, at first the effect of congruency was shown only for older adults: increased amplitude for the congruent condition compared with incongruent condition. This finding may be due to the level of decision confidence. Palmer, Nasman, and Wilson (1994) suggested that more difficult tasks are associated with reduced levels of decision confidence and that they produce smaller P3 amplitudes. Thus, in the present study, it is possible that the relatively small P3 amplitude was produced in older adults for the incongruent condition (i.e., more difficult condition), which resulted in a lower degree of decision confidence in comparison to the congruent condition. By contrast, it is possible that younger adults were able to make decisions with a relatively high degree of confidence, even in the incongruent condition and, as a result, show no differences between the task conditions. If this assumption were true, the effects of aerobic exercise would be observed only in younger adults and not in older adults. Subjective task difficulty decreased (i.e., level of decision confidence increased) in younger adults due to improvements in cognitive functions following moderate exercise, and P3 amplitude increased compared with the baseline session. Subjective task difficulty may not have changed in older adults after exercise, even though cognitive function improved as a result of acute aerobic exercise. As mentioned earlier, we have previously reported that the arousal level was affected by acute aerobic exercise, and it is possible that the P3 amplitude was influenced by those changes (Kamijo et al., 2004a). The differential changes in P3 amplitude between the age groups also suggest that acute aerobic exercise influence not only arousal level but also cognitive functions because P3 amplitudes should be changed in a similar manner across groups if changes in arousal level only influenced to improvement in cognitive function.

In conclusion, light and moderate aerobic exercise improves cognitive function across the adult lifespan, although the mechanisms underlying the observed acute aerobic exercise effects on cognitive function may be age dependent. The present study provides additional support for the beneficial effects of exercise on cognition during older adulthood.

FUNDING

This study was supported by the Nishihira/Tsukuba Project of COE (Center of Excellence) from the Japan Ministry of Education, Culture, Sports, Science, and Technology.

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Received July 16, 2008
Accepted December 23, 2008
Decision Editor: Rosemary Blieszner, PhD

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