Physiological changes following a 12 week gym based stair-climbing, elliptical trainer and treadmill running program in females

M. EGAÑA, B. DONNE

Department of Physology
Trinity College Dublin, Dublin, Ireland

Aim. **Despite the growing popularity in recent years of the elliptical trainer aerobic exercise modality the physiological changes induced following a training program using elliptical trainers remains unknown. The present study investigated the metabolic and cardiorespiratory improvements following a 12-week aerobic training program using elliptical trainer, treadmill or stair-climbing modalities.**

Methods. **Twenty-two moderately active females (28.6±5.3 y, 1.65±0.05 m) were randomly assigned to treadmill running (n=7), elliptical trainer (n=8) or stair-climber (n=7) groups and trained 3 days.week^{-1} initially at 70-80% of maximum heart rate (HR_{max}) for 30 min, progressing to 80-90% HR_{max} for 40 min. Subjects performed incremental exercise to volitional exhaustion using an electronically loaded cycle ergometer before and upon completion of the program. In addition, subjects performed sub-maximal fixed load tests at 0, 4, 8 and 12 weeks, using ergometers specific to their exercise group.**

Results. **No significant inter-group differences were recorded for pre-training $\dot{V}O_{2max}$ or $\dot{V}_{Emax}$. Significant ($p<0.05$) post-training increases in cycling $\dot{V}O_{2max}$ and $\dot{V}_{Emax}$ were observed for treadmill (mean±SEM, 40.7±2.2 *vs* 43.4±2.6 ml.kg^{-1}.min^{-1} and 82.9±5.1 *vs* 90.2±6.4 l.min^{-1}), elliptical trainer (36.9±2.5 *vs* 39.6±2.4 ml.kg^{-1}.min^{-1} and 86.8±2.3 *vs* 92.5±4.1 l.min^{-1}) and stair-climber (37.4±2.9 *vs* 39.2±3.1 ml.kg^{-1}.min^{-1} and 95.9±5.8 *vs* 97.4±5.8 l.min^{-1}) modalities, however, the increases were not significantly different between groups. For all groups, sub-maximal HR significantly decreased from week 0 to 4, and from week 4 to 8.**

Conclusion. **In moderately active females similar physiological improvements were observed using stair-climber, elliptical trainer and treadmill running when training volume and intensity were equivalent.**

KEY WORDS: Exercise - Physical fitness, psysiology - Females.

In recent years the elliptical trainer has been developed as a new aerobic exercise modality, to capture the popularity of participants in fitness clubs and the home consumer market. Despite minimal scientific evidence detailing aerobic training benefits, elliptical trainers have nevertheless attained high usage rates among gym participants of both genders. Following a single bout of exercise elliptical trainers reportedly provide sufficient metabolic challenge for the development of cardiovascular fitness.[1, 2] A study conducted at a self-selected intensity,[1] reported that heart rate (HR) and oxygen uptake ($\dot{V}O_2$) data when exercising on the elliptical trainer were not significantly different ($p>0.05$) from treadmill running, but were significantly higher ($p<0.05$) than exercise on a stair-climber. However, although statistically significant, the actual differences between the elliptical trainer and treadmill running groups compared to the stair-climbing group were small ($\dot{V}O_2$, 32.9, 31.5 and 28.8 ml.kg^{-1}.min^{-1},

The data have been presented in poster format at an International Congress of Sport Medicine, hosted by Trinity College Dublin, Ireland, 2001.

Received June 17, 2003.
Accepted for publication July 21, 2003.

Address reprint requests to: Dr. B. Donne, Department of Physiology, Trinity College Dublin, Dublin 2, Ireland. E-mail: b.donne@mail.tcd.ie

and HR 157, 161 and 152 beats.min^{-1}, respectively) and therefore, the results suggested the elliptical training, stair-climbing and treadmill running during a single bout of exercise at self-selected intensities offered similar training stimuli. To date there have been no direct comparisons using elliptical trainers and other common gym-based aerobic exercise devices following a training program, therefore it is unknown whether the small mode differences reported in responses to acute exercise [1] will produce different benefits following a medium-term exercise training program.

The aim of the present study was to compare the metabolic and cardio-respiratory improvements induced following a HR controlled aerobic training program using elliptical training, stair-climbing (free-climber device) and treadmill running exercise modalities. Untrained females were selected to participate, because they constitute a large proportion of gym users engaged in aerobic training. We hypothesized that stair-climbing and elliptical training groups exercising at intensities recommended by the ACSM would increase their $\dot{V}O_{2max}$ and that the increases in $\dot{V}O_{2max}$, in both groups would be equivalent to those elicited in a group undertaking treadmill training of similar volume and intensity.

Materials and methods

Subjects

Twenty-four moderately active healthy females, currently full members of a gym participated in this study. Subjects were considered "moderately active" if their initial fitness level ($\dot{V}O_{2max}$) was nominally between 30 and 45 ml.kg^{-1}.min^{-1}. None of the subjects were performing regular treadmill running, stair-climbing or elliptical training prior to the present investigation. Subjects were randomly assigned to the 3 exercise groups. The first 8 were assigned to the treadmill (710 Trotter, Cybex Ltd., USA), the next 8 to the elliptical trainer (EFX 546 Precor Ltd., USA), and the final 8 to the stair-climber (FreeClimber 4400 PT, StairMaster Ltd., USA) group. Before completing the entire program, 2 subjects dropped out, so the final sample consisted of treadmill (n=7), stair-climber (n=7) and elliptical trainer (n=8). Descriptive characteristics of the groups are presented in Table I. There were no significant differences across groups for all baseline measures. All subjects provided informed written consent in accordance with the Ethical Committee of Trinity College Dublin.

TABLE I.—*Mean±SD, age, height, body mass, body fat and body mass index.*

	Treadmill	Elliptical trainer	Stair-climbing
Age (y)	28.6±5.3	29.6±4.7	30.7±2.8
Height (m)	1.65±0.05	1.68±0.07	1.69±0.09
Body mass (kg)	62.5±7.3	76.7±16.7	73.2±7.5
Body fat (%)	26.0±4.4	31.1±4.3	30.9±3.1
BMI (kg.m-2)	22.5±2.4	26.4±4.2	26.6±3.5

Training protocol

Each subject performed 3 supervised exercise sessions weekly for 12 weeks. During this period, subjects were asked not to alter their regular activity pattern outside of training. Exercise intensity was based on a percentage of the exercise-specific maximal heart rate (HR_{max}) observed during an incremental test on an electronically loaded cycle ergometer. The training program was designed to satisfy the ACSM guidelines for improving cardio-respiratory fitness.[3] During the first 4 weeks, subjects trained at 70% to 75% HR_{max} for 30 min per session; progressing for weeks 5 to 8 to 40 min at 75% to 80% HR_{max}; and progressing for the final 4 weeks to 80% to 90% HR_{max} for 40 min. During all supervised training sessions, performed in an indoor air-conditioned gym, subjects were provided with a heart rate monitor (Cardiosport Ltd., Taiwan) to ensure and facilitate adherence to the correct exercise intensity.

Testing protocol

INCREMENTAL MAXIMAL TEST

The effectiveness of the training programs were monitored using a standard maximal incremental test to volitional exhaustion on an electronically loaded Tunturi EL 400 cycle ergometer (Tunturi Ltd., Finland) before and upon completion of the program. The test protocol employed was a continuous maximal incremental test, followed by an active recovery period. Following warm-up and stretching, subjects rested for 3 min and then began exercising at 60 W; intensity subsequently increased by 20 W every 3 min. Subjects maintained cadence between 60 and 70 rev.min^{-1} and were instructed to continue cycling until exhausted. Variables $\dot{V}O_2$, respiratory exchange ratio (RER) and

TABLE II.—*Mean±SEM, pre- and post-training (%) body fat, $\dot{V}O_{2max}$, $V E_{max}$ and max workload.*

	Treadmill	Elliptical trainer	Stair-climbing
Body fat (%)			
Pre	26.0±1.7	31.1±1.5	30.9±1.2
Post	23.9±1.3*	29.3±1.5*	30.2±1.1*
Body mass (kg)			
Pre	62.5±2.8	76.7±5.9	73.2±2.8
Post	62.4±2.6	75.8±6.1	72.3±2.8
$\dot{V}O_{2\ max}$ ($l.min^{-1}$)			
Pre	2.52±0.11	2.75±0.13	2.71±0.17
Post	2.68±0.13*	2.93±0.16*	2.81±0.20*
$\dot{V}O_{2\ max}$ ($ml.kg^{-1}.min^{-1}$)			
Pre	40.7±2.2	36.9±2.5	37.4±2.9
Post	43.4±2.6*	39.6±2.4*	39.2±3.1*
$\dot{V}_{E\ max}$ ($l.min^{-1}$)			
Pre	82.9±5.1	86.8±2.3	95.9±5.8
Post	90.2±6.4*	92.5±4.1*	97.4±5.8*
Max load ($W.kg^{-1}$)			
Pre	2.76±0.17	2.52±0.19	2.57±0.26
Post	2.88±0.18*	2.74±0.19*	2.68±0.25*

* Significant training induced improvement at $p<0.05$.

minute ventilation ($\dot{V}_E$), were recorded continuously using the Metamax metabolic cart (Cortex Ltd., Germany) and data at 10 s intervals during the final minute of each increment were recorded and averaged. Mean HR by radiotelemetry was calculated over the last minute of each successive 3 min increment. Criteria for $\dot{V}O_{2max}$ were to attain at least 2 of the following: a) plateau of $\dot{V}O_2$ as indicated by a difference between the last 2 stages of <2.1 $ml.kg^{-1}.min^{-1}$, b) an RER ≥ 1.15 or c) a HR within ± 10 $beats.min^{-1}$ of the subject's age predicted HR_{max} (220-age).

TEST TO DETERMINE LOAD FOR THE SUB-MAXIMAL TEST

All subjects performed fixed sub-maximal tests at 0, 4, 8 and 12 weeks using ergometers specific to their exercise group. Initially a graded test to determine individual sub-maximal exercise response was carried out at least 24 h before the 1st fixed load sub-maximal test to assess individual load at HR of 150 $beats.min^{-1}$. Subjects were instructed to keep exercising until the end of the 3 min element during which their HR was equal to, or greater than, 150 $beats.min^{-1}$. In addition, active recovery periods were established for the individual groups. During the sub-maximal tests and training program, subjects were allowed to lightly hold onto the supports when stair-climbing and elliptical training.

SUB-MAXIMAL TESTS

Before the sub-maximal fixed load test, subjects warmedup for 5 min on their specific ergometer and subsequently performed stretching exercises. During the sub-maximal test, each subject exercised for 15 min at the same relative intensity attained in the test to determine individual load at HR of 150 $beats.min^{-1}$ at the outset of the training program, followed immediately by a 5 min active recovery period at respective intensities. Mean HR was calculated during the last minute of each successive 3 min interval. During the 5 min active recovery period HR data were recorded every min. Before each sub-maximal test, percentage body fat was assessed by the 4 site skinfold protocol.[4]

Data analysis

A multi-factor analysis of variance (ANOVA) with repeated measures was used to compare training induced responses in maximal test data, and changes in sub-maximal test data at 3, 9 and 15 min of sub-maximal exercise and at 3 min into active recovery within group and between groups. For all ANOVA tests, post-hoc analyses of significant differences were quantified using Tukey's HSD test. For all statistical tests values of $p<0.05$ were considered statistically significant.

TABLE III.—*Mean±SEM HR data (beats.min^{-1}) at min 3, 9 and 15 during sub-maximal exercise and at min 3 during active recovery.*

	Time (min)			
	Exerc. 3	Exerc. 9	Exerc. 15	Recovery 3
Treadmill				
Week 0	153±1	159±2	162±2	117±3
Week 4	145±3*	150±4*	152±4*	109±4*
Week 8	141±3*§	145±3*§	147±3*§	103±5*§
Week12	138±4*§	143±3*§	147±3*§	100±5*§
Elliptical				
Week 0	151±1	158±2	158±2	140±4
Week 4	144±2*	146±2*	148±2*	130±3*
Week 8	141±2*§	143±3*§	144±3*§	127±2*§
Week12	138±2*§	141±3*§	143±3*§	123±3*§
Stair-climbing				
Week 0	152±1	162±3	165±4	142±4
Week 4	144±4*	150±4*	151±4*	128±5*
Week 8	139±2*§	146±3*§	144±3*§	124±3*§
Week 12	140±2*§	147±4*§	147±4*§	125±4*§

* Significantly different (p<0.05) from week 0; § significantly different (p<0.05) from week 4. The heart rates during active recovery on the treadmill were lower than the heart rates during active recoveries on the elliptical trainer and the stair-climbing ergometers. This was because the relative intensities during the 5 min active recovery periods were different across the 3 groups, mainly due to the different intensity settings of the exercise ergometers.

Results

Subject training compliance was high, overall (93%), and across groups (mean ± SEM), 91.7±2.9, 94.1±1.9 and 93.3±2.8% for treadmill, elliptical trainer and stair-climber groups, respectively. No significant inter group differences (ANOVA, $p>0.05$) were recorded for pre-training $\dot{V}O_{2max}$ (specific or absolute), maximum load.kg^{-1} body mass or for $\dot{V}_{Emax}$. After training, significant increases (2-way ANOVA) in specific and absolute $\dot{V}O_{2max}$, max workload.kg^{-1} body mass and $\dot{V}_{Emax}$ (Table II) were observed for all groups. The increases observed post-training for these variables were not significantly different across groups. Pre-training mean body fat (%) and body mass were not significantly different across groups (Table I). Body fat (%) significantly decreased ($p<0.05$) in all groups post-training (Table II), however, the decreases were not significant across groups. Mean body mass did not decrease significantly (Table II). In addition, monthly assessments of body mass and % body fat did not change significantly in any of the training groups.

Sub-maximal tests

For all groups, HR data during the fixed load sub-maximal tests decreased consistently across the training programs; within mesocycles, decreases in HR were significant from week 0 to 4, and from week 4 to 8 (Table III).

Discussion

Our results support the hypothesis that elliptical training and stair-climbing exercise modalities provide sufficient stimuli to develop cardiovascular fitness. The main finding of this investigation was, supporting our 2nd hypothesis, that similar significant physiological improvements ($\dot{V}O_{2max}$, maximum load.kg^{-1} body mass and $\dot{V}_{Emax}$) were observed using stair-climbing, elliptical trainer and treadmill running, when the training volume, frequency and intensity (% HR_{max}) were similar.

To our knowledge, no previous studies have investigated sub-maximal and incremental tests to volitional exhaustion in non-trained females during and following a controlled training program using an elliptical trainer exercise modality. Consequently, our results can only be compared and contrasted to training programs using stair-climbing and treadmill running. Three previous studies have evaluated stair-climbing ergometer training program on $\dot{V}O_{2max}$ in females.[5-7] However, the stair-climbing model used in previous studies was similar to an escalator, known as step-mill, whereas the model used in the present study, known as "free climber", had independent pedals, and produces less impact in the lower limbs than the step-mill device.

$\dot{V}O_{2max}$

Although monthly sub-maximal tests were performed in the gym using ergometers specific to exercise groups to monitor *interim* improvements, pre- and post-training maximal incremental tests were carried out in the laboratory using an electronically loaded cycle ergometer. This fact needs to be considered, as the use of the cycle ergometer during the maximal incremental test may have effected the overall results.

Ruby *et al.*,[8] used a similar test protocol to the present study in an investigation of untrained females training 4 days.week^{-1} for 10 weeks at 70-80% heart rate reserve. Subjects were divided into run, cycle or both run and cycle groups. After 10 weeks, all groups significantly ($p<0.05$) improved their $\dot{V}O_{2max}$ data on both treadmill and cycle ergometer, and the magnitude of the improvements were similar for both exercise modes. Consequently, an ergometer specific training induced improvement in $\dot{V}O_{2max}$ was not identified and therefore, we can assume *a priori* the fact that although the initial $\dot{V}O_{2max}$ data could possible have been greater if the maximal tests were performed on a treadmill,[8-12] ergometer specific training induced improvements were unlikely to happen in the present study, and therefore performing $\dot{V}O_{2max}$ tests on the cycle ergometer was considered a reasonable option.

The magnitude of the increases in specific $\dot{V}O_{2max}$ observed in the present study (5.7±1.8% for the treadmill running, 6.8±2.8% for the elliptical trainer and 4.4±1.3% for the stair-climbing groups) were reasonably consistent across groups, but slightly lower when compared with previous running and stepping studies using untrained subjects and programs of similar frequency, duration and intensity.[5-8, 13] Taking into account that subjects in the present study were moderately active, it is possible that the initial training intensity used (70-75% HR_{max}) did not provide sufficient stimulus, to induce as large a $\dot{V}O_{2max}$ improvement (9% to 16%) as that previously reported in subjects of similar initial fitness levels. In addition, HR max data on the treadmill, the ergometer used in the aforementioned studies,[5-8, 13] is normally significantly higher for this population of subjects than on the cycle ergometer,[14, 15] and in the present study the incremental tests were carried out on the cycle ergometer.

Sub-maximal tests

All groups significantly reduced fixed load sub-maximal HR data from week 0 to week 12 investigated at 3, 9 and 15 min of sub-maximal exercise and at min 3 of active recovery. Across all groups, within each mesocycle of training (4 week period) sub-maximal HR significantly decreased ($p<0.05$) between week 0 and 4 and between week 4 and 8, with the greatest decrease observed between week 0 and 4. It is possible that the greatest sub-maximal HR data reductions observed from week 0 to week 4 were in part due to familiarisation with the specific ergometers used as there were no significant differences observed from week 8 to 12. It is possible that the increase in the exercise intensity while keeping the duration constant from week 8 to 12 did not produce a sufficient overload to induce further sub-maximal HR improvements.

Conclusions

In conclusion, the results of this investigation indicate that in young to middle age semi-sedentary females, similar physiological improvements were observed using stair-climber, elliptical trainer and treadmill when the training volume, intensity and frequency were similar. Therefore, the main recommendation from these data is that previously untrained females can train using either elliptical trainer, treadmill or stair-climbing regimens and derive similar aerobic benefits for up to 12 weeks. The data imply that performing the incremental maximal tests on the cycle ergometer may have been a factor, which limited or biased the overall study findings. Therefore, future studies investigating these exercise modes could possible involve mode specific graded incremental tests for pre- and post-training maximal data assessment.

References

1. Porcari JP, Zedam JM, Naser L, Miller M. Evaluation of an elliptical exerciser in comparison to treadmill walking and running, stationary cycling and stepping. Med Sci Sports Exerc 1998;30:s168.
2. Kravitz L, Wax B, Mayo JJ, Daniels R, Charette K. Metabolic response of elliptical exercise training. Med Sci Sports Exerc 1998;30:s169.
3. American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. Baltimore: Williams & Williams; 1995.p.137-64.
4. Durnin JV, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. Br J Nutr 1974;32:77-97.
5. Loy SF, Holland GJ, Mutton DL, Snow J, Vincent WJ, Hoffman JJ *et al.* Effects of stair-climbing *vs* run training on treadmill and track running performance. Med Sci Sports Exerc 1993;25:1275-8.
6. Rosentswieg J, Verstraete D, Basset G. Stair-climbing as a training modality for women. Med Sci Sports Exerc 1986;19:s28.
7. Loy SF, Conley LM, Sacco ER, Vincent WJ, Holland GJ, Sletten EG *et al.* Effects of stairclimbing on $\dot{V}O_{2max}$ and quadriceps strength in middle-aged females. Med Sci Sports Exerc 1994;26:241-7.

8. Ruby B, Roberts R, Leadbetter G, Mermier G, Chick T, Stark D. Cross-training between cycling and running in untrained females. J Sports Med Phys Fitness 1996;36:246-54.
9. Hermansen L, Saltin B. Oxygen uptake during maximal treadmill and bicycle exercise. J Appl Physiol 1969;26:31-7.
10. Londeree BR, Thomas TR, Ziogas G, Smith TD, Zhang Q. %$\dot{V}O_{2max}$ *versus* %HR_{max} regressions for six modes of exercise. Med Sci Sports Exerc 1995;27:458-61.
11. Smith TD, Thomas TR, Londeree BR, Zhang Q, Ziogas G. Peak oxygen consumption and ventilatory thresholds on six modes of exercise. Can J Appl Physiol 1996;21:79-89.
12. Ben-Ezra V, Verstraete R. Stair climbing: an alternative exercise modality for firefighters. J Occup Med 1988;30:103-5.
13. Melanson EL, Freedson PS, Jung Bluth S. Changes in $\dot{V}O_{2max}$ and maximal treadmill time after 9 wk of running or in-line skate training. Med Sci Sports Exerc 1996;28:1422-6.
14. Keren G, Magazanik A, Epstein Y. A comparison of various methods for the determination of $\dot{V}O_{2max}$. Eur J Appl Physiol Occup Physiol 1980;45:117-24.
15. Martinez ML, Ibanez Santos J, Grijalba A, Santesteban MD, Gorostiaga EM. Physiological comparison of roller skating, treadmill running and ergometer cycling. Int J Sports Med 1993;14:72-7.