Effects of High-Intensity Endurance Training on Maximal Oxygen Consumption in Healthy Elderly People

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The primary intent of this study was to determine whether high-intensity endurance training increased maximal oxygen consumption (VO_{2max}) *in an older adult population. Twenty-one healthy, untrained men and women (69.7 years,* SD *2.7 years) participated and were randomly assigned to a high-intensity training group (TG)* ($n = 10$) *and a control group (CG)* ($n = 11$). *The TG trained three times a week for 10 weeks. Each 60-minute training session included four repetitions of exercise at approximately 85% to 95% of maximal heart rate separated by 4-minute rest periods. The control group was encouraged to perform no additive strength or endurance training during the study period. Maximal oxygen consumption increased significantly* ($p < .05$) *(13.2%) in the TG compared to the CG. Walking economy and maximal walking speed were unchanged after the training intervention. This training study demonstrates that high-intensity endurance training significantly improves* VO_{2max} *in older adults.*

Keywords: *endurance; high-intensity; elderly; maximal oxygen consumption*

Adaptations to exercise are considered to be primarily dependent on the specific type of exercise training performed. Endurance training is based on movements performed with a high number of repetitions and low resistance. As numerous people are involved in cardiorespiratory fitness and endurance training programs, the need for guidelines for exercise prescription is apparent. However, recommendations in the literature for endurance training among elderly people are not consistent (Green & Crouse, 1995; Panton, Graves, & Pollock, 1996). The adaptive response varies widely depending upon factors such as the initial level of the function and the intensity of the stimulus. Due to effects of aging, older people may not respond in the same manner as young adults to interventions (Pickles, 1989).

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Throughout the years, many studies have demonstrated an age-related decline in cardiorespiratory function, as exemplified by the body's maximum capacity to utilize oxygen (VO_{2max}) (Morio et al., 2000; Wilmore & Costill, 1994). Endurance training could reverse this decline in aerobic capacity in older individuals. However, previous studies on older adults have usually involved only mild- to moderate-intensity exercises, with intensity 60% to 75% of maximal heart rate, and prolonged high-intensity endurance training has often been limited to 70% to 85% of maximal heart rate (Hagberg, Mountain, Martin, & Ehsani, 1989; Seals, Hagberg, Hurley, Ehsani, & Holloszy, 1984). To increase VO_{2max} in healthy younger adults, well trained or not, it is recommended that a significant part of the training be at a level of 85% to 95% of maximal heart rate intensity ($f_{c,max}$). This high-intensity training may be particularly beneficial to increasing the stroke volume of the heart (Åstrand & Rodahl, 1986; Helgerud, Engen, Wisløff, & Hoff, in press). Despite reported risks such as musculosceletal injuries and coronary heart disease (Pollock & Wilmore, 1990; Siscovick, Weiss, Fletcher, & Lasky, 1984), it is of theoretical and practical interest to investigate the response of controlled, high-intensity endurance training in elderly individuals.

VO_{2max}, regarded as the best single indicator of an individual's cardiorespiratory capacity (e.g., Åstrand & Rodahl, 1986), is determined by oxygen availability, involving oxygen transport pathway components including ventilation, cardiac output, lung oxygen diffusion conductance, muscle oxygen diffusive conductance, and hemoglobin concentration (Wagner, 2000). Meredidt et al. (1989) showed that peripheral adaptations in elderly men and women were important factors in the response to moderate-intensity aerobic exercise training. They suggested that the skeletal muscular training response at moderate-intensity training was due to capillary density, number of mitochondria, and oxydative enzymes density. Work economy (C) is commonly defined as the ratio between work output and oxygen cost (Pate & Kriska, 1984). Work economy when walking (C_w) may affect the ability to perform activities of daily living, particularly in elderly people. The primary intent of this study was to investigate whether high-intensity endurance training improves VO_{2max}, C_w, and maximal walking speed.

Method

This experiment was carried out at the Department of Sport Sciences, Norwegian University of Science and Technology, Trondheim, and approved by the regional medical ethics committee.

Participants

Inclusion criteria were that the participants did not perform any regular exercise training, were more than 65 years old, and passed a medical evaluation by a physician. Twenty-four volunteers fulfilled the inclusion criteria and completed the pretest. Exclusion criteria were pathological resting electrocardiogram, hypertension (resting systolic blood pressure greater than 170 mmHg [millimeters mercury]), or forced expiratory flow during 1 second (FEV1) less than 70%. All procedures and potential risks were explained to the participants. The participants were observed by a physician during all testing and told that they could end the test if they felt any discomfort and/or undue fatigue. The participants were then matched by gender and randomly assigned to the test group (TG) or the control group (CG). The CG included 7 women and 4 men, and 6 women and 4 men completed the intervention in the TG. Mean values for the physical characteristics of the participants are presented in Table 1. Participants were excluded from the project if they failed to carry out 75% of the planned exercise training or if they were absent for more than 2 uninterrupted weeks during the training. No participants were excluded because of absence, but 3 did drop out of the TG due to lateral ankle distortion during exercise, low back pain partly due to exercise training, and eye surgery.

Apparatus

Oxygen uptake when walking or running on a motorized treadmill was measured by a gas analyzer (Jaeger EOS-Sprint, GmbH, Germany). The participants breathed through a respiratory valve with a mouthpiece. The expired air was collected in a bag and analyzed automatically every 30 seconds. The results were registered both graphically and numerically in a computer (Compac descpro 286e). Cardiac frequency (f_c) was measured every 5 seconds by heart rate monitor and a belt with electrodes (Polar Sporttester, Polar, Finland) fastened to the participant. Walking speed was determined using an electronic system (Brower timing system, Bid ID Training System, USA) with frequency modulation (FM) transmitter and emitter on start, at 5 meters (m), and again at 15 m. Vital capacity and FEV1 were measured by a spirometer (Jaeger, Flowscreen, Germany). Hemoglobin concentration was determined using a Reflotron (Mannheim Boehringer) reflectometer. Hematocrit was determined from blood samples from the fingertip centrifuged at 11,500 revolutions per minute for 60 seconds in a Microspin Ames (Bayer Diagnostic GmbH, Germany). Systolic and diastolic blood pressure were measured using standard brachial artery cuff pressure readings.

Table 1. Physical and Physiological Characteristics of Participants Before Training

	Exercise Group (n = 10)		*Control Group (n = 11)*	
Variable	M	SD	M	SD
Age (years)	68.9	2.8	70.5	3.0
Body mass (kg)	76.6	10.4	74.1	12.2
Body height (cm)	172.1	11.1	170.7	7.4
$f_{c,peak}$ (beats × min^{-1})	157.7	12.1	152.6	20.9
[Hb] (g × dl^{-1})	15.0	1.3	14.7	0.1
Hematocrit (%)	44.1	3.8	42.9	2.7
Vital capacity (liters)	3.29	1.01	3.20	1.28
FEV1 (%)	79.3	5.7	80.5	4.8
Systolic blood pressure (mmHg)	155.1	12.5	153.7	11.9
Diastolic blood pressure (mmHg)	90.8	5.7	88.0	7.4

NOTE: kg = kilograms; cm = centimeters; f_c = cardiac frequency; min = minute; [Hb] = hemoglobin concentration; g = gram; dl = deciliter; FEV1 = forced expiratory flow (1 second); mmHg = millimeters mercury.

Testing procedure

Maximal walking speed was measured as mean velocity over a 15 m distance. The participants were encouraged to walk as fast as possible. Time taken was recorded at both 5 m and 15 m. The time for the best of three trials was selected. VO_{2max} and C were tested during graded treadmill walking. Following a 10-minute warm-up low-intensity period on the treadmill, the participants walked continually in three periods. In the first period, the speed was 4.5 kilometers (km) × hour $(h)^{-1}$ and the inclination 6%. In the second period, the speed was increased to 5.5 km × h^{-1} with the same inclination. Heart rate and VO_2 were noted during these two initial periods. In the last period, the inclination was gradually increased every 2nd minute until the participants were exhausted. The peak heart rate was noted as the participants ended the testing. All of them met the two following criteria to ensure that VO_{2max} had been attained: plateau in VO_2 and a respiratory exchange ratio (R) greater than 1.05. Comparisons of VO_{2max} using the traditional expression milliliter (ml) × kilogram $(kg)^{-1}$ × minute $(min)^{-1}$ are both very routine and functionally imprecise. VO_2 is a measure of power, and in order to be mass independent, should be expressed in ml per body mass raised to a power of 0.75 (Berg, Sjødin, Forsberg, & Svedenhag, 1991; Helgerud, 1994). If dimensional scaling is not taken into account, the heaviest person will be

underestimated. C_w was manually calculated from the data, and expressed as $ml \times kg^{-0.75} \times m^{-1}$; gross oxygen cost of walking.

Training

The training period for the exercise group was set to 10 weeks and consisted of three sessions each week. The participants trained outside, as a group under supervision, but the intensity was individually controlled. After 10 to 15 minutes of low-intensity warm-up walking period, the participants performed 4 minutes of high-intensity (85%-95% of $f_{c,peak}$) dynamic exercise four times, with 3-minute rest periods in between (60%-70% of $f_{c,peak}$). Before ending the session, the participants performed 10 to 15 minutes of low-intensity exercise (60%-70% of $f_{c,peak}$). The total training time for each session was 60 minutes. The activity consisted of outdoor running. Participants who preferred to reach the recommended high-intensity training zone by walking fast were guided to do this in uphill terrain. The running was over the same course and same terrain for each participant. The participants recorded any daily physical activity independent of the structured exercise regimen during the experimental period.

Statistical analysis

Data were analyzed using SPSS (release 8.0). The results are presented as means and standard deviations. The independent samples *t* test was used to decide whether differences between the groups in physical characteristics and in physiological scores at the pretest and the posttest were significant. The paired samples *t* test was used to assess the significance of the differences between the pretest and the posttest in the two groups separately. Repeated measures analysis of variance (ANOVA) was used to test differences in the physiological variables from pretest to posttest between the exercise group and the control group. The criterion for assessing the statistical significance of mean differences was a probability level of $p < .05$.

Results

The results from the study are presented in Table 2. The differences between the TG and the CG were not significant according to any of the variables at the start of the study. Nine of 10 TG participants completed the scheduled exercise during the 10-week training period.

Table 2. Results From Endurance Testing Before and After 10 Weeks of High-Intensity Training

	Experimental Group (n = 10)				*Control Group (n = 11)*			
	Pretest		*Posttest*		*Pretest*		*Posttest*	
Variable	M	SD	M	SD	M	SD	M	SD
VO_{2max} ($l \times min^{-1}$)	1.89	0.39	2.14*	0.40	1.94	0.54	1.95	0.53
VO_{2max} ($ml \times kg^{-1} \times min^{-1}$)	24.2	2.5	27.8*	2.3	26.7	6.4	26.2	6.2
VO_{2max} ($ml \times kg^{-0.75} \times min^{-1}$)	71.5	8.9	82.3*	8.6	77.8	18.6	77.7	18.3
C_w ($ml \times kg^{-0.75} \times m^{-1}$) ($4.5\ km \times h^{-1}$)	0.81	0.11	0.77	0.09	0.78	0.09	0.77	0.08
C_w ($ml \times kg^{-0.75} \times m^{-1}$) ($5.5\ km \times h^{-1}$)	0.76	0.12	0.74	0.09	0.75	0.10	0.75	0.10
Body mass (m_b) (kg)	76.6	10.4	76.4	9.7	72.9	12.2	73.4	12.3
Respiratory exchange ratio	1.07	0.05	1.08	0.05	1.09	0.06	1.08	0.06

NOTE: VO_{2max} = maximum capacity to utilize oxygen; min = minute; ml = milliliter; kg = kilogram; C_w = walking economy; m = meter; h = hour; respiratory exchange ratio = ratio of carbon dioxide exhaled/oxygen inhaled at maximal effort.
*$p < .05$.

This exercise training led to a significant increase in VO_{2max} ($p < .05$) at all intensity levels from pretest to posttest, compared to the CG. The TG increased VO_{2max} from 71.5 to 82.3 $ml \times kg^{-0.75} \times min^{-1}$ (13.2%) or 24.2 to 27.8 $ml \times kg^{-1} \times min^{-1}$ (14.9%). There were no changes in the CG during the experimental period. Table 2 shows that there was no significant difference in C_w (working economy) at either of the two walking velocities between TG or CG participants. There were also no significant differences between the TG and the CG in either body mass or respiratory exchange ratio.

The data from the heart rate monitors were analyzed after every training session to assure that the participants maintained the recommended training intensity. After the first week, the participants were able to function at the recommended intensity of 85% to 95% of $f_{c,peak}$ during training. The training diary showed that none of the participants in the TG or in the CG had performed any other endurance training in addition to the experimental procedure.

Discussion

The primary intent of this study was to determine whether high-intensity endurance training is applicable to an older population in the same manner as

in younger people. The TG in this study performed interval training of 85% to 95% $f_{c,max}$ three times a week for 10 weeks. The significant increase in VO_{2max} in the TG compared to the CG indicates that high-intensity interval training is effective in untrained older people. In people unused to high-intensity endurance training it might be difficult to sustain the recommended intensity for the whole training session. The authors found no other study in which heart-rate monitors were used during training to validate exercise intensity (Green & Crouse, 1995). Seals et al. (1984) claimed that their participants were performing at 85% to 95% of $f_{c,peak}$ heart rate up to 40 minutes, which would be difficult due to lactate accumulation, resulting in an underestimation of $f_{c,peak}$.

The TG increased VO_{2max} from 71.5 to 82.3 $ml \times kg^{-0.75} \times min^{-1}$ (13.2%) during 10 weeks of training, where the first 2 weeks were used primarily to adapt gradually to high-intensity exercise. In a meta-analysis by Green and Crouse (1995) of 29 studies of endurance training among people between 60 and 78 years of age, the mean increase in VO_{2max} was 14%, when expressed in $ml \times kg^{-1} \times min^{-1}$. However, the mean intervention period in these studies was 25 weeks, more than twice as long as this study. Most of these studies were based upon low-intensity intervention, and they do not indicate whether VO_{2max} increased prior to the conclusion of the training period. The rapid increase in VO_{2max} shown in this study suggests that high-intensity exercise may be of greater benefit to elderly people than lower intensity regimes.

The American College of Sports Medicine (1998) has issued recommendations for the quantity and quality of exercise for developing and maintaining cardiorespiratory fitness in healthy adults. Although the frequency and duration components of the exercise prescriptions are straightforward, the intensity component is less so. Exercise intensity can be expressed as a percentage of VO_{2max}, $f_{c,max}$, or heart rate reserve ($HR_{reserve}$). Kohrt, Spina, Holloszy, & Ehsani (1998) recommended heart rate expressed as a percentage of $f_{c,max}$ as an appropriate method of prescribing exercise intensity in healthy, sedentary, 60- to 72-year-old women, based upon heart rate and VO_2 values during treadmill walking. However, very few studies include exercise intervention with heart-rate monitors, as used in the present study. Although it is likely difficult to measure maximum heart rate in elderly people due to health matters, it is important to include heart rate as an indicator of work intensity during exercise.

The TG did not show significant improvement in C_w during treadmill walking from pretest to posttest at any of the walking velocities. C_w is referred to as the ratio between work output and oxygen cost. Causes of intraindividual variation in gross oxygen cost of activity are not well understood, but it seems likely that anatomical traits, mechanical skill,

neuromuscular skill, and the storage of elastic energy are important (Pate & Kriska, 1984). Although a major part of the intervention in the TG was high-velocity uphill walking, this did not influence significantly C_w from pretest to posttest. A 10-week intervention period may not be long enough to enhance walking economy. In addition, walking on a treadmill may not be a valid substitute for outdoor C_w.

No improvements were found in maximal walking speed among the participants in this study. Sipila, Multanen, Kallinen, Era, and Suominen (1996) found that endurance training increased maximal walking speed as well as muscle strength in elderly women, though their endurance training intensity was lower (but not described precisely) than in the present study.

The public health importance of physical activity may relate not just to its role in preventing decline, but also its role in enhancing physical function. Little information exists on training-induced adaptation in the determinants of VO_{2max} (i.e., maximal stroke volume, maximal heart rate, and maximal arteriovenous O_2 difference) in older individuals (Dishman, 1994; Seals et al., 1984). According to Seals et al. (1984), the increase in VO_{2max} in response to training at 70% to 75% of VO_{2max} may primarily result from an increase in maximal arteriovenous O_2 difference, with little augmentation of maximal cardiac output. Panton et al. (1996) claimed that when younger and older people exercise at the same relative intensity (i.e., same percentage VO_{2max} or percentage $f_{c,max}$), the exercise is perceived as easier among older compared to younger people. A calculation of maximal heart rate that is too low is a serious mistake when considering relative intensity among older adults. Because lactate production limits exercise duration at high relative exercise intensities, it is possible that age-related difference in perceived extension is related to a reduction in lactate production. Loss of type II muscle fibers with aging could play a role in this. In this study, the heart-rate monitor showed that the participants were able to perform the recommended intensity (85%-95% of $f_{c,peak}$) without excessive pain or discomfort.

All participants in the TG knew that they were serving as subjects in an investigation and that they would undergo a posttest similar to the pretest. This might positively affect motivation and lead to more training than observed by the investigators. The training diary was checked every week to make sure that the participants did not perform other training during the intervention period. A common problem with studies based on voluntarism is that study participants are usually more concerned with their health than those who choose not to participate. Berger and Hecht (1989) claimed that only those who saw themselves as physically competent would volunteer for

exercise training studies. Because many of the people who participated in this study were active and socially oriented, this sample may not represent all elderly people. However, there were no differences in average VO_{2max} between the TG and the CG in this study.

Even a small gain in physiological function may translate into functional improvement and greater independence for older people. People at a very low level of fitness can achieve significant training effects with training heart rates as low as 40% to 50% of $f_{c,peak}$, whereas those with higher fitness levels require higher levels of training stimulus (deVries, 1971; Wenger & Bell, 1986). The results of the present study suggest that high-intensity endurance exercise may be beneficial, both prophylactically and to promote health. Because the benefit of endurance training in elderly people over a short period is reversible (Morio et al., 2000), one should consider increasing endurance training intensity to maintain enhanced cardiorespiratory capacity.

It should be mentioned that orthopedic injuries are more common and of greater severity during high-intensity compared to low-intensity training programs (Pollock & Wilmore, 1990; Seals et al., 1984). One out of three dropouts in the exercise group in this study had a lateral ankle distortion. Furthermore, the risk of increasing training intensity too quickly during a training program should be considered, due to undiagnosed coronary heart disease (Siscovick et al., 1984). As in any training regimen, it is important to increase the total amount of physical strain gradually, particularly among older people who are not trained well or have sedantary lifestyles. People suffering from coronary or pulmonary disease should see a doctor before starting high-intensity endurance training.

Conclusion

Although the present results should be treated with caution because participants volunteered, suggesting that they were healthier than average for their age group, and the number of participants in the study was relatively small, the data support previous observations about age-related changes in high-intensity endurance training. This study demonstrates that elderly people respond positively to high-intensity endurance training. One should, however, be aware of the risk of orthopedic or cardiorespiratory injuries during high-intensity training involving elderly people. This experiment complies with the current laws of Norway, where the experiment was performed.

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