Effects of Habitual Moderate Exercise on Response Processing and Cognitive Processing in Older Adults

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Abstract: We examined the effects of habitual moderate exercise on central information processing in older individuals using the reaction time (RT) and P3 component of event-related brain potentials (ERP). The present study was designed to assess cognitive function by comparing groups of 20 older individuals (69.20 ± 1.3 years active group) who regularly engage in moderate physical activity with 20 subjects (66.90 ± 1.1 years inactive group) who do comparatively little exercise. Subjects performed a somatosensory oddball task composed of pressing a button with their right foot as fast as possible following an electrical stimulus applied to the right index finger, and not responding to an electrical stimulus applied to the left index finger.

Electroencephalogram (EEG) was recorded at the frontal (Fz), central (Cz), and parietal (Pz) sites according to the International 10–20 system referenced to linked earlobes. The RT was faster for the active group than for the inactive group, and the P3 amplitude of the active group was significantly larger than that of the inactive group. Moreover, the P3 amplitude for the active group was maximum at Pz and significantly larger than at Fz and Cz, but for the inactive group it was identical between Fz and Pz. The results suggest that habitual moderate exercise exerts positive influences in older adults not only on response processing, but also on cognitive processing. [The Japanese Journal of Physiology 55: 29–36, 2005]

Key words: aging, moderate exercise, information processing, P3, ERP.

Physiological functional capacity declines at some point with advancing age even in healthy adults, resulting in a reduced capacity to perform certain physical tasks [1]. For example, reaction time (RT) and movement time experiments revealed that older adults always respond slower than younger individuals [2, 3]. In normal aging, the human brain begins to lose tissue early in the third decade of life. Average losses are estimated at roughly 15% of the cerebral cortex and 25% of the cerebral white matter between the ages of 30 to 90 [4, 5]. Furthermore, normal aging is associated with changes in electroencephalogram (EEG) and the P3 component of event-related brain potentials (ERP), which reflects cognitive processing [6]. P3 latency has been considered an index of stimulus evaluation [7, 8]

or classification speed [9], and P3 amplitude is proportional to the amount of attentional resources [10] or context updating of working memory resources [11]. With age, P3 latency consistently increases and P3 amplitude usually decreases and becomes more evenly distributed over the scalp [12, 13]. Moreover, both cognitive processes and motor responses slow as individuals get older [3, 6].

On the other hand, long-term physical exercise results in adaptations of the neuromuscular [14], metabolic [15], cardiovascular [16], and endocrine systems [17]. It has also been reported that these adaptive changes occur in older adults [15, 18]. The results of cross-sectional studies of humans are also in agreement with the notion that the RT has typically been

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found to be shorter in physically active adults than in inactive older ones [3, 19]. Although behavioral and psychomotor measurements have been extensively employed in studies on exercise and aging of the brain, little investigation into the relationship between long-term exercise and cognitive processing in adults has occurred using electrophysiological measurements [20]. Dustman *et al.* [21] reported that P3 latency was faster in aerobically trained older men than in inactive ones. However, two previous studies reported no significant difference in P3 latency between high-fitness and low-fitness older adults [20, 22]. These studies, correlating the effects of long-term exercise on central information processing in older adults, have compared cognitive functions between aerobically high-fitness older participants and low-fitness ones. However, high-intensity or heavy exercise such as aerobic high-fitness training is not appropriate for older adults.

Moderate- and light-intensity activities, such as walking for pleasure, gardening, housework, and slow dancing belong to normal everyday life, and have been demonstrated to produce significant long-term health benefits and to lower the risk of cardiovascular events [23]. Regular physical activity positively influences several factors that may retard or prevent age-related cerebral atherogenesis and sustain cognitive abilities [24]. Colcombe *et al.* [25] suggested that increased cardiovascular fitness affects improvements in the plasticity of the aging human brain. Recently, Harada *et al.* [26] showed that habitual jogging improved performance in a prefrontal branching task. Furthermore, light-intensity exercise represents an important component of most clinical programs of rehabilitation [27]. Regardless of its importance, the effect of moderate- and light-intensity exercise on the central nervous system (CNS) of older adults is not fully understood. Thus, it is necessary to investigate the effect of moderate exercise on cognitive function in older individuals. The hypothesis that has guided the present study is that habitual moderate physical activity exerts beneficial influences resulting in the attenuation of cognitive function decline in older adults. We examined the effects of habitual moderate exercise on response processing and cognitive processing in older participants by the use of an ERP study.

METHODS

Subjects. Healthy right-handed individuals from the physically active and inactive groups were matched by age (69.20 ± 1.3 vs. 66.90 ± 1.1 years) and sex (10 males and 10 females in each group). Table 1 presents

Table 1. Age and anthropometric data for active and inactive older participants.

Measurement	Active	Inactive
Age (year)	69.20 ± 1.3	66.90 ± 1.1
Height (cm)	155.65 ± 1.7	158.35 ± 2.2
Weight (kg)	56.30 ± 1.5	60.85 ± 2.0

Values are means $\pm$ SE.

their characteristics. The active group comprised vigorous participants who had taken part in physical exercises for more than three years; the exercise consisted of one 90 min session once a week in Tsukuba City. Moreover, almost all were accustomed to walking for more than 60 minutes every day. In contrast, the inactive group, which comprised newcomers to the physical exercise class in Tsukuba City, had no history of physical exercise. They independently participated in the present study before starting the class. All subjects reported being free of neurological or psychiatric disorders and provided informed consent. The appropriate committee at the University of Tsukuba approved the experimental protocols.

Physical exercise. Trained physical educators guided the class-based multi-component exercises, which comprised movements typically involving rhythm, aerobic performance, muscle strength, flexibility, and stretching (Table 2). The muscle strength exercises were performed with the use of rubber bands or the participants' own body weight. The relative workload was estimated from the maximal heart rate, and the relative exercise intensity was approximately 60–70% during aerobic performance. The participants could rest to drink water whenever they felt tired. No accidents or medical complications that related directly to the physical exercise were observed.

Procedure. The subjects were comfortably seated in a chair, placed their right foot on and depressed a button fixed on the floor. The room was dimly lit and air-conditioned (25°C). They were asked to keep their eyes open and fixated on a target placed about 1 m in front of them in order to eliminate blinks and slow eye movements.

Somatosensory stimuli with 0.2 ms duration were delivered to the index finger of each hand using a constant current stimulator through ring electrodes. The left (non-target, 80% of total) and right index finger stimuli (target, 20% of total) were randomly delivered. The interstimulus interval (ISI) varied randomly from 800 to 1,400 ms. The stimulus intensity was adjusted to three times the individual sensory threshold (range 5.4–8.7 mA). The stimuli caused neither discomfort

Table 2. The program at the exercise club in Tsukuba City for individuals more than 60 years old.

Menu	Contents	Time
Warm-up	Rythmical step and static stretching	20 min
Aerobic exercise	Movements back and forth, right and left, and combinations of them by moving the upper and lower limbs to the sound of music	30 min
Muscle conditioning	Activation of both agonist and antagonist muscles by using rubber bands	20 min
Stretching, relaxing, and cooling down	Taking the stiffness out of muscles and relaxation (respiratory method)	20 min

nor startle reactions. A total of 150 stimuli were delivered (30 targets and 120 non-targets).

Task. Subjects performed a somatosensory oddball task composed of pressing the button with their right foot as fast as possible following an electrical stimulus to the right index finger (target), and not responding to an electrical stimulus applied to the left index finger (non-target). All subjects were instructed to minimize upper body movements and to avoid eye movements and blinking as much as possible.

Electrophysiological recording. Electroencephalogram (EEG) was recorded at Fz (frontal site), Cz (central site), and Pz (parietal site) according to the International 10–20 system referenced to linked earlobes. To monitor possible artifacts due to eye movements, electrooculogram (EOG) was recorded using electrodes above and below the right eye. The EEG and EOG were recorded using a digital evoked potential measuring system (Neuropack, MEB-2216, Nihon Kohden), with a filter set to a band pass of 0.1–100 Hz.

DATA ANALYSIS

The reaction time (RT) between 250 and 800 ms after the stimuli was recorded as a correct response. All subjects performed the task with an error rate of less than 5%. Somatosensory ERP was obtained with right index finger stimuli (target) and left index finger stimuli (non-target). The averages of 20 waveforms for the target and all non-target trials were analyzed for 1,000 ms, including 100 ms before and 900 ms after each electrical stimulus, respectively. The baseline for measuring the amplitude of recognizable potentials was determined by averaging the 100 ms just before each electrical stimulus presentation. Trials with eye blinking (EOG greater than $\pm 50 \mu\text{V}$), movement artifacts (EEG greater than $\pm 100 \mu\text{V}$) and response errors were excluded from the averaging. Waveforms from each electrode and stimulus condition were analyzed with the P3 component, defined as the largest

positive going peak occurring for all electrode sites with a latency window from 250 to 500 ms. The P3 amplitude was measured relative to the prestimulus baseline, with peak latency defined as the time point of maximum positive amplitude.

STATISTICS

Reaction time. Statistical comparisons for each time window from 250 to 800 ms after the onset of the somatosensory stimulus were made with the Fisher PLSD post hoc procedure (analysis of variance).

P3 component. A repeated measures analysis of variance was performed on the P3 component for the following variables: Group (active, inactive) $\times$ Electrode location (Fz, Cz, Pz). To decrease the experiment-wise error rate due to the repeated measures design involving multiple dependent variables, a Greenhouse and Geisser adjustment of the degrees of freedom was performed. This correction was applied when the violations of sphericity for significant effects occurred in the analysis of variance with two or more degrees of freedom [28]. Post hoc testing was conducted only when preceded by a significant analysis of variance effects. Statistical significance was set at $p < 0.05$.

RESULTS

Reaction time

The reaction time (RT) was recorded for each run and was faster for the active group (379.98 ± 14.3 ms) than for the inactive group (432.49 ± 15.9 ms, $p < 0.05$) (Table 3).

Event-related brain potential waveforms

Figure 1 shows the averaged event-related brain potentials (ERP) recorded during a somatosensory oddball task at each scalp location. A distinct positive P3 component (250–500 ms) was identified.

Fig. 1. A: 20 grand average event-related brain potentials (ERP) of somatosensory targets for the active older (thick line) and inactive older (dotted line) groups. **B:** 100 averaged non-target ERP waveforms. ERP was recorded at the frontal (Fz), central (Cz), and parietal (Pz) midline locations. P3: P3 component of ERP.

P3 latency

There were no significant main effects for either the Group or Electrode location, and no significant interactions between them (Table 3).

P3 amplitude

Both the Group and Electrode location showed significant main effects on the P3 amplitude values ($F_{1,39} = 6.725, p < 0.05$; $F_{2,39} = 16.033, p < 0.001$) (Table 3).

Table 3. The analysis variance results of the main effect for reaction time, P3 latency, and amplitude for the Group type (active vs. inactive).

Components	Group	
	Active	Inactive
Reaction time (ms)	379.98 ± 14.3*	432.49 ± 15.9
P3 latency (ms)	372.57 ± 5.4	364.97 ± 4.7
P3 amplitude (µV)	11.11 ± 0.6*	7.54 ± 0.7

Values are means ± SE. A significant difference between active and inactive groups * $p < 0.05$.

There were also significant interactions between the Group and Electrode location ($F_{2,39} = 3.84, p < 0.05$). Post hoc tests showed that the P3 amplitude of the active group was larger than that of the inactive group at all electrode locations (Fig. 2). Moreover, post hoc tests showed that the active group exhibited an increased P3 amplitude at Pz compared with Fz ($F = 15.52, p < 0.001$) and Cz ($F = 34.19, p < 0.001$) (Fig. 2). In contrast, the P3 amplitude for the inactive group was identical between Fz and Pz. Furthermore, post hoc tests showed that the P3 amplitude at Cz was significantly smaller than at Fz ($F = 15.19, p < 0.001$) and Pz ($F = 15.37, p < 0.001$) (Fig. 2).

DISCUSSION

We examined the effects of habitual moderate exercise on central information processing in older adults using the reaction time (RT) and P3 component of event-

Fig. 2. Group (active, inactive) $\times$ Electrode location (Fz, Cz, Pz) interaction for the P3 amplitude. The active older group is depicted by white bars, and the inactive group is illustrated by black bars. The active group exhibited an increased P3 amplitude at Pz compared to Fz and Cz ($***p < 0.001$). In contrast, P3 amplitude for the inactive group was identical between Fz and Pz, and P3 amplitude at Cz was significantly smaller than at Fz and Pz ($###p < 0.001$).

related brain potentials (ERP). The exercise program in the present study consisted of various activities focused on enhancing the possibility of independent living. This involved movements important for everyday activities with demands on various physiological functions, such as aerobic capacity, muscle strength, and flexibility. The exercise intensity adopted in the present study corresponded to roughly 60–70% of the maximal heart rate during aerobic exercise and revealed an appropriated level required for enhancing aerobic capacity [29, 30]. The active group had regularly partaken in an exercise program for more than three years. In contrast, the inactive group had no history of physical exercise.

The RT was faster for the active group than for the inactive group, which supports the findings that the capacity to react quickly is retained by older individuals who are physically active [2, 3]. The present results are consistent with previous studies and suggest that habitual moderate exercise also promotes response processing in older individuals.

The P3 latency was no different between the active and inactive groups in this study. Dustman *et al.* [21] reported that the P3 latency tended to be longer for a low-fitness elderly group than for a high-fitness one. In contrast, Bashore [22] demonstrated a non-significant difference for shorter P3 latency in high-fitness elderly persons than in low-fitness ones. Hillman *et al.* [20] also failed to replicate the P3 latency results reported by Dustman *et al.* [21]. On the other hand, P3 latency is reasonably stable and varies relatively little as a function of task variables when the subject is

engaged in an explicit discrimination task [31]. Thus, it is valid to conclude that P3 latency was no different between the active and inactive groups in this study.

In the present study, active older adults showed significantly higher P3 amplitude and faster reaction time than inactive ones. Kida *et al.* [32] found that the P3 amplitude was larger when the RT was fast and speculated that when more attentional resources were allocated to the given task, the motor outputs were faster. The present results support their findings and indicate that habitual moderate exercise affects both response processing and cognitive processing. Thus, exercise participation has consistently emerged as a key indicator of improved cognitive function [24, 33, 34]. Furthermore, a retrospective analysis found that behavioral stimulation and physical activity reduced the risk of developing Alzheimer's disease [35].

However, it is possible that the P3 amplitude is affected and changed by an arousal level or subject motivation. Polich and Kok [36] claimed that P3 is influenced by biological processes such as fluctuations in the arousal state of subjects. Kamiyo *et al.* [37] examined the relationship between P3 and exercise intensity and suggested that changes in the P3 amplitude are an inverted U-shaped behavior of differences in exercise intensity. They reported that P3 amplitude might be influenced by the arousal state of subjects. Furthermore, long-term physical activity may enhance the arousal or motivation levels of older adults. In the current study, it is thought that these levels were almost the same between the active and inactive groups because the inactive individuals were new members of the exercise class and participated voluntarily before starting the class.

Moreover, we suggest that the exercise programs adopted in this study also affected the cognitive processing of active older individuals. Specifically, aerobic performance participants had to rhythmically perform upper- and lower-limb gymnastics to the sound of music. They needed to self-examine their movements and correct them by watching the educator's performance. Thus, the participants had to quickly transform various sensory inputs (e.g., auditory, visual, and somatosensory) into motor outputs and simultaneously needed to recall movement patterns. The repetition of sensori-motor processing, such as in our exercise programs, accompanied by motor learning may activate cognitive functions in older adults. Motor skill learning has been shown to increase cortical thickness and synaptogenesis [38], as well as the number of synapses per neuron in the cerebellum [39,

40]. It is clear that voluntary exercise can increase levels of brain-derived neurotrophic factor (BDNF) and other growth factors, stimulate neurogenesis, increase resistance to brain insult, and improve learning and mental performance [41]. Moreover, van Praag *et al.* [42] found that physical activity increased cell proliferation, cell survival and neurogenesis in the hippocampus to improve hippocampus-dependent spatial learning. It has been reported that P3 occurs in the hippocampus and adjacent structures [43, 44]. On the basis of previous studies and the present findings, we suggest that long-term moderate exercise with motor learning may cause plastic changes to the hippocampus of active older adults and improve cognitive processing in comparison to inactive older individuals.

With regard to electrocortical patterns, the active group showed maximum P3 amplitude at Pz, and the P3 amplitude for the inactive group was identical between Fz and Pz. Previous studies found a more frontal and equipotential P3 scalp distribution with increasing age in contrast to the parietal distribution in young subjects [12, 13]. The inactive group showed a typically older P3 scalp distribution; however, the distribution of the P3 amplitude in the active group appeared predominantly at the parietal site and more closely resembled that found in younger adults. The P3 amplitude at Cz was the smallest in both active and inactive groups. This result depends not only on age-related changes in the scalp distribution of P3, but also on the readiness potential (RP) associated with button pressing. The RP starts about 1.5–2.0 s before the movement onset and is maximal at the mid-line vertex (Cz) [45]. The generator source of the RP has been thought to include at least the foot area of the primary motor cortex [46] and of the supplementary motor area (SMA) [47], corresponding to the mid-line vertex [Cz]. Therefore, the decline of the P3 amplitude at Cz might be caused by the superimposition of the RP. However, we conjecture that RP hardly affects P3 amplitude at Pz because the interstimulus interval (ISI) was not fixed and was of a relatively short duration. Moreover, the movement task consisted simply of button pressing, requiring little effort. We presume that the significant difference in P3 amplitude at Pz between active and inactive groups resulted from the effects of long-term moderate exercise.

The main findings of the present study are that older individuals who maintain moderate physical activity have improved reaction speeds in a somatosensory oddball task, and they also have improved

P3 amplitude relative to age-matched inactive peers. Specifically, the electrocortical patterns of activity in the active older group appeared to more closely resemble those of younger adults. In conclusion, habitual moderate exercise exerts a positive influence in older adults not only on response processing, but also on cognitive processing.

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