Effects of a Quantitated Physical Training Program on Middle-Aged Sedentary Men

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SUMMARY

The effects of a 15-week quantitated training program were evaluated in nine men, 32 to 59 years old. All had been blind for 10 years or more but were otherwise in good health. They were sedentary with a stable activity pattern. Training sessions were held three times per week and consisted of four 3-minute exercise periods on a bicycle ergometer, each followed by a rest period of equal duration. Heart rates at the end of the fourth exercise period averaged 27 beats below individual maximal heart rates.

Maximal oxygen uptake increased from 24.0 to 28.5 ml/kg x min or by 19%. Total heart volume and mean serum cholesterol decreased significantly, and psychological tests showed improvement.

Five subjects continued exercising at the same intensity but only once weekly for another 14-week period. Mean maximal oxygen uptake decreased to 6% above the control level. Four subjects who discontinued training after 15 weeks were retested at the same time and had a mean value 5% below control maximal oxygen uptake.

Additional Indexing Words:
Interval training  Physical work capacity  Maximal oxygen uptake  Heart rate
Heart volume  Mechanical efficiency  Serum lipids

Physical training is now widely used in the treatment of angina pectoris and as a preventive measure against coronary heart disease. The literature on the effects of training in various groups of patients and normal subjects is rapidly expanding, but sufficient information to provide a firm basis for exercise prescriptions is not available.

Studies on the effect of training programs characterized in detail with respect to type of activity, duration, frequency, and intensity of exercise are clearly needed, particularly from groups with low initial levels of physical fitness. However, strict control of a training program is difficult to accomplish in a normal, free-living population.

Few studies2-7 on the effect of physical training in middle-aged and older sedentary men have included direct measurement of changes in maximal oxygen uptake (V̇O₂max). Maximal oxygen uptake is the product of maximal cardiac output and arteriovenous oxygen difference and reflects both the performance of the heart as a pump and the efficiency of distribution of blood flow.8 V̇O₂max has been widely accepted as an index of the functional capacity of the circulatory system and of aerobic physical work capacity. Measurements may be repeated at frequent intervals since the technic is noninvasive. Thus, V̇O₂max constitutes a relevant and convenient standard by which the effect of a physical training program may be judged.

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It was suggested by Lamm\(^9\) that blind subjects may constitute an ideal experimental group since they are restricted to a low level of physical activity and to a stable pattern of life. In the present study a group of middle-aged men who all had been blind for many years was recruited. A simple, closely monitored program of interval-training type was administered; that is, exercise sessions consisting of repeated short periods of relatively heavy exercise with intervening short rest periods. An attempt was made to gain specific information on the amount of training required to produce and to maintain a significant increase in maximal oxygen uptake. A preliminary report of this study has been presented.\(^10\)

**Methods**

**Subjects**

Nine male subjects from the Dallas Lighthouse for the Blind were studied. The group was interviewed in August 1967. The details of the proposed study were carefully explained to each man.

Basic data on age, weight, height, and the duration and etiology of blindness of each subject are given in table 1. The age of the subjects ranged between 32 and 59, with a mean age of 46. They had been restricted in their physical activity for at least 10 years because of blindness. A medical history was obtained, and a physical examination was carried out by an independent physician at the beginning of the study. All subjects appeared to be in good health except for their blindness and a slightly elevated diastolic blood pressure (92 to 100 mm Hg) in subject TC. None of the men had diabetes.

**Laboratory Determinations**

Methods for measurements of maximal oxygen uptake, blood lactate, hemoglobin, hematocrit, serum cholesterol and triglycerides, and for recording of the Frank lead ECG have recently been described in a report from this laboratory.\(^11\) Total heart volume was calculated according to the formula given by Larsson and Kjellberg\(^12\) from biplane radiographs taken simultaneously with the x-ray tubes at 90° angles and the subject in the prone position. Measurements of cardiac diameters were made independently by three observers and averaged.

A standard psychological test (Minnesota Multiphasic Personality Inventory, MMPI)\(^13\) was administered. Questions were prerecorded and answers recorded on magnetic tape during the control and post-training periods. Exercise during testing and physical training was performed on a mechanically braked bicycle ergometer.\(^*\) Bicycle ergometer work loads were measured in kilopond meters per minute (kpm/min). One kilopond is the force acting on the mass of 1 kg at normal acceleration of gravity. One hundred kilopond meters per minute equal 723 foot pounds per minute, or 16.35 watts. Standard pedaling rate was 50 rpm. Actual rpm counts were recorded mechanically.

Each submaximal work period lasted 6 minutes and the maximal run 3 to 6 minutes. The subjects rested 5 to 10 minutes between initial submaximal work loads and 20 to 30 minutes before the maximal run. A warm-up period of 1 to 2 minutes at the second submaximal work load immediately preceded the maximal run. Collection of expired air for measurement of oxygen uptake at submaximal loads was started after 5 minutes of exercise and completed within 1 minute. Duplicate measurements of the oxygen uptake were made at

\(^*\)Cykelfabriken Monark, Varberg, Sweden.
QUANTITATED PHYSICAL TRAINING PROGRAM

maximal levels. Expired air was collected over 30-second periods. Maximal oxygen uptake was established by the criterion of leveling of the oxygen consumption with increasing work loads. Age-specific maximal heart rates for normal subjects and postexercise lactic acid levels were used as ancillary criteria to establish that a true maximal level had been reached. The laboratory was air conditioned, and the temperature varied between 20 and 23°C.

The ECG was continuously monitored during exercise and recovery. A Frank lead ECG was recorded during the last minute of exercise, immediately after, and 3 minutes after exercise.

Experimental Design

Control studies were carried out over a 3-month period. The response to submaximal and maximal exercise was studied in each subject on three separate occasions with intervals of approximately 6 weeks. Blood chemistry and radiological and psychological studies were made at the initial visit to the laboratory.

All nine subjects took part in the training program during the first 15 weeks. Results after 7 weeks were evaluated by measurement of maximal oxygen uptake and heart rate during submaximal and maximal exercise. After 15 weeks' training the subjects underwent the full complement of tests performed during the control period. Maximal oxygen uptake was determined twice on separate days.

The subjects were then arbitrarily divided into two groups. One group (first five men in tables 1 and 2) continued to exercise but only once per week as compared to 3 times weekly initially. The second group (four men) discontinued training.

Both subgroups were restudied after 14 weeks of this regimen, that is, 29 weeks after the beginning of the intervention.

The training program during the first 15 weeks was aimed at production of an increase in maximal oxygen uptake. The reduced frequency of training sessions in the five men who exercised during the final 14 weeks of the study represented an attempt to define the minimum amount of exercise required to maintain an improved $\dot{V}_{O_2max}$.

Paired $t$-tests were used to evaluate the results.

Training Program

The format of the training sessions was kept the same throughout the study and may be characterized as interval training. The exercise room was not air conditioned. Room temperature varied between 21 and 28°C. Each session was supervised by one of the authors and consisted of four periods of bicycle ergometer exercise, each lasting for 3 minutes and followed by a 3-minute rest period. The ECG was continuously displayed on an oscilloscope for monitoring and recorded during the last 15 seconds of each work and rest period (fig. 1). A simple transthoracic bipolar ECG lead was used. Heart rate at the end of the fourth 3-minute period of interval exercise was used as an indicator of the intensity of work. Maximal heart rates varied widely within the group. The heart rate during the final 15 seconds of exercise at each session was therefore measured in terms of beats below individual maximal heart rate rather than as absolute values in order to provide a more precise index of relative load. Average heart rate data representing the intensity of exercise for each training session are presented in figures 1 and 2 and table 2.

Work loads were adjusted during the course of the experiment to produce a heart rate at the end

Figure 1

Format of all training sessions with mean heart rates (circled numerals) during the last 15 seconds of each exercise and rest period. Heart rate data based on complete sets of measurements in all subjects during all sessions of the 15-week training program.

Figure 2

Relative changes in mean maximal oxygen uptake (in per cent of mean control value) related to duration, frequency, and intensity of training. Each bar in the lower panel represents a training session, and the height indicates the beats below maximal heart rate during the last exercise period of each session (cf fig. 1). The broken line represents the subgroup of four subjects who discontinued training after 15 weeks.
### Table 2

**Bicycle Ergometry: Maximal Oxygen Uptake, Maximal Heart Rate (HR\(_{\text{max}}\)), Maximal Work Capacity (W\(_{\text{max}}\)), Work Load at Heart Rate 130 (W130), and Intensity of Training**

<table>
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<th>Subject</th>
<th>No.</th>
<th>(\dot{V}_\text{O}_2) max (L/min)</th>
<th>HR(_{\text{max}}) (beats/min)</th>
<th>W(_{\text{max}}) (kpm/min)</th>
<th>W130 (kpm/min)</th>
<th>Training intensity (HR(<em>{\text{max}}) - HR(</em>{\text{work}}))^a</th>
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*HR\(_{\text{work}}\)* is the heart rate at which work load is performed.
Quantitated Physical Training Program

The fourth exercise period within 20 to 30 beats of maximal heart rate of each subject. Somewhat lighter loads were used in subject TC because of diastolic hypertension during exercise and in subject LL because of frequent premature ventricular beats occurring during heavy exercise. Average final heart rates during exercise in these two men were 39 and 35 beats per minute below the maximal level. The group average was 29 beats below maximal heart rate during the first 7 weeks of training. Corresponding figure for the following 8 weeks was 24. This difference, implying a higher intensity of training during the second period, was significant (P < 0.01). The five subjects who continued to meet once weekly during the last 14 weeks of the study after the group was divided had an average final heart rate during exercise of 17 beats below their maximal level. This did not represent a significant change as compared to their heart rates during the first 15 weeks.

During the initial 15 weeks the group met three times weekly. Mean attendance rate for the group was 2.6 times per week (range of individual averages 2.4 to 3.0). The five subjects who continued to exercise after this period met once weekly for 14 weeks with a mean attendance rate of 0.9 time per week (range 0.6 to 1.0).

Results

Maximal Work

Changes in mean maximal oxygen uptake values are displayed in figure 2. The relation between individual changes in VO2max and age is presented in figure 3. Table 2 gives detailed individual data.

Mean maximal oxygen uptake was 1.63 L/min or 24.0 ml/kg × min for the nine subjects at the control study. The mean difference between repeated determinations of VO2max during the 3-month control period was 0.04 ± 0.005 L/min, with a standard deviation of 0.02 L/min.

The initial 7 weeks of triweekly training sessions resulted in an increase in mean VO2max to 1.79 L/min and 26.5 ml/kg × min, or to 10% above control levels. Mean maximal uptake was 1.94 L/min or 28.5 ml/kg × min at the end of the 15-week period of triweekly exercise, representing an increase of 19% above control levels. Thus, the rate of improvement was nearly equal during the first and second halves of the conditioning period. The increase in VO2max resulting from an average of 30
minutes of actual exercise per week for 15 weeks was highly significant ($P < 0.001$).

The 14-week maintenance regimen in five men, consisting of only one session per week, resulted in a decrease in $\dot{V}_{O_{2max}}$ to a mean value only 6\% above the control level (fig. 2). The four men who did not exercise during the final 14 weeks had a mean $\dot{V}_{O_{2max}}$ 5\% below their control level at the end of the study.

Mean maximal heart rate in the nine men was 167 during the control period, 165 after 7 weeks, 169 after 15 weeks of triweekly exercise, and 164 after the final 14 weeks of once weekly or control level activity. These differences were not significant.

Peak lactic acid levels of arterialized fingertip blood after maximal work were similar at each test session. Mean concentrations were 109, 104, 113, and 100 mg/100 ml. The differences were not significant.

Maximal work load data are presented in table 2. Average duration of work at the maximal level, 3.5 min, did not change. The average maximal work load during the control period was 626 kpm/min and increased to 790 kpm/min after 7 weeks of triweekly exercise. Mean maximal work load was 869 kpm/min at the end of 15 weeks of conditioning, representing an increase of 243 kpm/min or 39\% above control levels. This difference was highly significant ($P < 0.001$) and larger than the change in $\dot{V}_{O_{2max}}$.

A dissociation between changes in maximal work load and in $\dot{V}_{O_{2max}}$ was also evident when mean maximal work loads were calculated separately for the two subgroups with different regimens during the last phase of the study. The group of five men who continued exercising during the final 14 weeks had reached a mean maximal work load of 796 kpm/min or 44.5\% above the control level after the initial 15 weeks of training. The maximal load decreased to 733 kpm/min after 14 weeks of exercise only once per week or a final maximal load 33\% above the control value. Corresponding figures for the group of four men who did not train during the last 14 weeks were 959 kpm/min at the end of conditioning and 843 kpm/min at the end of the study or 17.4\% above their control value.

**Submaximal Work**

The submaximal work load required to produce a heart rate of 130 beats/min ($W_{130}$) was calculated from individual work load-heart rate points. The difference between the control and final submaximal work load was 75 kpm/min, 22.5\% higher than the end of the study and 30 kpm/min, 19.3\% above the control value.

![Figure 3](image-url)

*Figure 3*

Individual changes in maximal oxygen uptake related to age. Subject identification (within the circle indicating maximal oxygen uptake at the control study) as in table 1.

![Figure 4](image-url)

*Figure 4*

Relative changes in the work load required to produce a heart rate of 130 beats/min during the sixth minute of exercise. Mean work loads are given for the total group for the studies performed during the control period and after 7 and 15 weeks of training. Separate mean control and final values (far right) are listed for the subjects who discontinued training after 15 weeks (broken line) and subjects who continued to exercise once weekly.
rate data by interpolation. Results are presented in table 2 and figure 4. Mean W130 was 357 kpm/min during the control period, 500 kpm/min after 7 weeks of triweekly exercise, and 516 kpm/min after 15 weeks. The increase of W130 to 44.6% above control levels after 15 weeks was highly significant ($P < 0.001$). Less work was required to reach W130 after 14 weeks of either no conditioning or once weekly exercise. The heart rate of the men who continued once weekly exercise had declined to a mean W130 of 30% above control levels. The four subjects who did not exercise showed a decrease in mean W130 to 34% above their control W130. Thus, changes in W130 reflected changes in $V_{O_2max}$ even less accurately than changes in maximal work load.

**Heart Volume**

Total heart volume was measured in seven of the nine subjects from biplane radiographs taken during the control period and after 15 weeks of triweekly exercise. Data are presented in figure 5. The x-rays were of poor technical quality in RW and were not available after conditioning in JP.

Heart volume decreased in all seven subjects during conditioning from a mean of 980 to 895 cc ($P < 0.05$).

**Electrocardiograms**

The analysis of Frank lead electrocardiograms at rest and during exercise did not show any abnormalities in six of the nine men. Horizontal ST depression of 0.05 mv or more was present during maximal exercise in subjects DA, LL, and TC. TC also developed frequent premature ventricular contractions during maximal work. These ECG changes were not altered by physical training.

**Other Measurements**

Mean total body weight did not change significantly during the study. The largest individual changes noted during triweekly exercise were gains of 2.2 kg each in subjects LL and DA.

Mean serum cholesterol levels decreased significantly ($P < 0.01$) from 247 mg/100 ml to 210 mg/100 ml during the initial 15 weeks of training. Mean triglyceride levels also declined from 137 mg/100 ml to 82 mg/100 ml; however, this change was not significant.

The subjects experienced a uniform subjective improvement in mood during training. The group mean scores for the Minnesota Multiphasic Personality Inventory are summarized.

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**Figure 5**

Maximal oxygen uptake in relation to total heart volume. Filled circles denote individual values before and open circles values after 15 weeks’ training. Regression equations based on data from Astrand and co-workers$^{21}$ (young men, top line) and from Blomqvist and Stenberg$^{16}$ (middle-aged men, bottom line). $Y = \text{maximal oxygen uptake in liters per minute, and } X = \text{total heart volume in milliliters.}$

**Figure 6**

Group mean T scores before (solid line) and after training (broken line), Minnesota Multiphasic Personality Inventory.
Discussion

The results of this study are in keeping with the contention that blindness of long standing is associated with a stable and low level of habitual physical activity that results in a low maximal oxygen uptake. The mean control $\dot{V}O_{2\text{max}}$ value of 24.0 ml/kg × min is lower than values reported from other groups of sedentary men in the same age range.4–7,15 This difference probably reflects a more severe limitation of the level of physical activity among men who are restricted by blindness rather than being sedentary by choice. Only one subject had $\dot{V}O_{2\text{max}}$ above 31 ml/kg × min. Variations in $\dot{V}O_{2\text{max}}$ during the 3-month control period were small. Furthermore, the rapid return to control levels in the group who stopped training after 15 weeks supports the view that the training program represented an isolated change in the subjects' physical activity pattern. There is no evidence that the low $\dot{V}O_{2\text{max}}$ was related to clinical cardiopulmonary disease in any of the men. The appearance of asymptomatic horizontal ST-segment depression during maximal work in one third of the men during heavy exercise parallels the findings of other studies.16,17 Serum lipids were within normal limits.

The discrepancy between changes in $\dot{V}O_{2\text{max}}$ and changes in maximal work load and W130 is larger than expected and may reflect an unusually large increase in mechanical efficiency during training of this population. No measurements of oxygen uptake at submaximal work loads were made, but the combination of data on external work performed at the maximal level and the lack of significant changes in work time and lactic acid concentration after maximal work indicates an improvement in mechanical efficiency that was retained past the point of decreasing $\dot{V}O_{2\text{max}}$ during the final phase of the study.

Five of seven studies on physical training in sedentary middle-aged and elderly men,
including our own (table 3), show remarkably similar results, that is, an increase in $V_{O2\text{max}}$ from 16 to 19%. The results of the two studies dealing with 70-year-old men are divergent. Benestad\textsuperscript{2} was unable to demonstrate any training effect on $V_{O2\text{max}}$, whereas Barry and co-workers\textsuperscript{3} reported a large increase, 38%. The lack of trainability shown in the report by Benestad\textsuperscript{2} may have been related to the short training period, initial level of fitness, and low intensity of exercise during training, or it may reflect a true age difference. The results reported by Barry and co-workers\textsuperscript{3} may at least be partially explained by the data obtained in the control period. Significantly lower peak heart rates and blood lactic acid levels at the control study suggest that the subjects did not reach a true maximal oxygen uptake before training.

The degree of similarity between our study and those by Hartley,\textsuperscript{5} Naughton,\textsuperscript{6} Hanson,\textsuperscript{4} Mann,\textsuperscript{7} and their co-workers may be fortuitous. There is evidence from studies of both young\textsuperscript{11} and middle-aged\textsuperscript{8} men to suggest an inverse relation between the relative change in $V_{O2\text{max}}$ and initial $V_{O2\text{max}}$. This trend was not apparent in our series. The control level was uniformly low, but the groups listed in table 3 cover a wide range. Average initial $V_{O2\text{max}}$ varies between 40 ml/kg x min in the group studied by Hartley and associates\textsuperscript{5} and 24 ml/kg x min in our series.

It seems reasonable to postulate that the number of sessions per week, the total duration of training, the effective duration of each session, and the intensity of exercise influence the degree of improvement. The number of training sessions per week was the same in four of the series compiled in table 3 with a variation in the total duration of training from 8 to 28 weeks. The group studied by Mann and co-workers\textsuperscript{7} trained 5 days per week for 6 months. The average rate of improvement in $V_{O2\text{max}}$ in our own series was approximately equal during the first and second halves of the conditioning program, suggesting that a longer period of training may have produced a larger increase in $V_{O2\text{max}}$. The effective duration of each session in the five series ranged from 12 to 60 minutes. Sufficient data on the intensity of work to permit a meaningful comparison are not available. Bidirectional variations with respect to duration and intensity may be responsible for equalization of the results.

Data from the literature and from our study offer some support for an alternate hypothesis. The dose-response curve characterizing the relation between the quantity of training and the improvement in $V_{O2\text{max}}$ may be hyperbolic (S-shaped) with virtually no improvement in $V_{O2\text{max}}$ below a certain threshold quantity of training and rapidly diminishing returns once a critical level has been exceeded. The quantity of training may in turn be a nonlinear function of intensity, frequency, duration of session, and duration of program, but lack of data makes it impossible even to approximate this function. A threshold effect has been demonstrated with respect to the intensity of training measured as heart rate during exercise. The critical level approximately corresponds to resting heart rate plus 60% of the difference between resting and maximal heart rates\textsuperscript{19-20} or about 130 beats/min in the age group 40 to 50. Furthermore, Mann and associates\textsuperscript{7} found no significant difference in the degree of improvement between subjects who had an attendance record of 50 to 79% and those who participated in 80 to 100% of their available five sessions per week over 6 months. Once-weekly half-hour sessions with caloric expenditures varying as widely as from 300 to 1,175 proved equally effective in maintaining the improvement in $V_{O2\text{max}}$. Consistent with the hypothesis also is the fact that training 2.6 times per week for an effective total of 30 minutes resulted in a significant increase in $V_{O2\text{max}}$ in our series, but 0.9 session per week or 10 effective minutes failed to maintain the improvement.

Previous studies\textsuperscript{11} have demonstrated that the increase in $V_{O2\text{max}}$ after training in sedentary normal young subjects is due to both an increase in maximal stroke volume and a widening of the maximal arteriovenous oxygen difference. Hemodynamic data from the series studied by Hartley and associates\textsuperscript{5} sug-
systolic middle-aged men may be attributed solely to an increase in maximal stroke volume. Cross-sectional studies have shown that there is a linear relation between total heart volume and maximal oxygen uptake in both young and middle-aged normal men (fig. 5). Changes in total heart volume closely paralleled changes in stroke volume, cardiac output, and maximal oxygen uptake in a series of five young normal subjects studied in this laboratory after bed rest and after physical training. A significant decrease in total heart volume after training is surprising in the present series of middle-aged men against this background, but similar results have been reported from a study of a comparable group. However, Mann and associates found an increase in heart volume after training, and Hartley’s group reported no significant change. X-rays for determination of total heart volume were taken with the subject in the prone position to minimize measurement errors and to conform to previous studies relating heart volume to physical performance.

The decline in mean serum cholesterol values after conditioning was small but significant, whereas the decrease in mean serum triglyceride levels was variable. Other investigators have found more reduction in triglyceride levels than in cholesterol. On the other hand, Mann and associates reported a decrease in cholesterol and an increase in triglycerides after training. It should be noted that the decrease in serum cholesterol occurred without any loss in total body weight. The possibility that the fall in serum cholesterol reflected seasonal changes cannot be excluded. Control samples were drawn during September and October, and the training phase was concluded during May.

The psychological improvement after conditioning may be related to several factors in the study, for example, the medical and personal attention that the subjects received. The men were able to improve their self image as a result of this factor, and they also realized that their work capabilities were improving. Therefore, the effect of increased physical work capacity on mood and anxiety cannot be evaluated independently. Similar changes in MMPI factors have also been reported by Hellerstein and associates after training in patients with clinical coronary disease.

The subjects tolerated the interval training program quite well, with only trivial muscular pain during the first week of the program. This is in keeping with the current concepts that interval training technics allow heavy central circulatory loading without producing progressive skeletal muscle metabolic changes. The appeal of pedaling a bicycle indoors may be limited. Many subjects will undoubtedly find it boring to use only one type of exercise and one particular pattern. On the other hand, the program requires a minimum of time and is extremely simple to administer and monitor. The general pattern of activity may be applied to any type of exercise involving large muscle groups.

References


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