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Aerobic Exercise Training and Improved Neuropsychological Function of Older Individuals[1]

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DUSTMAN, R. E., R. O. RUHLING, E. M. RUSSELL, D. E. SHEARER, H. W. BONEKAT, J. W. SHIGEOKA, J. S. WOOD AND D. C. BRADFORD. *Aerobic exercise training and improved neuropsychological function of older individuals*. NEUROBIOL AGING 5(1) 35–42, 1984.—The effects of a four month aerobic exercise conditioning program on neuropsychological test performance, depression indices, sensory thresholds, and visual acuity of 55–70 year old sedentary individuals were evaluated. Aerobically trained subjects were compared with two age-matched control groups of subjects: those who trained with strength and flexibility exercises and others who were not engaged in a supervised exercise program. The aerobically trained subjects demonstrated significantly greater improvement on the neuropsychological test battery than did either control group. Depression scores, sensory thresholds, and visual acuity were not changed by aerobic exercise. The pattern of results suggests that the effect of aerobic exercise training was on central rather than on peripheral function. We speculate that aerobic exercise promoted increased cerebral metabolic activity with a resultant improvement in neuropsychological test scores.

Aerobic exercise Aging CFF Depression Digit span Digit symbol Human Memory Response time Sensory thresholds

GROWING old is accompanied by a gradual decline of the central nervous system (CNS). Measures of higher mental function such as intellect, memory, attention, and perception evidence decline [12] and behavior slows as demonstrated by prolonged reaction times [12], reduced brain wave (EEG) frequency [51], increased latency of event related potentials [6,25], and slower nerve conduction velocities [24].

It has been suggested that decrements in mental and electrophysiological functioning of older individuals may, in part, result from the brain being mildly hypoxic [33,47]. There are two factors which contribute to reduced cerebral oxygenation in old age and thus may adversely affect brain function: the increasing presence of atherosclerosis [8,49] and an inability to efficiently transport and utilize oxygen resulting from physically inactive life-styles [22]. The latter can be improved by aerobic exercise [22] and there is growing evidence suggesting that the rate of decline of physical and cognitive abilities is governed by physical conditioning level as well as by age [10, 11, 23. 32]. For example, response times of older men who had maintained an active participation in physical activities such as racquet sports and running were significantly faster than those of age-matched sedentary men and little different from response times of much younger sedentary subjects [60,64]. Also, highly fit older individuals scored higher on tests of fluid intelligence than did less fit subjects [28,56].

Results such as these raise important questions. Does the better performance of physically active older individuals reflect a predisposition for superiority in both athletic and cognitive abilities, or does exercise *per se* have a beneficial effect on CNS functioning? If the latter is true, can CNS functioning of older people be significantly improved by a program of physical activity even though they have maintained a sedentary life-style for many years? Is the type of exercise important? Exercise that results in increased aerobic efficiency, i.e., an improved ability to transport oxy-

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gen from the environment to consumer cells [23], may have more effect on brain function than physical activities that do not improve aerobic capacity.

The present study was designed to evaluate the effects of an aerobic exercise training program on brain function of sedentary older people.

METHOD

Sedentary individuals aged 55–70 years were solicited from the community and screened for health problems which would preclude their participation in an exercise program. Those who stated that they actively engaged in physical conditioning activities were not considered further. The research was described in greater detail at a formal meeting and prospective subjects were provided an opportunity to ask questions and become familiar with a treadmill on which maximal exercise tests were to be performed. They were told they would be paid a modest sum at the end of the study for their participation and were given informed consent forms to review. The protocol for this study and the consent forms were approved by the University of Utah Review of Research with Human Subjects Committee (IRB).

Individuals who elected to participate in the research were scheduled for a maximal exercise test. Immediately before this test they were examined by a physician for health problems which would exclude them from safely performing a maximal exercise test and/or engaging in an exercise program. Those selected to participate performed a modified Balke exercise test on a motor driven treadmill [2]. During the test their electrocardiogram was continuously monitored by a physician and their blood pressure was measured every two to three minutes. The treadmill was set at a speed of 67.0 m/min and 1% slope. While the speed remained constant, the slope of the treadmill was increased 1% each succeeding minute of exercise until a maximal effort was achieved [1]. During the test a standard open-circuit indirect calorimetry system was used so that measures of minute ventilation and maximal oxygen uptake (VO_{2max}) could be obtained. On completion of the maximal exercise test, subjects were alternately assigned to the experimental group (aerobic exercise training) or to an exercise control group. A questionnaire revealed that only three subjects smoked on a regular basis; these were in the aerobic exercise group.

Additional measures were obtained during two test sessions, each about 90 minutes in duration, from subjects in the experimental and exercise control groups and from a third group of older volunteers. The latter, nonexercise controls, did not participate in an exercise program and were not tested on the treadmill. They were screened for health problems during a structured interview. Electrophysiological measures (EEG and evoked potentials), auditory, visual and somatosensory thresholds, and a measure of visual acuity were obtained during one test session. During the other, measures were obtained for several neuropsychological tests and two depression inventories, the Beck Depression Index [4] and the Self-Rating Depression Scale [69]. The EEG and evoked potential results will be reported elsewhere. All subjects reported they were right-handed.

Sensory Thresholds and Visual Acuity

As part of the procedures for recording auditory brain stem potentials, an auditory threshold was measured. Both ears were tested; the best ear was reported. Clicks were generated by a Grass Auditory Stimulus Control Module (S10ASCM) and delivered monaurally to subjects via earphones. Somatosensory thresholds were established for 0.5 msec shocks generated by a Grass S10SCM stimulator and delivered to the median nerve of the dominant hand. Flashes, generated by a Grass PS22 Photostimulator, backlighted a narrow black diagonal line placed in a viewing box towards which the subject's gaze was oriented. Neutral density filters were used to change stimulus intensity. Visual threshold was defined as the lowest intensity at which subjects could correctly report the orientation, left or right, of the line [27]. Visual acuity was measured with a Bausch and Lomb Vision Tester (Model 712241). Vision of a number of subjects was corrected by glasses which were worn during testing procedures.

Neuropsychological Tests

(1) Critical Flicker Fusion Threshold (CFF) was measured with a Lafayette Instrument Flicker Fusion Control Unit (Model 12025) with attached viewing chamber (Model 12026) which presented a flashing light to the dominant eye. The light/dark ratio of the stimuli was 1:1. CFF threshold was the frequency (Hz) at which the flashes appeared to fuse into a continuous light. (2) Culture-Fair Intelligence, scale 3, Form A, consisting of four timed paper and pencil tests was used as a measure of intellectual performance [48]. (3) Digit Span, a subtest from the Wechsler Adult Intelligence Scale (WAIS) [68], provided a measure of recent memory. The subject's score was the number of digits in the longest series of numbers he/she could correctly repeat plus the number in the longest series which he/she could correctly report in reverse order. (4) Digit Symbol WAIS subtest [68]. Subjects were asked to match numbers with appropriate symbols to be drawn below the numbers. A key illustrating number-symbol matches was provided. Their score was the number of matches correctly made in 90 sec. (5) Dots Estimation. Sixteen slides, each containing from 1 to 16 opaque dots, were presented tachistoscopically on a screen for 200 msec. Subjects were asked to estimate the number of dots displayed with the score being the number of errors (difference between his/her estimate and the actual number of dots) averaged over two repetitions. (6) Reaction Time. Measures of simple and choice reaction time were obtained. Subjects sat facing a video screen while holding a response switch in each hand and were instructed to respond to appropriate stimuli as quickly as possible. For simple reaction time the imperative stimulus was an *X*. During choice reaction time trials an *X* and an *O* were presented simultaneously, one on the left and the other on the right of the screen. Subjects responded with their left switch when the *X* appeared to their left and with the right switch when the *X* was displayed to their right. Imperative stimuli were preceded by a warning stimulus, a small rectangle. The interval between warning and imperative stimuli was randomly varied among 0.50, 0.75, 1.00, and 1.25 sec. Inter-trial intervals were 1 sec. Fifty valid simple and choice reaction time trials were obtained from each subject. Invalid trials were those for which reaction times were less than 100 msec (anticipation), longer than 500 msec, or a wrong switch was depressed. The fastest and slowest five trials were discarded and mean reaction time was computed from the remaining 40 trials. (7) Stroop Color Test. Three 35.5×10 cm cards were used as stimulus materials. Card 1 consisted of 17 color names printed in black ink. Card 2 consisted of 17 colored bars. On card 3 were 17 color names printed in a different color of ink (e.g., the word "red" was

printed in blue ink). Words and color bars, each about 2–3 cm in length, were ordered vertically on the cards. Subjects completed four tasks, in order, as follows. They were asked to read the color words on card 1 (Task I), name the colors on card 2 (Task II), read the color words on card 3 (Task III), and to name the color of the ink used for each color word on card 3 (Task IV). The latter, an "interference" task, provides a measure of a subject's ability to "shift his perceptual set to conform to changing demands" ([45], p. 523), and is particularly sensitive to the effects of adult aging [16]. Each task was timed and subjects were asked to work as rapidly as possible.

Exercise Protocol

The exercise groups met for three one hour sessions a week over a four month period; each was supervised by a graduate student trained in exercise physiology. Every two weeks the instructors alternated groups. Subjects in the experimental group, following a few minutes of "warm up" exercises, then concentrated on aerobic exercise, consisting mostly of fast walking with occasional slow jogging. Their goal was to increase their heart rate to 70–80% of their heart rate reserve and to maintain it at this rate for longer periods of time as their conditioning improved [1]. The exercise control group participated in strength and flexibility exercises. They also monitored their heart rates but were encouraged to keep them below a level reported to improve aerobic efficiency. On conclusion of the four month exercise program, subjects in the exercise groups again performed the maximal exercise test; the remaining tests were administered to all subjects.

The aerobic exercise, exercise control and nonexercise control groups included, respectively, 13 subjects aged 55–68 years (mean=60.6), 15 subjects aged 55–70 years (mean=62.3) and 15 subjects aged 51–70 years (mean=57.4). Nine of the subjects in each group were males. The groups were equivalent in terms of number of years of education (15–16 years), scores on the Culture Fair Test of Intelligence, and mean number of days between pre- and posttreatment tests (about 140 days). The groups were not equal, however, with respect to age as subjects in the nonexercise control group were younger than those in the exercise control group ($p<0.05$).

RESULTS

Subjects in the two exercise groups were compared with respect to six physiological measures which are indicative of physical health condition: resting systolic and diastolic blood pressure, resting heart rate, maximum heart rate, maximum minute ventilation and maximum oxygen uptake (VO_{2max}). The latter three measures were obtained while subjects were performing the initial treadmill test; the other measures were obtained just before they walked on the treadmill. As shown in Table 1, the exercise groups did not differ on any of these measures. Nor, with the exception of age, did the experimental and control groups differ on any of the other measures obtained during pre-exercise testing ($p>0.10$).

To determine if our subjects had made a maximal effort on the treadmill exercise test, we compared mean O_2 uptake for the minute preceding the final minute of effort (22.1 ml/kg/min) with that for the final minute (22.9 ml/kg/min), a 0.8 ml/kg/min difference. Means were based on pre- and posttest evaluations of all of the exercise subjects. Maximum oxygen uptake is reportedly achieved if the difference between consecutive VO_2 readings, with increasing work loads, is less than 2.1 ml/kg/min [65]. Our data suggest that this criterion was met.

TABLE 1

PHYSIOLOGICAL MEASURES OBTAINED FROM THE AEROBIC AND EXERCISE CONTROL SUBJECTS WHILE AT REST IMMEDIATELY BEFORE THEIR INITIAL TREADMILL TEST (BLOOD PRESSURE AND HEART RATE) AND WHILE THEY WALKED ON THE TREADMILL (MAXIMUM HEART RATE AND MAXIMUM MINUTE VENTILATION [V_E]

	Aerobic		Exercise Control		
	Mean	S.D.	Mean	S.D.	*t*-Value
Blood Pressure (mm Hg)					
Systolic	140.1	15.3	135.8	9.2	0.882
Diastolic	90.7	6.1	85.9	9.1	1.651
Heart Rate (BPM)					
At Rest	82.4	16.3	79.9	12.5	0.450
Maximum	148.0	12.8	147.5	12.6	0.110
Maximum V_E (L/min)	64.9	22.1	65.2	18.8	0.025
VO_{2max} (ml/kg/min)	19.4	5.7	22.5	5.1	1.507

The probability for each t-value was >0.10 (26 *df*).

A Group × Session ANOVA was computed on pre- and posttreatment VO_{2max} values for the two exercise groups. A significant treatment effect was found with VO_{2max} means being larger at the conclusion of the exercise programs, $F(1,26)=23.6$, $p<0.001$. While the groups were not different for combined pre- and posttreatment values ($p>0.10$), a significant interaction, $F(1,26)=4.89$, $p=0.036$, indicated a differential effect of type of training on VO_{2max} improvement. VO_{2max} increase for the experimental group was significantly greater than that for the exercise control subjects as determined by a t-test of VO_{2max} change, $t(26)=2.153$, $p=0.04$. VO_{2max} for the aerobically trained group increased by 27%, from 19.4 to 24.6 ml/kg/min, $t(12)=4.08$, $p<0.002$, and 9%, 22.5 to 24.5 ml/kg/min, for the exercise control subjects, $t(14)=2.40$, $p=0.04$. The greater improvement for the aerobic subjects was not the result of more training hours since, on the average, individuals in the exercise control group attended 3.9 more training sessions than did the aerobically trained subjects.

Analyses of variance on scores from pretest and posttest sessions (Group × Session ANOVAs) revealed that sensory thresholds and indices of depression were not significantly changed from initial values after the four month experimental period. Visual acuity, however, improved significantly, from 20/23 to 20/21 ($p<0.05$). A nonsignificant Group × Session interaction indicated that the improvement was common to all groups suggesting a learning effect for this particular test.

Aerobic exercise training, however, was associated with a significant improvement on most neuropsychological measures. The aerobically trained group demonstrated significant improvement on Critical Flicker Fusion, Digit Symbol, Dots Estimation, Simple Reaction Time, and Stroop tests (Table 2). Their improvement on Digit Span approached significance ($p=0.08$). Digit span forward and backward each improved by 0.5 digits. Performance of the control groups significantly improved for only one test each:

TABLE 2

PRE- AND POSTTREATMENT VALUES FOR EIGHT NEUROPSYCHOLOGICAL TESTS AND FOR THE EIGHT TESTS COMBINED

	Aerobic			Exercise Control			Nonexercise Control		
	Pre	Post	*p*	Pre	Post	*p*	Pre	Post	*p*
CFF (Hz)	38.2	39.4	=0.002	38.5	38.8	ns*	38.8	38.8	ns
Culture Fair IQ	97.6	100.1	ns	94.4	99.3	ns	85.5	92.1	=0.014
Digit Span	12.6	13.6	=0.080	11.9	12.3	ns	11.7	11.5	ns
Digit Symbol	54.8	61.0	<0.001	54.1	56.0	ns	55.1	55.4	ns
Dots (errors)	40.8	34.9	=0.020	42.3	33.1	=0.005	38.0	35.7	ns
Simple Reaction Time (msec)	199.2	182.6	=0.020	196.0	189.0	ns	188.7	185.1	ns
Stroop (sec)									
Interference	18.1	15.2	<0.001	18.7	18.2	ns	17.2	16.9	ns
Total	41.6	36.1	<0.001	41.0	40.2	ns	38.1	38.0	ns
Combined Tests (Std scores)	97.3	106.1	<0.001	96.5	100.6	=0.011	99.7	100.6	ns

Pre- and posttests, separated by a four month interval, were administered to older individuals who received aerobic or strength and flexibility training (exercise control) or did not participate in an exercise program (nonexercise control).

Probability values were based on *t*-tests for correlated means.

*Not significant.

Dots Estimation for the exercise controls and Culture Fair IQ for the nonexercise controls. No improvement in Choice Reaction Time occurred, either for groups combined or for individual groups ($p>0.10$).

An evaluation was made of overall neuropsychological test improvement. Pre- and posttest scores of the 43 subjects for each of the eight measures listed in Table 2 were converted to standard scores with a mean of 100 and a standard deviation of 15. Scores were inverted about the mean when necessary so that for all tests a higher score represented better performance. A mean of the pre- and posttest standard scores was calculated for each subject and a Group × Session ANOVA was computed on these means. Mean standard scores of the three groups (combined across sessions) were not different. Posttest means, for groups combined, were significantly larger than pretest means, $F(1,40)=43.7$, $p<0.001$. The Group × Session interaction was also highly significant, $F(2,40)=8.23$, $p=0.001$, indicating a differential pre- and posttest change in performance among the three groups. Evaluation of change for each group by *t*-test documented significant cognitive improvement for both the aerobic ($t=5.66$, $p<0.001$) and the exercise control ($t=3.52$, $p<0.01$) groups. Cognitive performance of the nonexercise control subjects did not reliably improve ($p>0.10$). Mean pre- and posttest standard score values are illustrated in Fig. 1.

A single factor ANOVA was computed on post- minus pretest differences in mean standard scores to determine if the improvement evidenced by the aerobically trained individuals was significantly greater than that of the control groups. A significant Group effect was obtained, $F(2,40)=7.95$, $p<0.002$. *Post-hoc* comparisons of differences among group means indicated that test performance of the aerobically trained subjects improved more than the performance of the exercise control ($p<0.05$) and the nonexercise control ($p<0.01$) groups. The control groups did not reliably differ from each other with respect to amount of pre-posttest change.

Additional analyses were performed to increase our understanding regarding the significant time savings demonstrated by our aerobically trained subjects on the Stroop Interference Test (Task IV, see Table 2). First, a Group × Sessions ANOVA was computed on Stroop Task I scores, speed of reading color words printed in black. Two significant effects were obtained (Table 3). Reading times for groups combined were faster for the postexercise than for the preexercise session ($p<0.02$). A significant interaction ($p<0.001$) indicated that the time saving was not equal across groups. Analyses by *t*-test showed that reading speed was increased only for the aerobically trained individuals; mean reading time for Task I declined from 6.2 to 5.7 sec ($p=0.004$; $p>0.10$ for the two control groups). Second, to determine if the time savings at posttesting for the aerobic subjects on Stroop Task IV was a result of improved speed of reading rather than a reduction of an interference effect, Task I pretest values were subtracted from Task IV pretest values; similar data were derived from posttest scores. The results of an ANOVA computed on these data are listed in Table 3. Again, pre- posttest differences were evaluated by *t*-test. A significant reduction in interference effect was observed for the aerobically trained individuals ($p<0.002$) but not for the two control groups ($p>0.10$) (see Fig. 2).

The three subjects in the aerobic group who smoked were compared with the remaining ten who did not smoke on pretreatment VO_{2max} and neuropsychological test values and on amount of improvement in VO_{2max} and neuropsychological function at posttreatment testing. Scores of the two groups did not differ appreciably.

DISCUSSION

Following a four month program of exercise training, physical fitness level and neuropsychological test performance of previously sedentary elderly individuals were clearly improved. That the subjects had been sedentary was documented by their level of physical fitness prior to the start of the exercise activities. On the basis of their VO_{2max} values,

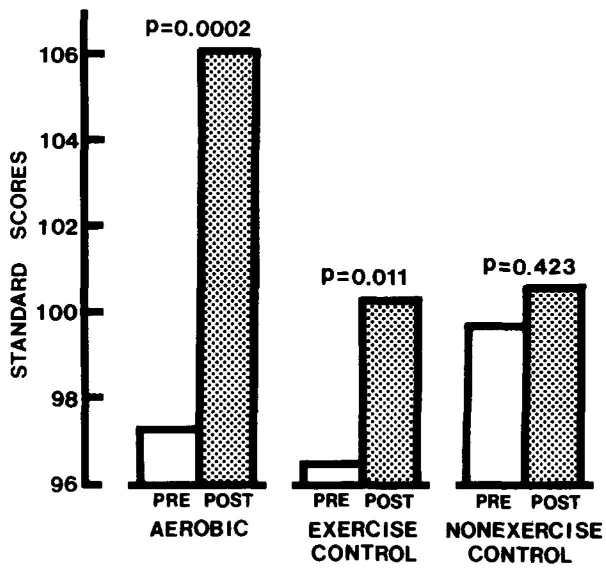

FIG. 1. Standard scores, averaged across the eight tests listed in Table 2 (see text), for three groups of older individuals: those who participated in an aerobic conditioning program (AEROBIC), in a program of strength and flexibility exercises (EXERCISE CONTROL), or who did not participate in an organized exercise program (NONEXERCISE CONTROL). Pre- and posttests were separated by four months. *p* (probability) values indicate significance of pre-posttest differences.

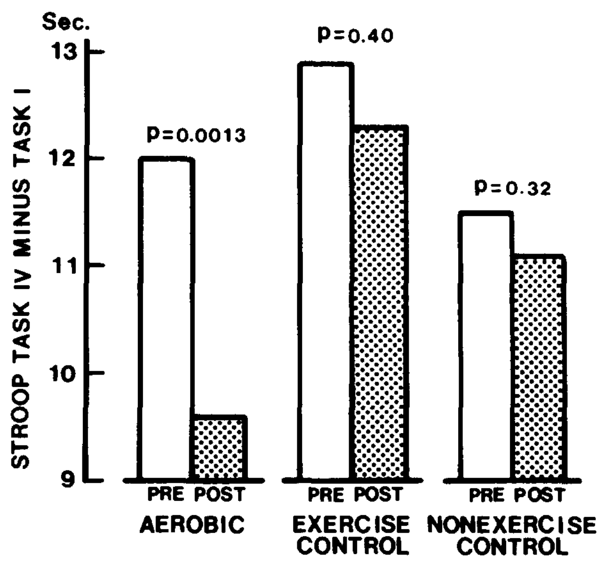

FIG. 2. The time to read a list of color names (Stroop Task I) was subtracted from the time required to name the colors in which color names were printed (Stroop Task IV, Interference test). This was done to determine if the improved scores at posttesting on the Interference test for the aerobically trained subjects were the result of improved motor ability. As illustrated, after Task I times were subtracted the aerobically trained subjects still demonstrated a significant pre- posttest time savings for Task IV. Note that this was not true for the control groups.

70% were rated as being in poor or very poor physical condition [19]; the remaining 30% were in fair condition. Our results strongly support the concepts that physically unfit elderly people can participate in a program of regular exercise at an intensity sufficient to significantly improve their physical fitness level [22] and that exercise can improve their mental as well as physical functioning.

Two complementary findings merit comment. The first is that on the average, both exercise groups improved on the neuropsychological tests, while the nonexercise control group did not. Moreover, the type of exercise was strongly related to the magnitude of test improvement. Subjects participating in aerobic activities, fast walking and some slow jogging, improved significantly more than those who did strength and flexibility exercises even though the latter subjects participated in slightly more exercise sessions. Differences in performance cannot be attributed to pre-existing differences between groups, as subjects were randomly assigned to the two types of exercise programs (resulting in equivalence between groups on all of the relevant measures) and training for both was administered by the same people.

The second relevant finding is that while groups differed in their mean scores, thus demonstrating an overall relationship between type of exercise and degree of cognitive improvement, that relationship did not hold up in analysis of individual scores. There was no correlation between posttreatment residual scores on the cognitive tests and posttreatment VO_{2max} residuals for either exercise group, where residuals were formed by partialling the pretreatment scores from the posttreatment scores. This finding is not surprising since our VO_{2max} measure, used to document exercise training effects, is not a measurement of regional oxygen consumption, rather it measures overall body oxygen consumption and is weighted more toward muscle than brain, e.g., the brain requires only about 20% of total body oxygen [52]. Since VO_{2max} is not specific for brain oxygen consumption and since there is no reason to expect that exercise related increases in oxygen to the brain would closely parallel increases to muscle, a direct relationship be-

TABLE 3

MEANS AND STANDARD DEVIATIONS (IN PARENTHESES) AND F AND *p* VALUES FROM GROUP × SESSION ANOVAs COMPUTED ON STROOP COLOR TEST TASK I SCORES (TIME IN SECONDS TO READ A COLUMN OF COLOR WORDS) AND ON TASK IV (INTERFERENCE TEST) SCORES AFTER TASK I SCORES HAD BEEN SUBTRACTED

	Task I	Task IV-Task I
Group		
Aerobic	5.92 (0.88)	10.76 (3.86)
Exer Cont	5.83 (0.69)	12.59 (4.40)
Nonexer Cont	5.77 (0.58)	11.31 (2.56)
F (2/40 *df*)	0.18	1.00
p	>0.10	>0.10
Session		
Pre	5.90 (0.74)	12.10 (3.48)
Post	5.77 (0.68)	11.07 (3.91)
F (1/40 *df*)	6.09	13.07
p	<0.02	<0.001
Group × Session		
F (2/40 *df*)	8.87	4.62
p	<0.001	<0.02

tween VO_{2max} and neuropsychological measures would not be predicted.

The pattern of results, i.e., improved neuropsychological function with no change in sensory threshold following aerobic conditioning, suggests that the effects of aerobic exercise were primarily on central rather than on peripheral mechanisms. The effects appeared to be widespread since improvement was observed for a variety of areas including the recall and reproduction of verbal and auditory materials, visuo-motor speed, critical flicker fusion threshold, and "mental flexibility," the ability to shift perceptual set as measured by Task IV of the Stroop Interference test [45].

As we were unable to monitor physiological changes that may have occurred in the brain as a consequence of our treatment procedures, we can only speculate that improved neuropsychological performance of our aerobically trained subjects occurred because of enhanced cerebral metabolic activity. There is reasonably good evidence that for average elderly people, those who do not experience unusually good health, brain perfusion and oxygen levels are reduced [31, 41, 62]. Oxygen is not only necessary for glucose metabolism at the cellular level but is an important substrate for turnover of neurotransmitters that are essential for cognitive and motor activities [3, 33, 61]. Neuropsychological test performance has proven to be sensitive to reduced levels of oxygen as demonstrated by impaired performance of young adults at altitude [47] and adverse altitude effects have been shown for some of the tasks used in the present study: critical flicker fusion threshold [59], digit symbol [30], memory [47], and response time [15, 38, 43]. The administration of oxygen to elderly subjects and to patients with chronic obstructive pulmonary disease has resulted in improved cognitive performance [9, 37, 39, 40], in the absence of recent memory loss [57] or other evidence of a dementing process [7, 44, 66].

As a result of the aerobic conditioning program VO_{2max} levels for our experimental group increased by 27%. The increase was 9% for the exercise control subjects who also demonstrated a reliable, although much smaller, increase in performance for combined neuropsychological tests. We suggest that the improved transport and utilization of oxygen was realized in brain as well as in other body tissues. An increase in cerebral oxygen might result in improved neuropsychological function because of increased turnover of neurotransmitters which are dependent upon oxygen for their metabolism. Hypoxia has been shown to cause a decline in acetylcholine metabolism [33] and oxygen is utilized directly for the synthesis and degradation of dopamine, norepinephrine (NE), and serotonin (5-HT) [33,34]. Each of these neurotransmitters has been implicated in human behavior and the functioning of each declines with approaching senescence [5].

Spirduso [63], reporting that the ability of rats to initiate fast movements was clearly related to nigrostriatal dopaminergic efficiency, suggested that chronic exercise can influence neurotransmitter systems. Direct evidence of this was provided by Brown and his colleagues [13,14]. They found an increase in whole brain levels of NE and 5-HT for rats which had participated in a running program designed to simulate middle distance running by humans.

It should not be surprising that mental function of older individuals can be improved since in recent years studies have documented that the "old" brain can be modified. For elderly rats housed in environments which provided for increased sensory and motor stimulation, the size and complexity of neuronal structures were increased, forebrains were larger and heavier, and cholinergic activity was enhanced [17, 18, 20, 58, 67]. These changes may have occurred because of increased perfusion and oxygenation of brain tissue. There is substantial evidence that movement, sensory stimulation, and even ideation results in an immediate increase of cerebral blood flow in activated cortical areas [29, 35, 42, 46, 54], with a concomitant flow increase in frontal association areas [36]. The physical activities associated with our exercise programs, in addition to improving aerobic efficiency, may have provided sufficient cortical stimulation to promote structural and functional change.

The fact that aerobic conditioning resulted in improvement for a variety of neuropsychological tests may indicate that this type of exercise affects processes underlying attention and concentration which in turn determine level of performance. Attention wanes during periods of hypoxia [53], perhaps due to a release of cortical inhibitory influence on the ascending reticular activating system [21,53]. On the basis of event related potential data, we have reported evidence of reduced inhibitory control in healthy elderly people which we speculated might be related to reductions in certain populations of cortical cells and to less efficient neurotransmitter systems [26, 27, 55].

The two depression scales were included in our battery of tests since it is known that there is a greater incidence of depression in the elderly [69] and that aerobic exercise may reduce level of depression [50]. For our subjects there was no change in scores of depression following four months of physical conditioning with aerobic or with strength and flexibility training, possibly because of their relatively good mental health. For example, none had scores on the Beck Depression Inventory which were as high as the mean score for a group of 127 patients rated by Beck *et al.* [4] as being mildly depressed. Morgan [50] stated that while regular physical exercise reduces depression scores of depressed individuals, scores do not change for those who are not initially depressed. A correlation of Beck Depression Inventory with Self-rating Depression scale scores of our 43 subjects was 0.72 ($p<0.001$).

In summary, we report that following a four month protocol of aerobic exercise training, performance of previously sedentary older individuals on a variety of neuropsychological tasks was significantly improved. These tasks purportedly measured response time, visual organization, memory, and mental flexibility. We suggest that improved neuropsychological performance of the aerobically trained group occurred as a result of enhanced cerebral metabolic activity. However, validation of our hypothesis must await research which employs modern noninvasive techniques to measure cerebral metabolism before and after an aerobic exercise training program.

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