Effect of Aerobic and Resistance Training on Fractionated Reaction Time and Speed of Movement

Lynn Bishop Panton,1 James E. Graves,1 Michael L. Pollock,1 James M. Hagberg,1 and William Chen1

1Center For Exercise Science, Colleges of Medicine and Health and Human Performance, University of Florida, Gainesville.
2Department of Health Science Education, University of Florida, Gainesville.

To evaluate the effect of aerobic and variable resistance exercise training on fractionated reaction time (RT) and speed of movement (SM) in elderly individuals, premotor time (PMT), motor time (MT), total RT, and SM were measured in 49 healthy, untrained men and women, 70 to 79 years of age, before and after 6 months of training. Subjects were randomized into either a walk/jog (n = 17), a strength training (n = 20), or a control group (n = 12). Improvements in aerobic capacity were only weakly related to reduced total RT (r = 0.30, p < .05). Analysis of covariance revealed that there were no differences (p > .05) among the three groups after training with respect to PMT, MT, total RT, and SM. These findings indicate that 6 months of aerobic and strength training did not induce significant changes in RT or SM in this group.

Psychomotor performance can be defined as the ability of an individual to process and react to specific external information. Decreased psychomotor performance is generally accepted as a consequence of aging (1). Studies have shown that an age-related deterioration of the neuromuscular system causes an inevitable lengthening of both total reaction time (RT, time required to initiate a movement following the presentation of a stimulus) and speed of movement (SM, time required to move from one position to another) (2–6). In a review of 26 studies on the relationship between simple RT and age, Birren et al. (2) reported that, on the average, there was a 20% decline in RT between 20 and 60 years of age.

Electromyography (EMG) can be used to fractionate total RT into nervous system (premotor time) and muscular system (motor time) components. Premotor time (PMT) is the time from stimulus onset to the appearance of an action potential at the involved muscle. Motor time (MT) is the time from the appearance of the action potential to initiation of limb movement (3). Investigations employing the fractionated RT technique indicate that differences in total RT between young and old individuals are primarily due to a lengthening of PMT (7, 8).

Baylor and Spirduso (9), Clarkson (3), and Spirduso (6) have suggested that physical activity may reduce the effect of age on psychomotor performance. Clarkson (3) found that individuals who were physically active throughout their lives (mean age = 65 years) had faster total RTs than sedentary individuals of similar age. Spirduso (6) showed that physically active older subjects also had a faster SM. The significantly faster neuromuscular responses of highly trained individuals further support a relationship between physical activity and psychomotor speed (3, 6). A study by Baylor and Spirduso (9) compared a small sample of aerobically active women with a nonexercise control group, a total of 16 women, mean age = 53 yrs). The results showed faster PMT, MT, total RT, and SM for the aerobic group. These data support the hypothesis that in older individuals, systematic aerobic exercise is associated with the maintenance of both the central and peripheral components of RT.

A relationship between physical fitness and psychomotor performance suggests that older persons may be able to improve RT and SM through exercise training. It has been hypothesized that the maintenance of aerobic capacity through regular physical activity ensures an adequate delivery of oxygen to the nervous system and an attenuated deterioration in psychomotor performance (4). Thus, improving aerobic capacity through exercise training in older persons might improve RT and/or SM.

At present, there are few studies on aerobic exercise training in the elderly, and the results have been inconclusive (10). Beise and Peaseley (11), Boorman (12), and Normand et al. (5) failed to find changes in the psychomotor performance of elderly subjects following several different exercise training programs. Barry et al. (13) found no changes in RT, but did find a significant improvement in the SM of eight elderly subjects (mean = 70 yrs of age) following a 3-month physical conditioning program. In contrast, two studies have reported RT benefits following aerobic training. Gibson et al. (14) reported an improvement in simple RT after a 6-week aerobic training program. Dustman et al. (4) found that individuals aged 55–70 yrs significantly improved their simple RT following a 4-month training program that elicited significant changes in aerobic capacity.

One limitation of the studies by Gibson et al. (14) and Dustman et al. (4) was that RT was not fractionated. Whether changes in their RTs were due to changes in PMT, MT, or both is unknown. Furthermore, no previous studies have investigated the influence of strength training and aerobic training programs on fractionated RT and SM for
individuals 70 years of age or older. Therefore, the purpose of the present study was to evaluate the influence of aerobic and variable resistance strength training on fractionated RT and SM in men and women 70–79 years of age.

METHODS

Subjects. — Twenty-three male and 26 female volunteers completed the testing and training required for the study. These subjects were retired professionals recruited from the university community of Gainesville, FL. They were sedentary nonsmokers who had no contraindications to exercise testing or training. The study was approved by the University of Florida College of Medicine Institutional Review Board. Documented informed consent was obtained from all subjects.

Pretraining testing. — During initial screening, subjects completed questionnaires on medical history, demographic history, physical activity, smoking, and nutrition. Subjects were then administered a medically supervised physical and cardiovascular examination that included a resting 12 lead electrocardiogram and a diagnostic graded exercise test (GXT) using a modified (2 min stages) Naughton protocol (15). The GXT was terminated when the subject was unable to continue or when signs or symptoms of cardiovascular decompensation became evident (16). The subjects included in the study were free of any overt evidence of coronary artery disease and other conditions that would limit their participation in a vigorous exercise program.

Measurement of aerobic capacity. — All subjects who were included in the study after the initial screening returned to the laboratory 6–7 days later to undergo a treadmill test to determine aerobic capacity (VO\textsubscript{2,max}). The modified Naughton protocol was used again. However, for those subjects who exercised longer than 12 min on their initial GXT, the initial speed was set at 3 mph rather than 2 mph. The VO\textsubscript{2,max} test was terminated when the subject was unable to continue.

During the VO\textsubscript{2,max} test, subject's expired air was collected minute by minute in meteorological balloons. The concentrations of oxygen and carbon dioxide in the expired air were determined using Ametek-Thermo (Pittsburgh, PA) gas analyzers calibrated with a primary standard gas mixture. Ventilatory volumes were measured using a 120 liter Tissot spirometer.

Strength and body composition measurements. — Muscular strength was assessed for two exercises with a one-repetition maximum (1-RM) test. One exercise involved muscles of the arms and chest and was completed on a Nautilus™ duo-decline press machine. The second exercise involved the quadriceps muscles of the legs and was completed on a Nautilus™ leg extension machine. For each 1-RM test, subjects started by lifting a relatively light weight. The weight was lifted by extending the arms or legs in a slow controlled movement and then lowering for one repetition. Weight was gradually added until the subject could not complete one more repetition. The last weight lifted was considered the criterion 1-RM score. A one-minute rest was provided between repetitions.

Body density was predicted from the sum of seven skinfold equations of Jackson and Pollock (17) and Jackson et al. (18). Percent fat was predicted from body density using the Siri (19) equation.

RT and SM measurement. — Total RT, fractionated RT, and SM measurements were obtained using electronic instrumentation to receive, transmit, and convert electrical signals. Surface electrodes (Disposable Triple Sensor Strips, Autogenic Systems, Chicago, IL) were placed over the belly of the biceps brachii of the dominant arm to detect the action potentials of the muscle. The electrodes were positioned along a line representing the greatest circumference of the flexed biceps. The skin over the biceps was cleansed with alcohol prior to electrode placement. Spectra 360 electrode gel (Parker Lab, Inc., Orange, NJ) was applied to the electrodes to facilitate conduction. The electrodes were connected to a Cyborg (Chicago, IL) EMG and Q700 RMS data accumulator. The EMG machines, light stimulus interface box, and telegraph keys (mounted on wooden platforms) were interfaced to a Compaq 286 microcomputer through a Techmar Lab Master A/D converter and interface card. Software was developed to calculate PMT, MT, Total RT, and SM values from the digital input.

For the RT trials, subjects sat in a comfortable position on a backed swivel chair in front of the RT apparatus. Both feet were placed comfortably on the floor. The nondominant hand rested on the table or on the subject's lap. Instructions were then given on the procedures of the test. To start each trial, subjects lightly depressed a standard telegraph key with the middle three fingers of the dominant hand. Subjects then waited for the presentation of a light stimulus. Following presentation of the stimulus, subjects moved their hand from the depressed telegraph key to an adjacent key 26 cm away as quickly as possible. If subjects were right-handed they moved their right hand to the left telegraph key; if they were left-handed they moved their left hand to the right telegraph key. For each trial, a preparatory signal of "ready" was given, and the investigator pressed a key on the computer keyboard to initiate the visual stimulus. The light stimulus appeared at a randomly generated time interval between 1 and 5 seconds. Each subject completed 15 trials.

Training. — After the subjects completed the pretraining testing, they began the training phase of the study. Subjects were randomly assigned to one of three groups: a control group, a walk/jog group, or a variable resistance strength training group. Randomization was completed with the restriction that twice as many subjects were assigned to the training groups than to the control group. Because the adherence to an exercise program in this group of subjects was unknown, more subjects were purposely randomized into the training groups to help ensure a sufficient number of subjects to validly address the specific aims of the study. Fifty-seven subjects began the training phase of the study. Group characteristics for the 49 subjects who completed the study are presented in Table 1.

Subjects completed three exercise sessions per week for
Table 1. Physical Characteristics of the Control, Walk/Jog, and Strength Groups (N = 49)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control (n = 12)</th>
<th>Walk/Jog (n = 17)</th>
<th>Strength (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men (n = 4)</td>
<td>Women (n = 8)</td>
<td>Men (n = 8)</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>71.0 ± 1.8</td>
<td>72.6 ± 3.4</td>
<td>71.9 ± 2.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.8 ± 11.6</td>
<td>158.6 ± 5.6*</td>
<td>171.3 ± 4.2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76.8 ± 10.6</td>
<td>57.4 ± 8.3*</td>
<td>78.1 ± 5.8</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>24.8 ± 5.9</td>
<td>35.2 ± 4.9*</td>
<td>22.6 ± 4.5</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>72.1 ± 3.0</td>
<td>71.8 ± 1.9</td>
<td>72.2 ± 2.5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.1 ± 10.9</td>
<td>164.3 ± 9.3</td>
<td>169.4 ± 9.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64.5 ± 13.0</td>
<td>69.6 ± 10.7</td>
<td>74.5 ± 13.6†</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>30.9 ± 7.6</td>
<td>29.4 ± 7.9</td>
<td>29.0 ± 7.5</td>
</tr>
</tbody>
</table>

Values are means ± SD.
*Values significantly different from men at p < .05.
†Significantly different from control group at p < .05.
‡Body density was predicted from the sum of seven skinfold equations of Jackson and Pollock (17) and Jackson et al. (18). Percent fat was calculated using the Siri (19) equation.

26 weeks. During the first 2 weeks of training, subjects were taught to monitor their heart rate (HR) by palpating their radial or carotid pulse. Heart rate and rating of perceived exertion (20) were recorded at the middle and end of each training session. All training sessions were supervised by experienced personnel, and the accuracy of the subject's palpated HR was checked at least once during each training session by the supervisor.

All training sessions were preceded by 5–10 minutes of stretching and warmup exercises, followed by 5 minutes of cool-down exercises. Subjects in the walk/jog group started training by walking for 20 minutes at 50% of their maximal HR reserve (HRRmax). The duration of walking was increased by 5 minutes every 2 weeks until the subjects were walking for 40 minutes. Training intensity was gradually increased until subjects could walk at 60–70% of HRRmax. During the 14th week of training, exercise intensity was increased further by alternating fast walk/moderate walk or fast walk/slow jog intervals. Five subjects increased their training intensity by walking uphill on a treadmill. By the 26th week of training, all subjects were exercising at 75–85% of HRRmax for 35–45 minutes.

Subjects in the strength training group exercised three times per week for approximately 30 minutes per session for the 26 weeks of the study. Workouts consisted of one set of 10 variable resistance Nautilus™ exercise machines (leg extension, side leg curl, super pullover, duo-decline press, 10 degree chest, rotary torso, low back, lateral raise, overhead press, and multi-biceps). The resistance training program was designed primarily to develop muscular strength, and a short rest was allowed between exercises. During the first week of training, subjects were instructed on the proper technique for each machine. During the first 13 weeks of training, subjects used light to moderate weights and performed 8–12 repetitions of each exercise. The goal of this phase of training was to allow for slow adaptation to prepare the subjects for more intense training, which began during the 14th week. During the last 13 weeks of training, resistance was increased substantially and subjects were encouraged to train to volitional muscular fatigue on each machine. When subjects could complete 12 or more repetitions on a given machine, the resistance was again increased.

Post-training testing. — The subjects in the control group were asked to not change their life style over the 6-month duration of the study. At the end of the 6-month training period, all subjects repeated the VO2max, strength, fractionated RT, total RT, and SM tests that they completed at the beginning of the study. These post-tests were then compared with the pretests to determine whether the exercise training influenced fractionated RT, total RT, and SM.

Data analysis. — Descriptive characteristics were compared among groups using analysis of variance (ANOVA). A repeated measures ANOVA was used to determine if there was a learning factor associated with the repeated fractionated RT and SM measurements. Helmert contrasts were used to determine when the performance curve leveled off. Repeated measures that did not differ significantly (p > .05) were blocked into two groups. The high and low measures in each block were omitted and the remaining values were averaged to obtain criterion measures for PMT, MT, total RT, and SM. Changes in PMT, MT, total RT, and SM were compared among groups by analysis of covariance. The covariate was the pretraining criterion value. An ANOVA on the strength and aerobic capacity measurements taken before and after training was used to determine if the training was effective in the experimental groups and whether there were differences in training among groups. Pearson product-moment correlations were used to determine if there were relationships between changes in PMT, MT, total RT, and SM with changes in aerobic capacity or strength. For all analyses, statistical significance was accepted at the p < .05 level.

RESULTS

Initially, the three experimental groups were similar (p > .05) with respect to age and height (Table 1). The strength
group, however, was different from the control group with respect to weight \((p < .05)\). The three groups were also similar \((p > .05)\) with respect to aerobic capacity (Table 2) and strength of the upper and lower body (Table 3). No time-by-gender interactions were noted for any of the training responses. Thus, the data were pooled for men and women for analysis. Aerobic capacity increased significantly \((p < .05)\) in the walk/jog group but not in the strength or control groups (Table 2). The strength-trained group showed a significant improvement in upper and lower body strength \((p < .05)\).

Repeated measures ANOVA on the 15 levels of trials revealed that pretraining PMT, MT, total RT, and SM decreased \((p < .05)\) during the first 4 to 5 trials. Thus, trials 6–15 of each measurement were used to calculate criterion measures. In attempting to eliminate the effect of anticipation and lack of attention, these trials were blocked into two groups of five. The high and low values were deleted from each block and the remaining 3 values were averaged to obtain criterion values. Although there was no trial effect \((p > .05)\) associated with the post-training measurements, to treat post-training and pretraining data equally, trials 1–5 of the post-tests were also omitted from the calculation of criterion measures.

Post-training PMT, MT, total RT, and SM values, adjusted for pre-training levels among groups, are presented in Table 4. No significant differences \((p > .05)\) were noted among the groups for PMT, MT, total RT, and SM. Because a trend toward reduced PMT and total RT values was noted for the training groups, a 2-way ANOVA was also used to examine the data. No significant group \(\times\) time interactions \((p > .05)\) further indicated no treatment effect for these parameters.

A low but significant correlation was noted between changes in \(\text{VO}_{2}\)\(_{\text{max}}\) and changes in total RT \((r = .30, p < .05)\). The correlations between changes in \(\text{VO}_{2}\)\(_{\text{max}}\) and changes in PMT, MT, and SM were \(r = .21, r = .10, \) and \(r = .04, \) respectively, and were not significant \((p > .05)\).

There were no significant correlations \((p > .05)\) found between initial \(\text{VO}_{2}\)\(_{\text{max}}\) and initial fractionated RT and SM values \((r = .26 \text{ for PMT, } r = .07 \text{ for MT, } r = .14 \text{ for total RT, and } r = .12 \text{ for SM})\). There were also no significant correlations \((p > .05)\) between initial \(\text{VO}_{2}\)\(_{\text{max}}\) and changes in fractionated RT and SM \((r = .05 \text{ for changes in PMT, } r = .05 \text{ for changes in MT, } r = .009 \text{ for changes in total RT, and } r = .004 \text{ for changes in SM})\).

**DISCUSSION**

A relationship between physical fitness and psychomotor
performance has been suggested by several investigators who believe that neuromuscular speed may be maintained by high levels of physical fitness (3,6,9). Studies involving elderly subjects who have been physically active for much of their lives show that these subjects have significantly faster reaction time profiles than their inactive counterparts (3,6).

It is of interest to note from Clarkson’s (3) data that the difference in PMT between young active and young inactive individuals (20.8 ms) is similar to the difference in PMT between old active and old inactive (21.3 ms) individuals. Thus, it is possible that individuals with fast PMTs are more likely to participate in physical activity, and that both active and inactive persons have a similar increase in PMT with age. For this reason, cross-sectional data are not conclusive in describing how exercise may affect age-related declines in psychomotor performance.

The proposed link between physical activity and psychomotor performance has been related to aerobic capacity (4,6). Dustman et al. (4) state that the onset of atherosclerosis (21,22) and a reduction in ability to efficiently transport and utilize oxygen contribute to reduced cerebral oxygenation in old age that may adversely affect brain function. Both atherosclerosis and reduced VO2max may result from physical inactivity (23). The aerobic capacity of elderly persons can be improved by aerobic exercise (24,25), and there is growing evidence that the rate of decline in physical and cognitive abilities is governed by physical conditioning levels as well as by age (23,26-28). Dustman et al. (4) and Spiridou (29) have proposed that an exercise-induced increase in aerobic efficiency facilitates the transport of oxygen from the environment to consumer cells in the brain which in turn may improve psychomotor aspects of brain function (28).

In previous studies (5,11,14), aerobic training levels were not directly measured but were estimated by subjects’ reports of exercise patterns. Thus, investigators have had difficulty quantifying subjects’ physical activities and associated aerobic changes. Dustman et al. (4) closely monitored changes in aerobic capacity with training and found a 27% increase in the aerobic capacity of their subjects (mean age = 60.6 yrs) following training. The significant increases in aerobic capacity for the elderly men and women studied by Dustman et al. (4) were associated with a corresponding decrease in simple RT. Dustman et al. (4) speculated that the improved psychomotor performance of the aerobically trained subjects was related to enhanced cerebral metabolic activity such as an increased turnover of neurotransmitters.

In the present study, intensity, duration, and frequency of exercise were carefully controlled during the 6-month training period. The aerobically trained group in this study significantly increased their aerobic capacity by 20.4%. If improved aerobic capacity is related to faster RTs, then a decrease in RT would be expected for the aerobic group. However, decreased RTs were not found in either the aerobic or strength groups. Both groups showed only minimal changes in RT. This finding and the weak correlation between changes in aerobic capacity and changes in RT fail to support the theory that psychomotor performance is related to aerobic capacity.

The aerobic group studied by Dustman et al. (4) was 60.6 years with an initial VO2max value of 19.4 ± 5.7 ml•kg⁻¹•min⁻¹. In the present study the mean age for the aerobic group was approximately 72 years and their VO2max was 22.5 ml•kg⁻¹•min⁻¹. It has been shown that maximal oxygen uptake decreases by 9% per decade in sedentary individuals (25). Considering there is a decade difference in age between the subjects in these two studies, the sample in the present study may have maintained a higher level of aerobic fitness for a longer period of time when compared to those subjects studied by Dustman et al. (4). For this reason, the subjects in the present study may already be performing at decreased RTs. Even if our subjects were able to increase their aerobic capacity, the amount of oxygen available to the nervous system prior to training may have been sufficient to maintain an adequate RT.

The brain requires only about 20% of the total body supply of oxygen (30). Although it is hard to believe that endurance training can increase oxygen delivery to brain at rest, there may be a threshold for aerobic capacity which is necessary to maintain psychomotor performance. Perhaps having subjects with lower initial aerobic capacities is required to show improvements like those seen in the study by Dustman et al. (4). In other words, subjects with relatively low aerobic capacities to start, may benefit to a greater extent from training than individuals with larger aerobic capacities.

Improvement in aerobic capacity is due to muscular and cardiac adaptations (25). Neural adaptations may be more difficult to achieve. Therefore, changes in psychomotor performance may occur only over long periods of time. Perhaps 6 months of training is insufficient to elicit a desirable response after many years of inactivity in healthy adults. Also, deficits in RT become more obvious with increasing complexity of behavior (31). The present study used a simple RT task. A more complex choice RT task, which involves more central processing, may be more likely to show improvements in RT after exercise training. In addition, it may be argued that once one reaches the age of 70, very little can be done to improve RT.

Decrements in SM due to aging may be due to a general reduction in strength, a decrease in muscle mass, and/or a reduction in the number of normally functioning fibers (32). Thus, one would expect a decrease in SM with an increase in strength. In this study, the strength group significantly increased in both upper (chest press) and lower body (leg extension) strength. However, neither of the trained groups showed improvement in SM when compared to the controls.

One reason for not seeing differences in SM among the three groups could be that the SM task did not require enough force generation by the muscles for strength to play a major role. Another possible explanation is that a greater gain in strength may be required to elicit a faster SM. Again, it may be that once an individual reaches the age of 70 it is very difficult to improve SM.

The findings of the present study indicate that six months of aerobic or variable resistance training, sufficient to elicit significant changes in aerobic capacity and strength, does not improve PMT, MT, total RT, and SM in previously sedentary but healthy 70–79-year-old men and women. This finding and the weak correlation between aerobic capacity and reduced RT fail to support the hypothesis that psycho-
motor performance is related to aerobic capacity. To elicit significant improvements in psychomotor performance, less fit subjects, younger subjects, exercise training for longer periods of time, or a more complex RT task may be required.

ACKNOWLEDGMENT

Address correspondence to James E. Graves, Ph.D., Center for Exercise Science, University of Florida, Gainesville, FL 32611.

REFERENCES

28. de Vries HA. Tips on prescribing exercise regimens for your older patients. Geriatrics 1979;34:75-81.

Received December 14, 1988
Accepted April 20, 1989