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The effect of heart rate controlled low resistance circuit weight training and endurance training on maximal aerobic power in sedentary adults

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The effects of a 12-week low resistance circuit weight training (CWT) on cardiovascular and muscular fitness were studied in 90 healthy sedentary adults. The subjects were randomized into three equally fit groups: CWT, Endurance (END) and Control (CON) according to their maximal aerobic power (VO_{2max}). Both training groups exercised for 12 weeks, 3 days a week in sessions of 40 min, with a heart rate (HR) level of 70–80% HR_{max}. The CWT group trained with air resistance machines. Heart rate was controlled by setting the speed of movement. The END group walked, jogged, cross-country skied or cycled. The net differences (between pre- and posttraining changes) between the CWT and CON groups was statistically significant for VO_{2max} (2.45 $ml \cdot min^{-1} \cdot kg^{-1}$, 95% CI 1.1; 3.8), for abdominal muscles (3.7 reps, CI 0.3; 7.1), for push-ups (1.1 reps, CI 0.2; 2.1), and for kneeling (2.25 reps, CI 0.01; 4.5). The net difference (between pre- and posttraining changes) in the END and CON groups was statistically significant for VO_{2max} (2.75 $ml \cdot min^{-1} \cdot kg^{-1}$, 95% CI 0.9; 4.6), and kneeling (3.0 reps, CI 0.7; 5.3). Low resistance CWT with moderately hard HR level has effects comparable to an equal amount of endurance training on the cardiovascular fitness of sedentary adults. The CWT model was benefical also on muscular fitness. Based on the results, this type of exercise can be recommended for beginners because of its multilevel effects.

Traditionally, strength training has been carried out with heavy loads and few repetitions for developing maximal strength. In circuit weight training (CWT), lower loads make it possible to do more repetitions. Thus, the exercise is supposed to have an effect both on strength and on cardiorespiratory fitness. Most studies on circuit weight training are carried out with loads of 40% repetition maximum (1RM) or more, and the results vary because of differences in the duration of workout, work/rest-ratio, intensity of work and the fitness level of the subjects (Verril et al. 1992).

Many studies about the acute effects of CWT suggest that CWT with loads of 40% 1RM does not stimulate the oxygen transport system even if the heart rate (HR) level is above 60% HR_{max} (Wilmore et al. 1978, Hurley et al. 1984, Ballor et al. 1987, Collins et al. 1991, Garbutt et al. 1994). There are many factors affecting HR and VO_2 relationship: type of exercise, load, rest between sets, fitness level and possible medication (Verrill et al. 1992). A short rest between sets is common in studies with positive effects of CWT on cardiovascular fitness (Gettman et al. 1982, Harris & Holly 1987, Haennel et al. 1989). In the studies where no improvement in VO_{2max} has been observed (Allen et al. 1976, Gettman et al. 1978, Marcinik et al. 1991), the training loads have been 50% of 1RM or more and the number of repetitions less than 15. Marcinik et al. (1991) suggest that CWT improves endurance performance even if there is no change in VO_{2max}. A significant reduction in plasma lactate concentration was found at relative exercise intensities between 55% and 75% of peak VO_{2max} after a training period. Garbutt et al. (1994) suggest that a lower load than that of 40% 1RM with increase in the number of repetitions is preferable, because the loads used caused muscles to rely mostly on anaerobic energy sources.

There are no studies about circuit training with loads of 20% 1RM. In our pilot study (in reporting phase) we investigated HR responses during two different training sessions with different work/rest-ratios. The training was carried out with air resistance machines (HUR Ltd., Finland). We concluded that circuit training with low resistance and appropriate work/rest-ratio is strenuous enough to increase HR responses to the level recommended by the ACSM (1998). This type of exercise may be beneficial both for cardiovascular and for muscular fitness in sedentary adults. By controlling the exercise via HR monitoring and choosing the right speed, it is easy to maintain an effective training level. Also Gettman & Pollock (1981) suggest in their review article that CWT may have value for beginners if the intensity and musculoskeletal stress are kept at a minimum in the early stages of the program.

The purpose of this study was to investigate the effect of a 12-week low resistance (20% 1RM) heart rate controlled CWT on VO_{2max} and compare it to an endurance-type training program of walking, cross-country skiing or cycling in sedentary adults.

Material and methods

Subjects

Ninety healthy, voluntary adults (45 men and 45 women) were selected from 224 persons on the basis of health-screening with a questionnaire. The subjects were sedentary people who regularly trained less than twice per week before intervention, because we did not want any of the subjects to decrease their exercice quantity. The subjects were divided randomly into three equally fit groups according to their VO_{2max}. The groups were the circuit weight training group (CWT; n=30), endurance group (END; n=30) and control group (CON; n=30). Descriptive statistics for the subjects and the subgroups are presented in Table 1. Before laboratory testing the subjects went through a medical examination. The exclusion criteria were hypertension, extreme overweight (BMI$<$35 $kg \cdot m^{-2}$) or other musculoskeletal or cardiovascular limitations. Written informed consent was obtained prior to testing from all subjects. The study protocol was approved by the ethics committee of Oulu University Hospital.

Test procedure

On the first day the subjects went through a medical examination including ECG, blood pressure, weight and height. After the medical examination the subjects performed a submaximal treadmill test (Treadmill Precor M 9.45, USA) to become familiar with the test protocol and the portable O_2-analyser (K4, Cosmed, Italy). During the treadmill test there was continuous ECG-monitoring. The test ended when the heart rate was 80% of the age-predicted HR_{max} (220 beats $\cdot$ min^{-1}−age). After the submaximal treadmill test the subjects performed repetition tests for muscular endurance measurement. The movements were sit-ups (repetition max) for abdomen muscles, back extension (repetition max) for back muscles, modified push-ups (repetition max in 40 s) for arm extensor muscles and kneeling (repetition max with 40% load of body weight) for leg extensor muscles.

On the second test day the subjects performed maximal treadmill test to exhaustion for maximal aerobic power measurement. There was one resting day between the test days. The test protocol was modified from that of Pennsylvania State University (Oja 1973) and consisted of the following: Warm-up 2–4 min (5 km/h, 2.5% incline), 1st step 1–3 min (5.0 km/h, 2.5%), 2nd step 3–6 min (5.0 km/h, 5.0%), 3rd step 6–9 min (5.5 km/h, 5.0%), 4th step 9–12 min (5.5 km/h, 7.5%), 5th step 12–15 min (5.5 km/h, 10.0%), 6th step 15–18 min (6.0 km/h, 12.5%), 7th step 18–21 min (6.0 km/h, 15.0%), 8th step 21–24 min (6.5 km/h, 15.0%). Oxygen consumption was measured with Cosmed K4 (Hausswirth et al. 1997) throughout the test and there was continuous ECG-monitoring during the test. After the treadmill test there was a 30-min rest before one-repetition maximum (1RM) estimation test for determining the training loads for CWT. The 1RM estimation test was carried out with HUR air resistance weight-training machines (HUR Ltd., Finland). The subjects performed 5 repetition sets with the loads of 10 kg, 20 kg, 30 kg etc., until they were unable to perform the sets properly. The corresponding 1RM was read in a table (McDonagh & Davies 1984). Rest between the sets was about 1 min. The subjects performed the test at 10 exercise stations: Leg extension, leg curl, abdomen, back, leg abduction, leg adduction, body twist right, body twist left, push-up and pull-down. Between the stations there was a 2-min rest.

According to the test results, the training loads were set at the 20% level of 1RM at every station.

Training program

The training started the following week after the tests. All the groups received their directions for the following 12 weeks: The CWT group was directed to exercise with HUR air resistance machines three times a week. One training session lasted 40 min, containing a 5-min warm-up with step-bench to reach the target heart rate of 70–80% HR_{max}. After the warm-up the subjects performed continuously 3 weight training circuits of which each contained 10 stations. The work/rest-ratio was 40 s work/20 s rest. The aim was to keep the heart rate at the targeted level throughout the session by setting the speed of movement. A heart rate monitor (Polar Edge NV™, Polar Electro Oy, Finland) was set to alarm below and above the target heart rate zone. The CWT session lasted 30 min and at the end there was a 5-min cool-down containing stretching for major muscle groups. The whole CWT session was instructed from a cassette tape recorder. The number of repetitions at each station during the CWT session were counted at week 1, week 6 and week 12 to detect possible changes.

The endurance group was directed to exercise by walking, biking, cross-country skiing or jogging for 40 min 3 times a week at the same HR level as the CWT group. A heart rate monitor (Polar Edge NV™, Polar Electro Oy, Finland) was set to alarm below and above the target heart rate zone.

The control group was directed not to change their exercise and other living habits. All the groups were instructed to fill in

Table 1. Descriptive statistics as mean±SD of the subjects and all subgroups. The training groups are circuit weight training (CWT), endurance (END) and control (CON) group

	All n=83	CWT n=27	END n=29	CON n=27	Male n=40	Female n=43
Age (years)	42.0±7	42.5±7	41.6±6	41.9±7	42±7	42±7
Height (cm)	170±10	170±10	171±10	170±10	178±7	162±5
Weight (kg)	75.7±13	78.7±16	75.4±13	73.2±10	85±12	66±7
BMI ($kg \cdot m^{-2}$)	26.0±2.8	26.9±3.2	25.7±2.8	25.4±2.3	27±3	25±2
VO_{2max} ($ml \cdot min^{-1} \cdot kg^{-1}$)	37.0±5.4	36.6±5.3	36.8±5.7	37.8±5.3	39.2±5.4	35.0±4.6
HR_{max} (beats $\cdot$ min^{-1})	176±12	176±11	178±13	174±12	175±12	177±13

BMI=body mass index, VO_{2max}=maximal aerobic power, HR_{max}=maximal heart rate.

an exercise diary with care; all vigorous physical activity and for the training groups also the time spent within the target HR zone during the training period were to be written down.

Statistical methods

Measured variables are given as means and standard deviation (SD). Differences in the measured variables between the groups were tested statistically with one-way ANOVA and between pre- and post-test with paired *t*-test and Wilcoxon-test. The significance level was set at $P<0.05$.

Results

Ninety subjects performed the pre-test and there were seven dropouts during the training period. Three persons in the CON group stopped immediately after hearing the results of randomization. In the END group, one subject moved abroad and in the CWT group there were three dropouts on account of pressure of their jobs.

Cardiovascular fitness

Maximal aerobic power (VO_{2max}) increased in the CWT group by 3.8 ± 2.2 $ml \cdot min^{-1} \cdot kg^{-1}$ and the net difference compared to the CON group was 2.45 $ml \cdot min^{-1} \cdot kg^{-1}$ (95% CI 1.1; 3.8) ($P<0.005$). In the END group, VO_{2max} increased by 4.1 ± 4 $ml \cdot min^{-1} \cdot kg^{-1}$ and the net difference compared to the CON group was 2.75 $ml \cdot min^{-1} \cdot kg^{-1}$ (95% CI 0.9; 4.6) ($P<0.005$). Table 2 illustrates the changes in VO_{2max} by training group.

Muscular endurance

The improvements in the repetition tests differed significantly between the training groups. The net difference between the CWT group and the CON group was 3.7 reps (CI 0.3; 7.1) in abdomen ($P<0.05$), 1.1 reps (CI 0.2; 2.1) in push-up ($P<0.05$) and 2.25 reps

Table 2. Mean±SD maximal aerobic power (VO_{2max}) before and after training, and the net differences observed during training (differences between the changes in the training groups and control group), 95% confidence intervals (CI) and *P*-values for statistical significance in the training and control groups

		n	Before	After	Net difference to control group		*P*
			Mean±SD	Mean±SD	Mean	95% CI	
CWT	($l \cdot min^{-1}$)	27	2.9±0.6	3.2±0.7	0.21	(0.11; 0.31)	<0.001
	($ml \cdot min^{-1} \cdot kg^{-1}$)		36.6±5.3	40.4±4.8	2.45	(1.07; 3.8)	<0.001
END	($l \cdot min^{-1}$)	29	2.8±0.7	3.0±0.7	0.17	(0.05; 0.28)	0.007
	($ml \cdot min^{-1} \cdot kg^{-1}$)		36.8±5.7	41.1±5.6	2.74	(0.89; 4.60)	0.004
CON	($l \cdot min^{-1}$)	27	2.8±0.5	2.9±0.6			
	($ml \cdot min^{-1} \cdot kg^{-1}$)		37.8±5.3	39.1±5.9			

CWT=circuit weight training, END=endurance training, CON=control group.

Table 3. Mean±SD repetitions in maximal repetition test before and after training, and the net differences observed during training (differences between the changes in the training groups and control group), 95% confidence intervals (CI) and *P*-values for statistical significance in the training and control groups

	n		Before	After	Net difference to control group		*P*
			Mean±SD	Mean±SD	Mean	95% CI	
CWT group	27	Abdomen	21.5±9	26.1±10	3.7	(0.27; 7.1)	0.035
		Back	52.1±10	52.2±10	2.4	(−3.0; 7.8)	
		Push-ups	12.5±2	14.4±2	1.1	(0.2; 2.1)	0.019
		Kneeling+40% BW	8.5±8	9.7±7	2.3	(0.01; 4.5)	0.049
END group	29	Abdomen	20.6±9	21.7±11	0.6	(−2.0; 3.2)	
		Back	51.1±11	53±11	4.1	(−1.1; 9.4)	
		Push-ups	11.8±3	12.9±2	0.36	(−0.6; 1.3)	
		Kneeling+40% BW	6.2±5	8.1±5	3.0	(0.75; 5.3)	0.01
CON group	27	Abdomen	22.7±13	23.6±12			
		Back	50.8±11	48.6±12			
		Push-ups	11.8±2	12.7±3			
		Kneeling+40% BW	9.4±7	8.5±6			

Net difference was significant between CWT and END group in push-ups ($P=0.044$) and almost significant ($P=0.055$) in abdomen. BW=body weight.

(CI 0.01; 4.5) in kneeling $P<0.05$). The net difference between the CWT group and the END group was 0.8 reps (CI 0.02; 1.5) in push-up ($P<0.05$) and 3.1 reps (CI –0.1; 6.2) in abdomen, which indicates a tendency of change ($P=0.055$). The net difference between the END group and the CON group was 3.0 reps (CI 0.7; 5.3) in kneeling ($P<0.05$). Table 3 illustrates the changes in the repetition tests by training group.

The mean number of repetitions per set increased from week 1 to week 12 in the CWT group as follows: push-up from 26±6 to 35±5 reps, pull-down from 35±5 to 47±5 reps, abdomen from 31±4 to 37±4 reps, back from 30±4 to 37±4 reps, body twist from 24±4 to 30±4 reps, leg abduction from 43±6 to 58±8 reps, leg adduction from 42±5 to 58±8 reps, leg extension from 46±7 to 54±6 reps and leg curl from 43±8 to 53±7 reps per set.

Discussion

The training frequency and intensity were chosen according to recommendations by the ACSM (1998). The training session for the CWT group was directed from a cassette tape recorder so there was an exact start and end in every session. The END group was instructed to walk, cross-country ski or cycle for the same duration at the same intensity, but the training diary showed that the sessions tended to last longer than in the CWT group. The CON group was supposed to continue their sedentary lifestyle during the training period. From the training diary, all activity that the subjects experienced as vigorous was counted. In the CON group the total amount of training was more than in the CWT group, but there was no intensity control in the CON group and a great part of their training was walking to work or shoveling snow etc. In the CWT group there was a remarkable increase in the amount of repetitions during the training session. The subjects had to increase their speed to keep the heart rate level within the target zone so this type of exercise may be benefical also for the rate of force development, as discussed in studies about velocity specificity (Behm & Sale 1993).

We found significant improvements in VO_{2max} after the training period. The change was equal in the CWT group (11%) and in the END group (12%). The improvement in VO_{2max} is comparable to the results obtained in a study about 15 weeks' walking training in healthy adults (Kukkonen-Harjula et al. 1998). The average increase in VO_{2max} in earlier CWT studies has been 5.1% for men and 8.0% for women (Gettman & Pollock 1981). In our study, the CWT male group improved their VO_{2max} by 12% and the female group by 10%. Possible reasons for greater improvements in this study are the duration of the training session and optimal work/rest-ratio so that the training provides an aerobic training stimulus, as recommended by the ACSM. In many studies about CWT the subjects have been young and fit persons (Ballor et al. 1987, Garbutt et al. 1994, Allen et al. 1976) with no improvement in cardiovascular fitness.

Heart rate monitoring is a new way to control exercise intensity during CWT. It motivates the subjects to perform at the target HR level and directs the start of the next exercise before the HR drops below the target zone. The counts of repetitions showed that the subjects increased the speed of movements as they progressed. The load in our study was lower than in earlier CWT studies. Garbutt et al. (1994) suggest that a lower load than 40% of 1RM with an increase in the number of repetitions is preferable to avoid overload, especially of smaller muscle groups. For the beginners, the load used (20% 1RM) caused increase in HR but was light enough to allow the sets to be performed properly. With air resistance machines it is possible to exercise with low loads and high speed whereas with weight machines it is more difficult. Usually beginners suffer from muscle soreness (Smith 1991) caused by training, but in this study the rate of muscle pain in the CWT group was low. One possible reason for this is the lack of inertia when training with air resistance machines.

In this study the effect of CWT on muscle strength was controlled with repetition tests. Previous studies have shown that CWT programs with loads of 40% of 1RM are benefical for muscular strength (Verrill et al. 1992, Gettman et al. 1978, 1982) although high-resistance, low-repetition weight training programs are optimal (Morrissey et al. 1995, Hickson et al. 1980). Strength improvements as a result of training must be interpreted carefully because of the specificity principle. When training and testing are done with the same equipment the results are usually better than using an uncustomized test protocol. We chose repetition tests without extra weight to investigate possible improvements in muscular endurance. The results showed that the CWT group improved their abdominal and arm muscles more than the other training group.

In summary, circuit weight training with loads of 20% 1RM with an appropriate HR level has effects on cardiovascular fitness comparable to walking in sedentary adults. The CWT model used was benefical also on muscular fitness so we can recommend this type of exercise, especially for beginners, because of its multilevel effects.

Key words: heart rate; exercise; fitness; air resistance.

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