Strength Training Improves Submaximum Cardiovascular Performance in Older Men

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ABSTRACT
Purpose: To determine if 16 weeks of strength training can improve the cardiovascular function of older men during submaximum aerobic exercise. **Methods:** Twenty four men aged 70-80 yr were randomly assigned to a strength training (ST; n = 12) and control group (C; n = 12). Training consisted of 3 sets of 6 - 10 repetitions at 70% to 90% of 1RM, 3 times per week, on an incline squat machine for 16 weeks, followed by 4 weeks detraining. Leg strength and maximum oxygen consumption (VO_2 max) were assessed every 4 weeks of the 20-week study. Cardiovascular function was assessed during submaximum cycle exercise at 40 Watts, 50% and 70% of VO_2 max before training, after 16 weeks training, and after 4 weeks detraining. **Results:** At 40 Watts, heart rate (HR), systolic blood pressure, and rate pressure product (RPP) were lower and stroke volume (SV) significantly higher after 16 weeks training and 4 weeks detraining: at 50% VO_2 max, HR and RPP were lower after 16 weeks training and 4 weeks detraining: at 70% VO_2 max, cycle ergometry power, VO_2 and arterio-venous oxygen difference ($a - \bar{v}\,O_2$) were higher after 16 weeks training. Leg strength and VO_2 max increased after 16 weeks training, with leg strength remaining above pre-training levels after 4-weeks detraining. **Conclusions:** Sixteen weeks of strength training significantly improves the cardiovascular function of older men. Therefore strength training not only increases muscular strength and hypertrophy but also provides significant cardiovascular benefits for older individuals.

Key Words: cardiovascular function, older men, strength training, submaximum exercise

INTRODUCTION

It is well established that progressive strength training in older individuals provides a mechanism to help reduce the effects of sarcopenia and loss of muscular strength associated with aging.[1] While there are also a number of other benefits that strength training provides older individuals,[2] the effects of strength training on cardiovascular function during dynamic exercise are not well understood.

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Traditionally improvements in VO_2 max and submaximum endurance are seen as regular consequences of aerobic training, having both central and peripheral changes associated with an increase in cardiovascular endurance.[3] There is growing evidence that strength training may produce changes in the metabolic quality of skeletal muscle which may, in turn, increase the aerobic capacity of strength trained individuals.[4,5] Indeed a recent examination of high intensity interval training found significant improvements in VO_2 max, with the increase in VO_2 max being driven by peripheral changes within the muscle.[6] Support for an increase in aerobic capacity of skeletal muscle in older individuals after a period of strength training is increasing.[7,8] While the cross transfer of physiological effects from strength training to aerobic capacity are encouraging, few studies have examined the cardiovascular response of submaximum aerobic exercise after a period of strength training. Significant increases in submaximum treadmill walking time have been reported after 12 weeks of strength training in older men and women, however, changes in VO_2max, and heart rate and systolic blood pressure measured during submaximum walking did not reach statistical significance. [9] Similar results have been reported elsewhere after a period of strength training[10-12] with no significant changes in VO_2 max or other cardiovascular measures during maximal and submaximum exercise despite significant increases in muscular strength.

While VO_2 max is a recognized measure of cardiovascular fitness, few individuals of any age regularly exercise or perform daily activities at VO_2max intensity. Therefore examining the cardiovascular response to submaximum aerobic exercise may be a more relevant measure of activities of daily living and relate to the health and function of older individuals than changes in VO_2max alone. Such information is important as the submaximum capacity most closely reflects the everyday living activities of older persons.[13]

While the benefits of strength training on improvements in muscular strength of older individuals are well established, the effect of strength training on the cardiovascular response to submaximum exercise is less clear. The purpose of this study was to measure the cardiovascular responses to submaximum aerobic exercise in men aged 70 to 80 years after 16 weeks of strength training.

METHODS

Participants

Participants were recruited through advertisements placed in local newspapers and consisted of healthy men aged between 70 and 80 years. Respondents to the newspaper advertisement completed a physical activity readiness questionnaire (“PAR-Q”) by telephone interview. Those respondents with a history of cardiovascular or respiratory disease, diabetes, orthopedic injuries or other medical conditions which contraindicated vigorous exercise, were excluded from further participation. Following the initial telephone interview, each potential respondent attended the laboratory on 3 separate occasions for further screening and familiarization with the study protocol. On these occasions, participants: (1) were provided with an information sheet setting out details of the experiment, (2) completed a medical history questionnaire, (3) had spirometry testing and a resting 12 lead electrocardiogram (ECG).

After a clear explanation of the project, including the risks and benefits of participation, written consent was obtained. Participants then underwent a detailed medical examination and an incremental exercise test, with direct medical supervision, to volitional fatigue on a cycle ergometer. As a result of the familiarisation and screening process, each participant selected for the study: (1) was clinically free from known cardiovascular and respiratory disease, (2) was not taking any medication known to interfere with the exercise response, (3) had normal spirometry and a resting 12 lead ECG, (4) had resting blood pressure of less than 150/90 mmHg, (5) had no evidence of clinically significant exercise induced myocardial ischemia.

Subsequently 24 older men who were moderately active with walking and gardening as their main activities but not participating in regular physical activity were selected to participate in the study. Participants were randomly assigned to either a strength training group [ST; n=12; mean age 74.1 (2.7) years; height 177.8 (4.8) cm; weight 79.4 (14.2) kg] or a nontraining control group [C; n=12; mean age 73.5 (3.3) years; height 177.0 (5.0) cm; weight 78.9 (11.3) kg].There were no significant difference between the 2 groups at baseline. The study was approved by the Griffith University Ethics Committee and written informed consent was obtained from all participants.

Experimental Design

The 20-week study consisted of 16 weeks of training and a 4-week detraining period. All participants were assessed for lower extremity strength (1RM), submaximum exercise response and VO_2max before and after 16 weeks of training and after the 4 week detraining period. Lower extremity strength and VO_2max were also tested every 4 weeks during the 16 weeks of training in both the test and control groups. Participants were advised to maintain their normal daily routines and eating habits and to refrain from beginning any new exercise program during the study. A diet and training log was kept by each participant for the duration of the study to ensure compliance.

Training Protocol

The 16-week training protocol consisted of training the lower extremities 3 times per week in nonconsecutive days with each session lasting approximately 25 minutes. Each participant was trained individually by the author on an incline squat machine (Body/Solid Inc., Broadview, Ill, USA). We used the incline squat as the training modality as squatting has been shown to stimulate greater gains in functional strength than other leg strengthening exercises such as leg extensions and leg press.[14] Each session consisted of a 5-minute warm-up on a cycle ergometer (Monark 828E) at 30 Watts followed by 5 minutes of quadriceps and hamstring stretching. Participants also completed 5 minutes of stretching at the end of each training session. The warm-up period was followed by 1 set of 10 repetitions at 50% of each participant's training load. A training intensity of 3 sets of 8 repetitions at 50% of 1 repetition maximum (1RM) was selected for the first 2 weeks of training to maximize participant safety and compliance. Training intensity was increased to 3 sets of 6 to 10 repetitions at 70% to 90% of 1RM in the third week of training and training continued at this intensity until the sixteenth week of training. Based on the results from the 4 weekly repeated measurements, absolute increments in the training load were added during the 16 weeks to maintain the participants' training intensity at 70% to 90% of 1RM. All sets throughout training were separated by 2 minutes of recovery time.

Strength Measurement

One repetition maximum (1RM) strength testing was assessed on the incline squat machine using standardized procedures as described previously.[15] All participants attended 2 familiarization sessions before the start of the study to reduce the risk of injury and muscle soreness during training and testing. Variations in strength values from test-retest measurements on the incline squat machine are less than 5%.

VO_2 max Measurement

Each participant performed an incremental exercise test,[16] using a continuous ramp protocol, to volitional fatigue on an electronically braked cycle ergometer (Excalibur Sport V2.0, Groningen, Netherlands). The exercise test began with a 3-minute warm-up period at 15 W, after which the power was incremented by 5 W every 20 seconds until volitional fatigue or the onset of clinical signs or symptoms that precluded further exercise. Percentage of expired oxygen and carbon dioxide were measured using a fast response zirconia transducer oxygen analyser and infrared transducer carbon dioxide analyser (Exerstress). Maximal values for oxygen consumption were calculated from the average of the last minute of exercise before volitional fatigue. The highest heart rate, power, and ventilation achieved at volitional fatigue were considered to be maximal values. A true VO_2 max was considered to be attained if 2 of the following 3 criteria were met: 1) a plateau in VO_2 (A plateau was defined as an increase in VO_2 of less than or equal to 2 ml $\cdot$ kg^{-1} $\cdot$ min^{-1} or 0.15 L$\cdot$ min^{-1} between 2 or more consecutive 1-min workloads in the final part of the exercise test), 2) respiratory exchange ratio >1.15; and 3) maximal heart rate (10 beats/min of age-predicted maximum (220 minus age).

Cardiac Function

Cardiac function was assessed using the acetylene re-breathing method described by Triebwasser[17] to estimate cardiac output (Q). The acetylene re-breathing maneuver was commenced with the participant connected to the open circuit compartment of the mouthpiece system. An evacuated re-breathing bag was filled with a volume of gas mixture containing 0.9% acetylene, 9.9% helium, 40% oxygen and a balance of nitrogen. The gas mixture was re-breathed 8 to10 times for approximately 15 to 20 seconds. The gas mixture was continuously sampled from the mouthpiece via a small bore sampling line. The concentration of the helium and acetylene was measured using an Airspec Model 3000 mass spectrometer.

Submaximum Exercise Testing

Approximately one week following the incremental exercise test, each subject undertook a cycle ergometer exercise test to determine the power output corresponding to 50% and 70% VO_2 max. Two days following the tests to determine relative exercise intensity, participants underwent submaximum exercise testing. The submaximum exercise responses were measured during 30 minutes of continuous exercise on an electronically braked cycle ergometer at three 10-minute submaximum exercise intensities (30W or 40W, 50% and 70% VO_2 peak). At each exercise intensity, Q was measured on 2 occasions, with the first measurement occurring after 4 minutes of cycling and the second occurring after 9 minutes of cycling to allow for the washout of C_2H_2 from the previous measurement of Q.

Oxygen uptake and heart rate were measured in the minute prior to the measurement of Q with the average Q, VO_2, and heart rate (HR) from the 2 measurements used for each exercise intensity. From the determination of Q, HR, and VO_2 the following calculations were made:

1) Stroke volume (SV) = Q / HR expressed as $mL \cdot beat^{-1}$
2) arterio-venous oxygen difference (a-$\bar{v}$ O_2 diff) = VO_2 / Q expressed as $mLO_2 \cdot 100mL^{-1}$

Blood pressure (BP) using a calibrated sphygmomanometer (Baumanonmeter) was recorded on 2 occasions during each exercise intensity. Thirty seconds prior to Q measurement, blood pressure was recorded by manual auscultation. From the determination of BP, HR, and Q the following calculations were made:

1) Rate pressure product (RPP) = HR × Systolic blood pressure (SBP) × 10^{-2} expressed as $mmHg \cdot beats \cdot min^{-1}$
2) Total peripheral resistance (TPR) = MAP / Q expressed as $mmHg \cdot L^{-1} \cdot min^{-1}$

Statistical Analyses

The Statistical Package for the Social Sciences (SPSS Version 10.0) was used for all analyses. Participant physical characteristics are reported as means and standard deviation [M (SD)]. For the purpose of comparing means within and between the ST and C groups all other data are reported as means and standard error of the mean [M (SEM)]. We chose to use SEMs to indicate how accurate estimates of the mean are. When means were compared, the SEM identifies whether there is a statistically significant difference between the means. A one-way repeated measure ANOVA was used to determine differences (on the 11 dependent variables) within each group during the 3 submaximum exercise intensities before training, after 16 weeks of training, and after 4 weeks of detraining. A repeated measures ANOVA using a general linear model was used to determine differences within and between groups every 4 weeks for leg strength and VO_2 max. Where significant results were noted, a Bonferroni *post hoc* test was used to determine the difference within and between groups. The level of significance was set at $P < 0.05$.

RESULTS

All subjects completed the study, with attendance rate for the ST group greater than 99%, with only 4 participants absent for 5 training sessions during the 16 weeks of training. The RT and C groups did not differ significantly in VO_2 max or strength prior to intervention.

Strength

Within-group analysis revealed a significant training effect as the ST group increased leg strength every 4 weeks over the 16-week training program (Table 1). After 4 weeks of detraining, leg strength had declined by 13 (3 kg) ($p < .000$) compared to after 16 weeks training. Detraining leg strength was greater than pretraining values ($p < .000$). Between-group analysis showed no difference in leg strength between the ST and C group during the first 4 weeks, with leg strength greater in the ST group for the remainder of the study (Table 1). Leg strength in the C group did not change significantly during the study period.

VO_2 max

For the first 8 weeks of training, within-group analysis revealed no change in VO_2 max in the ST group (Table 2). After weeks 12 and 16 of training, VO_2 max in the ST group was higher than pretraining values. After 4 weeks of detraining, VO_2 max in the ST group had returned to pretraining values (Table 2). Between-group analysis showed no difference in VO_2 max between the ST and C group during the 20 weeks of the study (Table 2) The VO_2 max in the C group did not change significantly during the study period.

Submaximum Exercise Testing: 40 Watts

In the ST group HR was lower after 16 weeks training at 88 (4) beats×min^{-1} ($p=0.01$) and after 4 weeks of detraining at 87 (4) beats×min^{-1} ($p=0.03$) compared to pretraining (0 week) values at 95 (5) beats×min^{-1}. Correspondingly, SV was higher after 16 weeks training at 85 (6) mL×$beat^{-1}$($p=0.01$) and after 4 weeks of detraining at 88 (6) mL×$beat^{-1}$ ($p=0.01$) when compared to pretraining (0 week) values of 78 (5) mL×$beat^{-1}$ (Table 3.). There was no significant difference at 40W in Q after 16 weeks training or after 4 weeks of detraining in the ST group.

Systolic blood pressure and the RPP were lower after 16 weeks training, 142 (5) mmHg ($p=0.03$) and 126 (8) × 10^{-2} $mmHg \cdot beats \cdot min^{-1}$ ($p<0.01$) respectively; and after 4 weeks of detraining, 137 (5) mmHg ($p < 0.01$) and 120 (8) × 10^{-2} $mmHg \cdot beats \cdot min^{-1}$ ($p=0.001$) respectively when compared to pretraining values, 150 (6) mmHg and 143 (10) × 10^{-2} $mmHg \cdot beats \cdot min^{-1}$, respectively (Table 3). In the C group there were no significant differences in the cardiovascular response to cycle exercise at 40 watts after 16 weeks training or after 4 weeks detraining (Table 4).

Submaximum Training: 50% VO_2 max

In the ST group HR was lower after 16 weeks training, 95 (3) beats×min^{-1} ($p=0.04$), and 4 weeks of detraining, 94 (6) beats×min^{-1} ($p=0.04$) when compared to pretraining values of 101 (4) beats×min^{-1}) (Table 3). Systolic blood pressure and the RPP were lower after 16 weeks training, at 152 (3) mmHg ($p=0.04$) and 145 (6) × 10^{-2} $mmHg \cdot beats \cdot min^{-1}$ ($p=0.01$) respectively, and after 4 weeks of detraining at 145 (4) mmHg ($p=0.001$) and 143 (9) × 10^{-2} $mmHg \cdot beats \cdot min^{-1}$, ($p < 0.001$) respectively, when compared to pretraining values of 161(2) mmHg and 160 (10) × 10^{-2} $mmHg \cdot beats \cdot min^{-1}$ (Table 3). In the C group there were no significant differences in the cardiovascular response to cycle exercise at 50% VO_2 max after 16 weeks training and after 4 weeks detraining (Table 4).

Table 1. Change in Leg Strength (kg) for the ST and C Groups after 16 weeks Training and 4 Weeks Detraining

	Leg Strength (kg)		p value	
Week	Control group	Strength Training group	Between groups	Within ST group (compared to pre-training)
0	48.6 (5.5)	41.9 (6.3)	.430	
4	48.2 (5.2)	57.3 (7.4)	.326	.001
8	46.8 (5.5)	66.5 (7.1)	.041	.000
12	47.8 (5.6)	72.5 (7.3)	.015	.000
16	48.2 (5.5)	79.5 (7.9)	.004	.000
20	48.0 (5.5)	66.3 (7.3)	.043	.000

Values are mean (SEM); 16 - 20 wk represents 4 weeks detraining.

Table 2. Changes in VO_2 max ($L \cdot min^{-1}$) for the ST and C Groups after 16 weeks Trainng and 4 weeks Detraining

	Leg Strength (kg)		P value	
Week	Control Group	Strength Training Group	Between groups	Within ST group (compared to pre-training)
0	1.85 (0.11)	1.94 (0.11)	.573	
4	1.83 (0.09)	1.89 (0.13)	.731	.458
8	1.79 (0.09)	1.96 (0.11)	.261	.605
12	1.82 (0.09)	2.01 (0.12)	.205	.041
16	1.82 (0.09)	2.07 (0.12)	.123	.000
20	1.82 (0.10)	1.92 (0.12)	.525	.648

Values are mean (SEM); 16 - 20 wk represents 4 weeks detraining.

Submaximum Training: 70% VO_2 max

In the ST group cycle ergometer power, VO_2 and $a\text{-}\bar{v}O_2$ diff were higher after 16 weeks training, of 86 (7) W, 1.53 (.10) $L \cdot min^{-1}$ and 14.9 (0.4) $mLO_2 \cdot 100mL^{-1}$, respectively, compared to after 4 weeks of detraining of 79 (6) W (p=0.03), 1.40 (0.08) $L \cdot min^{-1}$ (p=0.01), and 14.0 (0.4) $mLO_2 \cdot 100mL^{-1}$(p=0.01), respectively; and pre-training values of 81 (8) W (p=0.03), 1.42 (0.08) $L \cdot min^{-1}$ (p=0.02), and 13.5 (0.4) $mLO_2 \cdot 100mL^{-1}$(p=0.004), respectively.

Systolic blood pressure, MAP, and the RPP were lower after 4 weeks detraining at 168 (4) mmHg (p=0.03), 114 (2) mmHg (p=0.02), and 187 (13) $\times 10^{-2}$ mmHg · beats · min^{-1} (p=0.01) respectively, compared to pretraining values of 179 (3) mmHg, 120 (2) mmHg, and 219 (10) $\times 10^{-2}$ mmHg · beats · min^{-1}. In the C group there were no significant differences in the cardiovascular responses to cycle exercise at 70% of VO_2 max either after 16 weeks training or after 4 weeks detraining (Table 4).

DISCUSSION

These results demonstrate that lower limb strength training can improve the cardiovascular function of older men during submaximum aerobic exercise. Cardiovascular function during submaximum aerobic exercise has been shown to be a strong predictor of cardiovascular mortality and morbidity. Therefore reductions in the cardiovascular response during submaximum exercise in the present study suggest that resistance training may reduce the likelihood of some cardiovascular risk factors.

The strength trained men increased SV at 40 Watts and reduced HR at 40 Watts and 50% of VO_2 max after 16 weeks of training and 4 weeks of detraining (Table 3). The lower HR at 40 Watts and 50% of VO_2 max may be due to a lower level of sympathetic activity.[18] Although no strength training studies have examined the sympathetic response to submaximum exercise after a period of strength training, aerobic training has been associated with a reduction in plasma catecholamine concentration, in particular norepinephrine, at the same relative and absolute exercise intensity.[19,20] The reduced HR at 40 Watts may have allowed for greater ventricular filling time and an increase end diastolic volume. The increase in preload would ensure a greater reliance on the Frank-Starling mechanism and may account for the increase in SV found at 40 Watts.[21] Furthermore, reductions in SBP at 40 Watts could have reduced afterload and aided in the increase in SV.[22] Perini et al[29] suggested that lower arterial pressures at low-medium exercise intensities could reflect a lower level of activation of the sympathetic system elicited by the same absolute load after training.

The reduction in blood pressure during the submaximum aerobic tests requires particular mention. The present study found reductions in SBP at 40 Watts and at 50% VO_2 max and no increase in SBP at 70% VO_2 max (despite the higher workload) during the submaximum cycle ergometry tests after 16 weeks of lower limb strength training. While these results are consistent with previous reports examining the effect of aerobic[23] and combined aerobic and resistance training,[24] to our knowledge, no other studies have examined the effect of resistance training alone on blood pressure response to submaximum aerobic exercise. The SBP during submaximum aerobic exercise has been has been shown to be a valuable prognostic tool that predicts long-term mortality and cardiovascular events independently of resting blood pressure.[25,26] Furthermore the hemodynamic response during submaximum exercise better

Table 3. Cardiovascular Responses of the ST Group during Submaximum Exercise at Absolute and Relative Intensities

Strength Training Group									
	40 Watts			50% VO_2 max			70% VO_2 max		
	Pre-training	16 wk training	20 wk	Pre-training	16 wk training	20 wk	Pre-training	16 wk training	20 wk
V_E (L ×min^{-1})	31.5 (1.3)	31.0 (1.1)	32.0 (0.9)	37.7 (1.7)	37.3 (1.9)	36.5 (1.9)	50.0 (2.4)	53.5 (3.5)	48.5 (2.5)
RER	0.89 (0.02)	0.88 (0.02)	0.92 (0.03)	0.94 (.02)	0.91 (0.02)	0.95 (0.02)	0.99 (0.03)	0.98 (0.02)	0.99 (0.03)
Power (W)	40	40	40	54 (6)	55 (6)	53 (6)	81 (8)	86 (7)^b	79 (6)
VO_2 (L×min^{-1})	0.98 (0.04)	0.96 (0.04)	0.93 (0.03)	1.12 (0.08)	1.11 (0.07)	1.09 (0.07)	1.42 (0.08)	1.53 (0.10) ^{b}	1.40 (0.08)
HR (beats×min^{-1})	95 (5)	88 (4)*	87 (4)*	101 (4)	95 (3)*	94 (6)*	120 (5)	117 (4)	115 (7)
SV (mL×$beat^{-1}$)	78 (5)	85 (6)†	88 (6)†	85 (6)	86 (5)	88 (6)	88 (6)	89 (7)	89 (7)
Q (L×min^{-1})	7.3 (0.3)	7.4 (0.3)	7.5 (0.2)	8.4 (0.4)	8.1 (0.3)	8.4 (0.2)	10.6 (0.4)	10.3 (0.5)	10.0 (0.4)
a- $\overline{V}O_2$ diff (mL O_2·100mL^{-1})	13.6 (0.3)	13.2 (0.5)	12.4 (0.5)	13.2 (0.5)	13.7 (0.6)	12.9 (0.6)	13.5 (0.4)	14.9 (0.4)^b	14.0 (0.4)
SBP (mmHg)	150 (6)	142 (5)*	137 (5)*	161 (6)	152 (3)*	145 (4)*	179 (3)	170 (3)	168 (4)*
DBP (mmHg)	87 (2)	86 (3)	85 (2)	88 (2)	88 (3)	87 (2)	90 (2)	90 (3)	86 (2)
MAP (mmHg)	108 (3)	105 (4)	104 (3)	111 (3)	110 (3)	107 (3)	120 (2)	117 (3)	114 (2)*
RPP (mmHg×beats×min^{-1})	143 (10)	126 (8)*	120 (8)*	160 (7)	145 (6)*	143 (9)*	219 (10)	199 (6)	187 (13)*
TPR (mmHg · L^{-1} · min^{-1})	15.0 (0.7)	14.6 (0.7)	14.7 (0.5)	13.4 (0.7)	13.8 (0.7)	12.9 (0.5)	12.0 (0.5)	11.8 (0.7)	11.5 (0.6)

Values are mean (SEM). * P< 0.05, less than pre-training values; † P< 0.05, greater than pre-training values; a P< 0.05, less than after 16 weeks training; ^{b} P< 0.05, greater than pre-training and after four weeks detraining. V_E, ventilation (BTPS); RER, respiratory exchange ratio; VO_2, oxygen consumption; HR, heart rate; SV, stroke volume; Q, cardiac output; a- $\overline{V}O_2$ diff, arterio-venous oxygen difference; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; RPP, rate pressure product; TPR, total peripheral resistance. Week 20 represents 4 wk of detraining.

reflects common levels of work that an individual experiences during the day.[24] Therefore the changes in blood pressure during submaximum exercise may be more informative when evaluating an exercise training program and more clinically relevant to those individuals at risk of a cardiovascular incident.

An indicator of myocardial oxygen consumption (RPP) was also lower in the strength trained men at 40 Watts and 50% of VO_2 max. Myocardial oxygen consumption is considered an important indicator of the load placed on the heart.[27] Our results suggest at the same absolute load and at 50% of VO_2 max, the heart was required to do less work to maintain Q after 16 weeks of lower limb strength training. The reduction in RPP may be the result of improved systemic arterial compliance (reduced SBP) during the submaximum cycle ergometry test. This is of particular importance as systemic arterial compliance has been shown to be a major contributor to increased myocardial oxygen consumption during submaximum aerobic exercise.[28]

At 50% of VO_2 max, the strength trained men showed a reduction in HR although there was no difference in SV after 16 weeks of training. It would appear that between the fixed workload of 40 Watts and the relative load of 50% of VO_2 max (54-55 Watts) a threshold was reached where the activation of the sympathetic system increased. Although catecholamines were not measured in the present study, several studies have shown that workloads greater than 50% to 60% VO_2 max are required before significant increases in catecholamines are occur.[29,30] Perini et al[29] indicated that workloads greater than 1kp (50 Watts at 50 rpm) were required to increase the activation of the sympathetic system to maintain arterial pressure in older men (70-80 yr). The reduction in the HR at 50% of VO_2 max (54-55 Watts) from 101 (4) beats×min^{-1} (pre-training) to 95 (3) and 94 (6) beats×min^{-1} after 16 weeks training and 4 weeks detraining, respectively, may also decrease the risk of coronary heart disease and cardiovascular disease.[31] Savoren et al[30] found that the risk of death in middle-aged men was greater when a workload of <55 Watts achieved a HR of 100 beats×min^{-1} compared to a workload > 55 Watts.

At 70% of VO_2 max there was an increase in cycle ergometry power and subsequent increase in VO_2 for the strength trained men after 16 weeks of training. However the increase in VO_2

Table 4. Cardiovascular Responses of the Control Group during Submaximum Exercise at Absolute and Relative Intensities

Control group									
	40 Watts			50% VO_2 max			70% VO_2 max		
	Pre-training	16 wk training	20 wk	Pre-training	16 wk training	20 wk	Pre-training	16 wk training	20 wk
V_E ($L \times min^{-1}$)	29.4 (1.6)	29.6 (2.0)	29.6 (1.2)	29.7 (2.3)	29.9 (2.4)	30.1 (1.9)	41.4 (3.3)	41.9 (3.6)	42.2 (2.9)
RER	0.87 (0.03)	0.87 (0.03)	0.88 (0.03)	0.89 (0.02)	0.87 (0.03)	0.89 (0.03)	0.93 (0.02)	0.94 (0.02)	0.94 (0.02)
Power (W)	40	40	40	44 (3)	44 (3)	44 (3)	68 (5)	68 (5)	68 (56)
VO_2 ($L \times min^{-1}$)	0.89 (0.04)	0.87 (0.04)	0.87 (0.03)	0.89 (0.03)	0.91 (0.05)	0.90 (0.03)	1.21 (0.06)	1.19 (0.05)	1.19 (0.06)
HR ($beats \times min^{-1}$)	91 (5)	91 (3)	91 (4)	94 (4)	93 (3)	94 (3)	115 (5)	115 (4)	115 (4)
SV ($mL \times beat^{-1}$)	81 (5)	83 (3)	83 (5)	82 (4)	83 (6)	83 (6)	86 (6)	87 (6)	86 (7)
Q ($L \times min^{-1}$)	7.6 (0.3)	7.7 (0.2)	7.5 (0.2)	7.7 (0.3)	8.0 (0.3)	7.8 (0.2)	9.8 (0.5)	10.0 (0.5)	10.0 (0.4)
a-$\bar{V}O_2$ diff (mL $O_2 \cdot 100mL^{-1}$)	12.1 (0.3)	11.8 (0.5)	11.9 (0.5)	11.4 (0.5)	11.9 (0.6)	12.1 (0.4)	12.3 (0.4)	12.1 (0.5)	12.3 (0.4)
SBP (mmHg)	145 (8)	147 (5)	145 (5)	150 (7)	149 (5)	151 (5)	169 (7)	170 (7)	169 (6)
DBP (mmHg)	79 (3)	79 (3)	80 (2)	81 (3)	79 (3)	81 (3)	83 (2)	85 (3)	83 (2)
MAP (mmHg)	101 (4)	102 (3)	102 (3)	104 (3)	103 (3)	103 (3)	111 (3)	112 (3)	110 (3)
RPP ($mmHg \times beats \times min^{-1}$)	136 (14)	134 (8)	133 (9)	140 (9)	137 (9)	141 (9)	193 (12)	195 (13)	193 (13)
TPR ($mmHg \cdot L^{-1} \cdot min^{-1}$)	14.8 (0.5)	14.4 (0.7)	14.5 (0.5)	13.3 (0.7)	13.5 (0.6)	13.6 (0.6)	12.0 (0.4)	11.7 (0.6)	11.8 (0.6)

Values are mean (SEM. V_E, ventilation (BTPS); RER, respiratory exchange ratio; VO_2, oxygen consumption; HR, heart rate; SV, stroke volume; Q, cardiac output; a-$\bar{V}O_2$ diff, arterio-venous oxygen difference; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; RPP, rate pressure product; TPR, total peripheral resistance.

at 70% of VO_2 max was not accompanied by an increase in Q despite the increased workload (Table 3). The increased metabolic demands were met by an increase in a – VO_2 difference at the higher workload of 70% of VO_2 max. The widening of the a – VO_2 difference may be reflecting the formation of new capillaries[32] and an increase in mitochondria[33] and oxidative capacity[34,35] in strength trained muscles. The formation of new capillaries possibly occurs as a result of the increased metabolic rate, blood flow and cellular hypoxemia that occur with strength training.[36] In support of our findings, Hepple et al[7] examined the changes in capillary-to-fiber perimeter after 9 weeks of strength training in men aged 65 to 74 years. They found a significant correlation between increases in capillary-to-fiber perimeter exchange (12%) and VO_2 max (8.5%). The larger surface area available for exchange between the capillaries and muscle fibers presumably allows an increased capacity for oxygen exchange.

After 4 weeks detraining the changes in HR, SV, SBP, and RPP at 40 Watts were maintained although VO_2 max had returned to pretraining levels. Similarly changes in HR, SBP, and RPP at 50% of VO_2 max were also maintained after 4 weeks detraining (Table 3). This suggests that some cardiovascular benefits at a submaximum level are maintained after a short period of detraining.

The increase in muscular strength (Table 1) in the present study was an expected result. Similar increases in 1RM have also been reported in strength training studies of 16 to 20 weeks duration involving men of a similar age.[7,8,33,37-39] The increase in VO_2 max (Table 2) in this study agrees with some previous work[7,8] however not all studies report an increase in VO_2 max after a similar duration strength training.[2,9,11] Methodological differences in the exercise prescription, such as training intensity and loads used, could account for the disparity in the results. Furthermore, strength exercises like the squat (as used in our study) use a large muscle mass and expend a high volume of work. These type of exercises have been shown to cause the greatest increase in VO_2 max.[40] In addition, differences in the age, gender, and initial level of conditioning of the participants in other studies may have influenced the change in VO_2 max.

There area number of limitations to the study that should be addressed. First, the group sizes were relatively small and this may have limited the statistical power for showing significant changes. In particular, the small change in VO_2 max (8 (1%) within the ST group, while significantly different, was not significantly different when compared between groups (Table 2). Second, only within group statistical analysis was performed for the submaximum aerobic tests. We were primarily interested in the changes that occurred within the groups during the submaximum aerobic tests. The within group analysis provided a stronger statistical power and removed the inter-group variance, reducing statistical power when comparing ST and C groups. Third the participants in the study were healthy men aged 70 to80 yr who were free from cardiovascular and respiratory disease and not taking any medication that would interfere with the study. They may not be a true representation of their cohort in the general population and the findings of present study must be treated with caution as the results may not be applicable to other men over the age of 70 yr.

CONCLUSION

While the benefits of strength training on increasing muscular strength and hypertrophy are now well established the evidence that strength training can reduce cardiovascular risk factors is less certain. The results of this study demonstrate that 16 weeks of strength training can improve the cardiovascular function of older men during sub-maximum aerobic exercise, and as a result, potentially reduce some risk factors associated with cardiovascular disease. Leg strength and VO_2 max also significantly increased after 16 weeks of strength training. Furthermore significant gains in cardiovascular function remained after 4 weeks of detraining despite VO_2 max returning to pretraining levels. Our results indicate that clinicians and health professionals should consider the use of strength training to improve the cardiovascular function encountered in day-to-day activities by older individuals.

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