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Prediction of Change in Cardiorespiratory Fitness by the Stair-Climb Test After Ten Weeks of Aerobic Training

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Abstract

HYF, Tan., AR, Aziz., YHM, Chia. and KC, Teh. Prediction of Change in Cardiorespiratory Fitness by the Stair-Climb Test After Ten Weeks of Aerobic Training., Adv. Exerc. Sports Physiol., Vol.11, No.2 pp.61-67, 2005. The purpose of this study was to evaluate the sensitivity of the stair-climb test to predict changes in maximal oxygen uptake (VO_2max) following ten weeks of aerobic training. Twenty-two men (mean age 37±10 years) and 22 women (mean age 35±11 years) participated in the study. All subjects performed a pre-training treadmill test (TM1) and stair-climb test (SCT1) to obtain their measured and predicted VO_2max (MVO_2max & PVO_2max), respectively. Thereafter, they were randomized into the Exercise (E) and Control (C) groups. The training intervention for the E group consisted of thrice weekly 30-min sessions of aerobic exercises for ten weeks, with a target intensity ranging from 65 to 90% of maximum heart rate. The physical activity pattern of the C group remained unchanged throughout this period. Subsequently, all subjects performed a post-training treadmill test (TM2) and stair-climb test (SCT2). The difference between the changes in PVO_2max and MVO_2max following training ranged from -4.4 to 3.0 $ml \cdot kg^{-1} \cdot min^{-1}$. The Pearson product moment correlation coefficients (0.62 - 0.82; $P<0.01$) and the Spearman rank correlation coefficients (0.55 - 0.87; $P<0.01$) showed a moderate and positive relationship between PVO_2max and MVO_2max for men and women, pre- and post-training. In conclusion, the SCT (1) did not accurately track the changes in VO_2max after ten weeks of aerobic training; (2) but could acceptably rank or categorize subjects' VO_2max into broad fitness categories. The SCT serves as a simple and self-administered procedure to encourage sedentary individuals to engage in moderately intense aerobic exercise. We recommend that the SCT should not be used to precisely quantify or track small changes in cardio-respiratory fitness, but rather to create an interest in exercise by providing a broad estimate of aerobic fitness. It may also serve as a motivational tool to encourage individuals to use the stairs more often for exercise.

Keywords: sub-maximal, field test, maximal oxygen consumption

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Introduction

Maximal oxygen consumption (VO_2max) is an accepted index of cardio-respiratory fitness and functional aerobic capacity (2). The measurement of VO_2max in the laboratory is a costly and laborious task that does not lend itself to testing large number of subjects in a session. Therefore, numerous sub-maximal field tests have been developed to predict VO_2max or simply to categorize a person's cardio-respiratory fitness. These tests include stepping (7), walking and running (6, 8, 14) and more recently, stair-climbing (17). They are based on the relationship between field test measures and VO_2max obtained from the laboratory. These measures include performance time, heart rate and anthropometric variables in their predictive equations.

The Stair-Climb Test (SCT) was developed in our laboratory for use in healthy men and women aged 20 - 65 years (17). Subsequently, using a different group of subjects, the predictive ability of the SCT was validated against the oxygen uptake obtained in the laboratory (17). A follow-up study was also carried out to evaluate the reliability of the SCT (16). In a country where 86% of the people live in high-rise flats (13), it is appropriate to encourage the use of stairs for exercise. A national survey in 2001 reported that only 38% of the population exercised one or more times a week, citing lack of time as a major limiting factor (15). The SCT was developed with the aim to counter this reason for inactivity so that the population could be encouraged to use the stairs for exercise, as stairs are readily available to the majority of the poeple. A good way to promote stair climbing would be to introduce a stair-climb test so that individuals could assess their cardio-respiratory fitness by performing a few simple procedures. Briefly, the SCT requires the individual to measure his/her heart rate and the time needed to climb 22 Housing and Development Board (HDB) flights of stairs (11 floors), which are then used to calculate his VO_2max. The details of the protocol have been described in previous studies (16, 17). Following the development of the SCT, the Singapore Sports Council adopted it as one of the Sports For Life fitness assessments. In this instance, it is termed Step-FIT, which is the acronym for Self Test Estimate of Physical Fitness. Brochures and posters with instructions on how to perform the SCT are available to the public to encourage them to perform this test at their own time. The Step-FIT categorizes individuals' cardio-respiratory fitness into broad categories, namely, 'needs improvement', 'fair', 'good', 'very good' and 'excellent', rather than VO_2max values.

Despite the popularity of the SCT, especially in Singapore, the ability of the SCT to track changes in aerobic fitness over time, has not been addressed and is therefore in need of investigation. An appropriate field test that is sensitive to training may motivate individuals to start exercising and provide an impetus for them to continue with exercise and to monitor improvements in cardio-respiratory fitness over time. Therefore, the aim of the present study was to evaluate the sensitivity of the SCT to predict changes in VO_2max following ten weeks of aerobic training.

Materials and Methods

Subjects

Forty-four adult volunteers (Men N=22; Women N=22) between the ages of 20 and 53 years participated in the study. Subjects gave informed written consent to participate in the study. A medical screening consisting of a pre-participation medical questionnaire (PAR-Q), a resting 12-lead electrocardiogram (ECG) and a physical examination by a sports physician was performed on all subjects to ensure that they were free from high blood pressure, coronary artery diseases and orthopedic problems. The Singapore Sports Council Ethics Review Committee gave approval for the study.

Experimental design

Figure 1 depicts a schema of the experimental design. Results from the treadmill tests (TM1 & TM2) were the criteria reference upon which the results from the SCTs (SCT1 & SCT2) were compared with, in order to evaluate the sensitivity of the SCT to predict changes in VO_2max due to the training intervention.

Pre-training testing

Subjects performed a progressive maximal exercise test on the treadmill (Venus, H/P Cosmos) (TM1) to obtain their measured VO_2max (MVO_2max). Details of the protocol are described elsewhere (17). On a separate day, subjects' predicted VO_2max (PVO_2max) were determined using the SCT (SCT1). All SCT trials were conducted at the same HDB housing block. Temperature and humidity were monitored throughout all test sessions using a thermo-hygrometer (Hanna HI8564, Portugal). Environmental conditions were similar on all days (28.6 ± 0.7 ℃; 78.9 ± 2.3 %). No habituation was required as all subjects were familiar with the SCT protocol following their participation in the reliability study (16). Details of the SCT protocol are described elsewhere (16). By employing the sex-specific regression equations developed, the SCT predicted a person's VO_2max. The equation developed were: *Males*: VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)$=133-0.273$ (age in yrs)$-$ 0.672 (BMI) -0.236 (climb time in sec)-0.232 (heart rate at the end of climb); and *Females*: VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)$=66.69-0.135$ (age in yrs)-0.249 (BMI)-0.128 (climb time in sec)-0.021 (heart rate at the end of climb) (17).

Training intervention

Following the completion of the pre-training tests, subjects were divided at random into the Exercise (E) or Control (C) groups. Randomization was stratified according to gender and baseline cardio-respiratory fitness. There were no significant differences between the E and C groups in pre-training MVO_2max. The E group performed a variety of aerobic exercises that involved large muscle groups (e.g. walking, jogging, cycling, aerobics, stair-climbing, etc.) over a period of ten weeks, for a minimum of three times per week and 30 minutes per session. The exercise intensity was between 65 and 90% of their measured maximum heart rate obtained during the TM test. The training intensity is in accordance to guidelines set by the American College of Sports Medicine (ACSM) for healthy individuals to develop cardio-respiratory fitness through regular aerobic exercise (1). As the purpose of the study

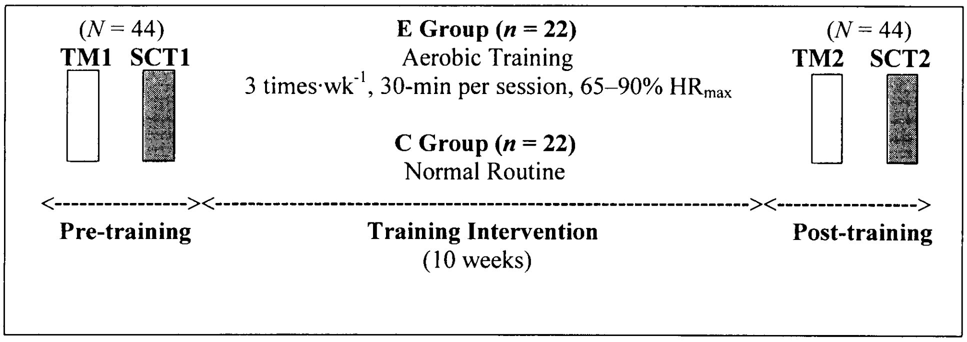

Fig. 1 Schematic of study protocol

was not to evaluate the effectiveness of a particular training regimen, the training intervention was not quantified in any greater detail over and above these guidelines. Each subject was assigned a training log to record the training data and a heart rate monitor (Polar S610, Kempele, Finland) to monitor exercise training intensity. Their heart rate data were downloaded and training logs were checked every week to assure compliance with minimum training guidelines. Subjects in the C group were told to keep their physical activity levels unchanged throughout the study period and were also advised not to alter their dietary habits.

Post-training testing

Following the training intervention, all subjects performed the treadmill test (TM2) in the laboratory and the SCT, at the same staircase and at the same time of day as the SCT1 (SCT2) and on two separate days in order to obtain post-training MVO_2max and PVO_2max, respectively. The procedures for TM2 and SCT2 were similar to those described for TM1 and SCT1. Environmental conditions were similar on all days (26.5 ± 0.8 ℃; 79.7 ± 3.2 %).

Statistical analyses

The Statistical Package for Social Sciences (SPSS 11.5 for Windows) was used for all statistical analyses. Descriptive data (means and standard deviations) of the subjects and their performance in the tests were computed. The changes in PVO_2max were compared with those of MVO_2max to evaluate the sensitivity of the SCT. Paired sample t-tests were performed to determine if there were significant differences in CT and HR_{end} for the E and C groups, before and after the training intervention. Differences between PVO_2max and MVO_2max for the E and C groups, before and after the training intervention were determined with two-way analysis of variance (ANOVA) followed by Tukey-HSD *post-hoc* test if the differences were significant. The Pearson product moment correlation coefficient and the Spearman rank correlation coefficient were used to determine the direction and strength of the relationship between the PVO_2max and MVO_2max, before and after the training intervention. The purpose of the latter was to determine the relationship between the rankings of subjects' PVO_2max and MVO_2max values. Statistical significance was set at $P<0.05$.

Results

The physical characteristics of the subjects are presented in Table 1.

Climb time and HR_{end} of the SCT are presented in Table 2. Following the training intervention, CT decreased significantly in the E group ($P<0.01$) for men, while HR_{end} decreased significantly in the E group ($P<0.05$) for women.

Predicted and measured VO_2max pre- and post-training are presented in Table 3. There were no significant differences between PVO_2max and MVO_2max in all groups. Although statistical significance was not achieved between pre- and post-training for PVO_2max and MVO_2max in all groups, there was noticeable improvement in MVO_2max (13.2%) in the E group for men.

Changes in VO_2max, the differences between the predicted and measured changes are presented in Table 4. The SCT under-predicted the differences of changes for the E group and over-predicted the differences for the C group.

The Pearson product moment correlation coefficients and the Spearman rank correlation coefficients for PVO_2max and MVO_2max for both men and women before and after the training intervention were significant ($P<0.01$). The results showed a moderate and positive relationship between PVO_2max and MVO_2max, thus indicating that the VO_2max estimates were ranked moderately similar as the actual VO_2max. The number of equally ranked subjects was increased when the VO_2max categories were broadened.

Table 1 Physical characteristics of the subjects (Men, N=22; Women, N=22). (Mean±SD)

	Men	Women
Age (yrs)	37 ± 10	35 ± 11
Body height (cm)	171 ± 7	162 ± 6
Body weight (kg)	70.0 ± 10.0	62.9 ± 11.9
Body mass index ($kg \cdot m^{-2}$)	23.8 ± 2.4	23.8 ± 3.7

Table 2 Climb time and heart rate at the end of climb (HR_{end}) during the SCT before and after ten weeks of aerobic training intervention. (Mean±SD)

	Men		Women	
	Pre	Post	Pre	Post
Climb Time (s)				
Exercise Group	95 ± 12	91 ± 11**	101 ± 13	98 ± 11
Control Group	100 ± 13	101 ± 12	106 ± 7	107 ± 9
HR ($beats \cdot min^{-1}$)				
Exercise Group	156 ± 13	155 ± 13	175 ± 10	172 ± 8*
Control Group	163 ± 15	161 ± 14	169 ± 8	169 ± 9

*$P<0.05$; **$P<0.01$

Table 3 Maximal oxygen uptake (VO_2max) ($ml \cdot kg^{-1} \cdot min^{-1}$) in the SCT and in the TM test before and after ten weeks of aerobic training. (Mean ± SD)

	Men		Women	
	Pre	Post	Pre	Post
Exercise Group				
MVO_2max	43.9 ± 6.5	49.7 ± 6.8	34.3 ± 6.8	35.7 ± 6.1
PVO_2max	48.8 ± 3.4	50.3 ± 3.5	39.4 ± 3.3	39.9 ± 3.1
Control Group				
MVO_2max	41.9 ± 6.5	39.4 ± 7.4	35.1 ± 6.1	34.5 ± 6.0
PVO_2max	45.0 ± 4.2	45.5 ± 4.3	38.9 ± 2.0	38.9 ± 2.1

Table 4 Changes in VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$) following training in the SCT and in the TM test and the differences of changes between the SCT and the TM test. (Mean ± SD)

	Changes in VO_2max		Differences of Changes
	MVO_2max	PVO_2max	
Exercise Group			
Men (N = 22)	5.9 ± 2.0	1.5 ± 1.0	− 4.4 ± 2.6
Women (N = 22)	1.4 ± 2.6	0.5 ± 0.6	− 0.9 ± 2.5
Control Group			
Men (N = 22)	− 2.5 ± 3.5	0.5 ± 1.5	3.0 ± 3.6
Women (N = 22)	− 0.6 ± 1.4	0.0 ± 0.4	0.6 ± 1.5

Table 5a. Number of subjects categorized into broad categories of aerobic fitness

Men				
VO_2max	Pre-training		Post-training	
($ml \cdot kg^{-1} \cdot min^{-1}$)	TM1	SCT1	TM2	SCT2
> 60	—	—	1	—
> 55	1	1	2	1
> 50	3	2	4	4
> 45	3	12	1	11
> 40	7	5	8	4
> 35	6	2	2	2
> 30	2	—	4	—
Spearman Rank Correlation	—	0.58**	—	0.55*
Number of equally ranked subjects		4		4
Pearson Correlation		0.62**		0.64**

Women				
VO_2max	Pre-training		Post-training	
($ml \cdot kg^{-1} \cdot min^{-1}$)	TM1	SCT1	TM2	SCT2
> 45	1	1	—	—
> 40	3	7	5	9
> 35	6	13	8	12
> 30	6	1	4	1
> 25	5	—	5	—
> 20	1	—	—	—
Spearman Rank Coefficient	0.87**		0.79**	
Number of equally ranked subjects	6		9	
Pearson Correlation	0.82**		0.78**	

$^{**}P < 0.01$

Table 5b. Number of subjects categorized into broader categories of aerobic fitness

Men				
VO_2max	Pre-training		Post-training	
($ml \cdot kg^{-1} \cdot min^{-1}$)	TM1	SCT1	TM2	SCT2
> 60	—	—	1	—
> 50	4	3	6	5
> 40	10	17	9	15
> 30	8	2	6	2
Spearman Rank Coefficient	0.58**		0.55*	
Number of equally ranked subjects	10		10	
Pearson Correlation	0.62**		0.64**	

Women				
VO_2max	Pre-training		Post-training	
($ml \cdot kg^{-1} \cdot min^{-1}$)	TM1	SCT1	TM2	SCT2
> 40	4	8	5	9
> 30	12	14	12	13
> 20	6	—	5	—
Spearman Rank Coefficient	0.87**		0.79**	
Number of equally ranked subjects	12		13	
Pearson Correlation	0.82**		0.78**	

** $P < 0.01$

Discussion

During the training intervention for men, the E group adhered to the training well and the increase in MVO_2max was clearly noticeable (13.2%) although statistical significance was not achieved (i.e. $P>0.05$). There was also a significant decrease in CT (4.2%, $P<0.01$) following training. However, HR_{end} showed no significant change. The result was a small and non-significant increment in PVO_2max (3.0%). The SCT failed to predict the improvement in VO_2max by the same magnitude as the TM test in the E group although the direction of change was similar. In the C group for men, there was a non-significant decline in PVO_2max (1.1%) and MVO_2max (6.0%).

For female adults, due to reasons that are not readily apparent, there was only a small and non-significant improvement in MVO_2max (4.1%) and PVO_2max (1.3%) in the E group. We may suggest some reasons based on data from the HERITAGE Family Study (5), which to the best of our knowledge is the only published study to date whose goal was to address the extent and the causes of the heterogeneity in response to regular exercise. Individual differences in the trainability of VO_2max in previously sedentary men and women were examined in the cited study. Results of the study showed that there was substantial heterogeneity in responsiveness of VO_2max in subjects after being trained over 20 weeks that involved 60 sessions. The responses in VO_2max after training ranged from zero gain to an increase of $>1.10\ L \cdot min^{-1}$. The authors concluded that the trainability of VO_2max is highly familial and includes a significant genetic component. Bouchard and Rankinen (4) in a review paper on the individual differences in response to regular physical activity highlighted that the exact nature of the mechanisms responsible for the heterogeneity in response to regular exercise is unclear. However, it is conceivable that there are 'responders' and 'non-responders' to aerobic training. Baseline characteristics of sedentary state may have a considerable impact on the responsiveness.

Very few studies have assessed the sensitivity of field-based cardio-respiratory fitness tests in a follow-up training intervention design. One of which was a study conducted by Laukkanen et al. (11) to examine the sensitivity of the 2-km UKK Walk Test (UWT) to detect changes in VO_2max after training. The study involved 25 men and 28 women who were trained aerobically for 15 weeks by walking four times weekly, at 65-75% VO_2max for 50 minutes per session. Correspondingly, 26 men and 29 women served as controls. Maximal oxygen uptake was measured and predicted by the TM test and UWT respectively, before and after the training intervention. The change in VO_2max was accurately predicted in the E group. However, the subjects in the cited study performed walking training that was specific to the walk test protocol. Therefore, besides cardio-respiratory fitness, the efficiency of walking could have improved substantially after numerous walking training sessions. This was supported by the fact that the UWT was unable to predict the change in VO_2max by the same magnitude as the TM test in the C group of the same study. Apparently, the C group also improved in their cardio-respiratory fitness but the change in VO_2max from the pre-test to the post-test, as reflected by the TM test, was twice as much as that predicted by the UWT for men and women. The results may suggest that in order to predict changes in cardio-respiratory fitness accurately, the mode of training should be specific to the test protocol.

In contrast to the cited study, the training intervention in the present study was not specific to the SCT protocol but designed as general exercise training to encompass all types of aerobic exercises, e.g. walking, jogging, swimming, rope jumping, etc. If the subjects had trained solely using the stairs, we could argue that the sensitivity of the SCT in tracking the changes in VO_2max in the E group might be improved. In support of this assertion, Boreham et al. (3) reported that subjects who stair-climbed five days per week for seven weeks substantially improved their exercise economy during the post-training stair-climb test.

Vehrs et al. (18) investigated the ability of the 1.5-Mile Run (1.5MR) to track improvements in VO_2max during and after 16 weeks of endurance running training. In the cited study, 21 men (mean age 23 years) jogged at least thrice per week, 30 to 60 minutes per session, for 16 weeks. Following training, the VO_2max predicted by the 1.5MR was significantly lower than the VO_2max as measured in the TM test. Nevertheless, the Spearman rank correlation coefficients between the 1.5MR and the TM test before and after the training intervention were significant (Pre: $r_s=0.91$, Post: $r_s=0.86$; $P<0.01$), thus indicating that the 1.5MR can acceptably rank subjects' VO_2max levels. Supporting a similar finding, the Spearman rank correlation coefficients between the SCT and TM tests, before and after the training intervention were significant for men and women in the present study. However, the correlations were stronger in women than in men, probably because the range of pre-training MVO_2max and PVO_2max and the changes in these values post-training were smaller in women. As a result, the spread in rankings was less and thus the correlation was higher. Collectively, these results demonstrated a moderate and positive relationship, which indicated that the PVO_2max were ranked similarly as the MVO_2max when categorized into broad categories. As illustrated in Tables 5a and 5b, when the categories of VO_2max values were broadened, the number of equally ranked subjects increased.

In comparison with the UWT and the 1.5MR, the SCT possesses some critical differences. Firstly, the mode of exercise for the criterion test upon which the SCT was developed was running. Therefore, there could be a mismatch between the TM and SCT tests since stair-climbing is quite different from running. Secondly, the duration of the SCT is relatively short. Even though Teh & Aziz (17) showed that most subjects reached steady state heart rate at about the 90-second mark, it could be argued that the duration of the SCT in this study (79-121 s) was insufficient to induce a steady state in oxygen uptake in some subjects.

There are several limitations in the present study. The heterogeneity in subjects' baseline cardio-respiratory fitness may warrant a larger sample size in order to establish significant improvements following training. Additionally, the training intervention could have been longer and/or more vigorous in order to bring about significant changes in VO_2max. The speculation about improvement in climbing efficiency and thus PVO_2max cannot be confirmed, as subjects did not train solely using the stairs during the intervention period.

In summary, the SCT (1) did not accurately track the changes in VO_2max after ten weeks of aerobic training; (2) but could acceptably rank or categorize subjects' VO_2max into broad fitness categories. The SCT serves as a simple and self-administered procedure to encourage sedentary individuals to engage in moderately intense aerobic exercise. We recommend that the SCT should not be used to precisely quantify or track small changes in cardio-respiratory fitness, but rather to create an interest in exercise by providing a broad estimate of aerobic fitness. It may also serve as a motivational tool to encourage individuals to use the stairs more often for exercise.

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