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A Stair-Climb Test of Cardiorespiratory Fitness for Singapore

K C Teh, A R Aziz

ABSTRACT

Objective: The purpose of this study was to develop a stair-climb test of cardiorespiratory fitness for adult Singaporeans, particularly those staying in Singapore Housing and Development Board (HDB) flats.

Method: 103 subjects [56 males, of mean (SD) age 44.8 (13.9) years and Body Mass Index, or BMI, 23.3 (3.2); and 47 females, of age 43.2 (12.9) years and BMI 21.9 (2.8)] were first assessed for their cardiorespiratory fitness, measured using maximal oxygen uptake (or VO_{2max}) on a treadmill, before undergoing a stair-climb test up to the 12th storey (11 floors) of a typical HDB flat (180 steps, vertical height 27.0 metres).

Results: The mean (SD) time taken for the climb (CT) and heart rate at the end of the climb (HR_{end}) averaged 111.3 (16) seconds and 154.4 (13.4) beats·min^{-1} respectively for males, and 121.0 (18.1) seconds and 164.6 (15.7) beats·min^{-1} respectively for females. Regression equations were developed to predict VO_{2max} from age (years), BMI, CT (seconds), HR_{end} (beats·min^{-1}):

For males: VO_{2max} (ml·kg^{-1}·min^{-1}) = 133 - 0.273 (Age) - 0.672 (BMI) - 0.236 (CT) - 0.232 (HR_{end}).

For females: VO_{2max} (ml·kg^{-1}·min^{-1}) = 66.69 - 0.135 (Age) - 0.249 (BMI) - 0.128 (CT) - 0.021 (HR_{end}).

Validation of the regression equations conducted on a different sample consisting of 18 subjects (11 male and 7 female) showed significant correlations between the predicted and directly measured VO_{2max} (males, r = 0.81 and females, r = 0.90; $p < 0.01$). There were no significant differences between the means of predicted and directly measured VO_{2max}.

Conclusion: A stair-climb test using HDB stairs was developed which was able to estimate cardiorespiratory fitness with reasonable accuracy.

Keywords: stair-climb test, cardiorespiratory fitness, VO_{2max}, Singapore

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Sports Medicine & Sports Science
Singapore Sports Council
15 Stadium Road
National Stadium
Singapore 397718

K C Teh, MBBS, MS (Sp Med)
Director and Consultant

A R Aziz, DPE, BPE
Exercise Physiologist

Correspondence to:
Dr K C Teh

INTRODUCTION

Singapore is a well-developed country which is densely populated (about 3.7 million in a small island of about 648 sq. km in 1997[1]). About 86% of the population lives in Housing and Development Board (HDB) high-rise flats[1].

A large percentage of the adult population is relatively physically inactive. In a 1997 survey, only 34% of the population sampled (15 years and older) exercised one or more times a week, citing lack of time as a major factor for remaining inactive[2]. To counter this reason for not being physically active, the population could be encouraged to use the stairs for exercise, as stairs would be readily available to most of them. One way to promote stair climbing as an exercise would be to introduce a stair-climb test of cardiorespiratory (or aerobic) fitness which is easy to conduct and can be done just outside the home.

By having a simple test, adult Singaporeans can then easily assess their fitness at regular intervals, and at their own convenience. Such a test would be a useful monitoring tool for Singaporeans who are too busy to take fitness tests available at the Singapore Sports Council (SSC) facilities or elsewhere. The use of stairs or steps for exercise and fitness tests is not new[3-10] but a test using the stairs in a high-rise public building has not been developed so far. The objective of this study, therefore, was to develop a stair-climb test to assess cardiorespiratory fitness using stairs of HDB flats that are easily available to adult Singaporeans.

METHODS

Procedures

The study consisted of three parts. The first part involved the determination of the subjects' maximum heart rate (HR) and cardiorespiratory fitness measured in the laboratory using maximal oxygen uptake or VO_{2max}. The second part was the stair-climbing field test at a HDB flat in the Marine Parade area of Singapore. The cohort of subjects involved in this part of the study was termed the development group since their data was used to develop the equations to predict aerobic fitness from performance in the stair-climb test. The third part consisted of validating the regression equations derived from the first two parts of the study. A different cohort of subjects (termed the validation group) was used to evaluate the regression equations. All field tests were conducted within two weeks of the laboratory assessment.

Subjects

Subjects were recruited via the Singapore Sports Council's e-mail system and through word of mouth. All subjects were thoroughly briefed on the purpose of the study and signed consent forms before participating. All subjects were screened with a health history questionnaire, a resting ECG, and underwent a medical check-up by a physician to determine their suitability for the study. Those with medical complications like orthopaedic problems and/or evidence of high cardiorespiratory risks were excluded from the study. A total of 103 subjects (56 males and 47 females) participated in the development group. The mean (SD) of the development group's characteristics is summarized in Table I. As the stair-climb test was potentially meant for the average adult Singaporean, we ensured that the number of subjects in arbitrarily-determined age-groups was fairly well-represented. In the following age groups of 20-29, 30-39, 40-49, 50-59 and those 60 years and above, there were 11 and 10, 11 and 10, 14 and 9, 10 and 12, and 10 and 6 male and female subjects, respectively.

Maximal Oxygen Uptake (VO_{2max}) Test

The test used a progressive incremental exercise protocol on a treadmill, Marquette model 1900 (Milwaukee, USA). All subjects were given 8 minutes of initial warming-up on the treadmill to familiarize with the testing procedures and for test safety, and also to establish the appropriate speed for the actual test. With younger subjects (below 35 years old), the protocol used on most occasions was a constant speed (9 to12 $km \cdot h^{-1}$) with a gradual increase in treadmill gradient. The gradient was increased by 2% every minute for the first five minutes and subsequently by 1% every minute until volitional exhaustion. In the case of the elderly subjects (and for some of the younger subjects), either a similar protocol but with a much slower speed (6 to 8 $km \cdot h^{-1}$) or a modification of the Balke protocol[11] (using a treadmill speed of 6 $km \cdot h^{-1}$) were used.

Oxygen uptake was measured using an open circuit system with a portable oxygen analyzer, the K4 (Cosmed, Italy), using the mixing chamber mode. This system has previously been validated[12]. The K4 system comprised the analyzer unit, battery pack and face-mask together with a heart rate monitor (Polar Oy model Sports Tester, Kempere, Finland). The equipment weighed about 800 g and was strapped onto a harness that the subject wore over his or her attire. The analyzer was calibrated according to the manufacturer's instructions prior to each test. In subjects below 35 years old, heart rate was continuously monitored with a short-range telemetry heart rate monitor (Polar Oy model Sports Tester, Kempere, Finland). Both the oxygen and heart rate data were averaged every 15 seconds throughout the test. In those above 35 years old, a 12-lead ECG monitoring system (Marquette model Case 15, Milwaukee; USA) was used to monitor heart rate as well as cardiorespiratory abnormalities during the maximal test.

The highest oxygen value observed during the test was reported as the subjects, maximum oxygen uptake (VO_{2max}). Subjects were considered to have attained their VO_{2max} based on two of the following criteria: i) volitional exhaustion, ii) respiratory exchange ratio of > 1.10, iii) reached or exceeded 95% of the individual's estimated maximum heart rate (based on the formula: *220 – age*). The maximum heart rate was the highest heart rate recorded during the test.

Stair-Climbing Field Test

The stair-climbing field test was conducted at a randomly-selected HDB flat in the Marine Parade Housing Estate. All field-testing was conducted in this block. For the stair-climb field test, subjects were required to climb up 11 floors (22 flights of stairs, ending on the 12th storey) of a typical HDB flat. Eleven floors was chosen because of i) the minimum average time taken for oxygen uptake to reach a steady state for a continuous type of climbing activity and ii) the minimum number of floors of an average HDB block. The total vertical distance covered in climbing the 11 floors was 27.0 metres. This vertical distance covered was based on the number of steps climbed and calculated as follows:

Height of a step = 15 cm

Number of steps per flight:
8 steps (except for first flight with 12 steps)

Number of flights
= 22 (1 flight with 12 steps and 21 flights with 8 steps)

Therefore, vertical height of 11 floors
= (15 cm x 12 steps) + (15 cm x 8 steps x 21 flights)
= 180 + 2520 = 2700 cm = 27.0 m

Subjects were clearly briefed on the test procedures just prior to their climb. Subjects were instructed to climb at a brisk, but even pace. Steps taken were to be of constant rhythm throughout the whole duration of the test. They were to take only one step at a time whilst running was not allowed. They were not allowed to stop

Table I. Summary of Laboratory and Field Measurements of Development (N = 103) and Validation Groups (N = 18).

	DEVELOPMENT Group		VALIDATION Group	
	Male (N = 56)	Female (N = 47)	Male (N = 11)	Female (N = 7)
Age (yr)	44.8 (13.9)	43.2 (12.9)#	38.1 (10.7)	27.4 (7.3)
Range	22.3 – 77.6	22.1 – 67.0	23.2 – 52.9	22.4 – 43.6
Height (cm)	168.4 (6.1)	157.8 (5.3)	170.5 (4.7)	159.8 (6.2)
Range	154.5 – 184.0	147.5 – 172.0	164.0 – 177.0	154.0 – 168.5
Weight (kg)	66.2 (10.6)	54.4 (7.2)	69.1 (8.4)	53.7 (6.2)
Range	48.3 – 90.8	42.7 – 69.0	57.1 – 84.0	47.9 – 63.2
BMI	23.3 (3.2)	21.9 (2.8)	23.7 (2.5)	21.0 (1.7)
Range	16.4 – 33.4	16.7 – 28.2	19.6 – 27.4	18.8 – 23.3
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	43.06 (8.45)	36.52 (5.36)#	47.75 (8.15)	43.90 (7.39)
Range	27.0 – 62.3	25.8 – 47.8	35.8 – 65.9	33.0 – 53.1
HR_{max} ($beats \cdot min^{-1}$)	179 (19)	178 (17)	185 (8)	185 (9)
Range	134 – 213	126 – 201	166 – 196	175 – 198
Time for Climb (s)	111.3 (16.0)*	121.0 (18.1)#	95.1 (5.1)	100.3 (7.9)
Range	83.0 – 171.0	90.0 – 159.0	86.0 – 103.0	91.0 – 111.0
HR_{end} ($beats \cdot min^{-1}$)	154.4 (13.4)	164.6 (15.7)	154.4 (11.9)	168.0 (13.6)
Range	127.0 – 189.0	116.0 – 192.0	126.0 – 196.0	151.0 – 187.0

* significantly different from male in the validation group, $p < 0.05$
# significantly different from female in the validation group, $p < 0.05$

at any point during the climb or use the side-railings for support. An investigator accompanied each subject on his or her climb to ensure that subjects followed the protocol accordingly. On the 12th storey, the investigator immediately noted down the subject's (i) heart rate (HR_{end}) and (ii) time of completion of the climb (CT). The duration of the climb was hand-timed using a stop-watch (Casio model HS-5, Tokyo, Japan).

During the stair-climb test, subjects were also equipped with the K4 gas analyzer system to determine their ascending heart rate and oxygen consumption characteristics. The equipment did not hinder or obstruct the movement or vision of the subjects. While the heart rate data was used in the current study, the oxygen data collected during the climb was not reported here as it was to be used in another study. All subjects underwent a standardized warm-up after being fitted with the K4. The warm-up, which was conducted by one of the investigators, included standardized stretching exercises for two to three minutes for the calf, hamstring and quadriceps muscles, followed by climbing of a flight of stairs thrice. This trial climb allowed the subjects to familiarize with and adjust their pace for the actual stair-climb test. A rest of one minute was given after this trial climb before the commencement of the actual climb test.

Validation of the Regression Equations

A follow-up investigation was subsequently conducted to validate the regression formulae developed for predicting VO_{2max} from the stair-climb test, using a different sample of 18 (11 male and 7 female) subjects. The mean (SD) of the validation group's characteristics is summarized in Table I. These subjects were made to go through the same tests and procedures as in the first two parts of the study, except that they were not equipped with the K4 gas analyzer during the stair-climb test.

Statistical Analyses

The Statistical Package for Social Sciences (SPSS 8.0 for Windows) was used for all statistical analysis. Descriptive data (means, standard deviations and range) for the subjects and their performances in the exercise tests were computed. The independent t-test was used to determine differences between the males and females of the two different groups, development and validation. Multiple regression equations were developed to estimate VO_{2max} from age (years), BMI, time of the climb (CT, in seconds), and heart rate at the end of the climb (HR_{end}, in $beats \cdot min^{-1}$).

To assess the validity of the regression equations, the Pearson Product Moment correlation analysis was used to determine the relationship between the predicted VO_{2max} and the directly measured VO_{2max} in the both the development and validation groups. The paired t-test was used to determine if there was any significant difference between the means of predicted VO_{2max} and directly measured VO_{2max}. The mean difference with its SD and the total error statistic E were used as error measures. The total error E of the prediction was calculated as

$$E = \sqrt{\frac{\Sigma(\hat{y}_i - y_i)^2}{n}}$$

where $\hat{y}_i$ is VO_{2max} predicted or estimated by the stair-climb test, y_i is VO_{2max} directly measured during the maximal exercise test and n is number of observations[13]. The level of statistical significance was set at $p < 0.05$.

RESULTS

Table I summarizes the subjects' characteristics and their laboratory and field measurements. During the conduct of the study, two elderly subjects (one male aged 65 years and one female aged 60) were unable to complete the stair-climb test (their data were excluded from the analyses). Both were breathless mid-way through the climb and had to stop. A plausible reason for this could be that they started off the test climb at too fast a pace.

There were no significant differences in the variables measured between males in the development and validation groups except for the time to climb the 11 floors during the stair-climb test. The average male in the development group was significantly slower than the average male in the validation group in the stair-climb test ($p < 0.001$). The average female in the development group was similarly slower than her counterpart in the validation group ($p < 0.05$). In addition, the average female in the development group was much older ($p < 0.001$) and had a significantly lower value for directly measured VO_{2max} ($p < 0.05$).

The regression equations developed to predict VO_{2max} from age (years), BMI, time of the climb (CT, in seconds), and heart rate at the end of the climb (HRend, in beats·min^{-1}) were:

For males:

VO_{2max} (ml·kg^{-1}·min^{-1}) = 133 - 0.273 (Age) - 0.672 (BMI) - 0.236 (CT) - 0.232 (HR_{end})

For females:

VO_{2max} (ml·kg^{-1}·min^{-1}) = 66.69 - 0.135 (Age) - 0.249 (BMI) - 0.128 (CT) - 0.021 (HR_{end})

DISCUSSION

The purpose of this study was to develop a field test that was able to determine the cardiorespiratory fitness of the average adult Singaporean with reasonable accuracy. The rationale for the use of the stairs as the testing mode was that stairs are easily accessible to the majority of the population. In addition, the proposed test had to be simple, require little equipment and should be easy to administer.

The mean (SD) aerobic power values of 43.06 (8.45) and 36.52 (5.36) ml·kg^{-1}·min^{-1} for the males and females respectively in the development group, showed that subjects in this study would be considered as having good cardiorespiratory fitness, when compared to a previous study done on Singaporeans[14] and with other populations[15].

Apart from the two variables of the time of climb and heart rate at the end of the climb that are necessary to develop the regression equations, the other variables of age and BMI were chosen for several reasons. It is well-established that cardiovascular fitness or aerobic power, decreases with age although regular physical activity may abate the rate of decline[16,17]. Body mass is a factor to consider when working against the force of gravity as the load carried throughout the climb affects heart rate. The BMI was used rather than body mass since the 2-km walk test conducted by the Singapore Sports Council uses it as well in predicting individual fitness levels. Using body weight in the regression equations would have resulted only in a slightly better correlation than using BMI (r= 0.772 for males and 0.710 for females versus r= 0.764 for males and 0.694 for females).

Fig. 1 shows the relationship between the predicted and directly measured VO_{2max} in the males of the development and validation groups. Fig. 2 shows the relationship for female subjects. The trend of the line of best fit showed a generally good relationship between the predicted and directly measured VO_{2max} in the two groups for both genders, although the relationship appeared closer in the male than the female cohort. Several reasons might explain this observation. Males in the development and validation groups were very similar, the only contrasting variable being the time for the stair-climb test (CT). In females, the validation group

Fig. 1 Directly Measured (DM) VO_{2max} vs. Predicted (P) VO_{2max} in Males of Development (N = 56) and Validation (N = 11) Groups.

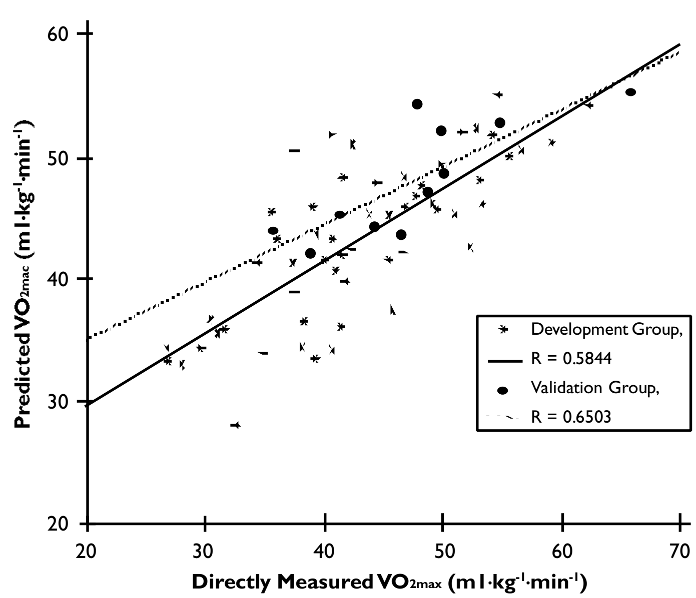


Fig. 2 Directly Measured (DM) VO_{2max} vs. Predicted (P) VO_{2max} in Females of Development (N = 47) and Validation (N = 7) Groups.

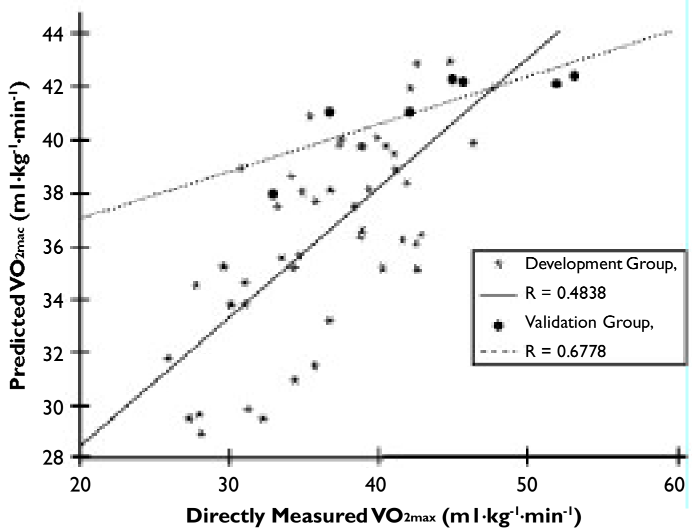
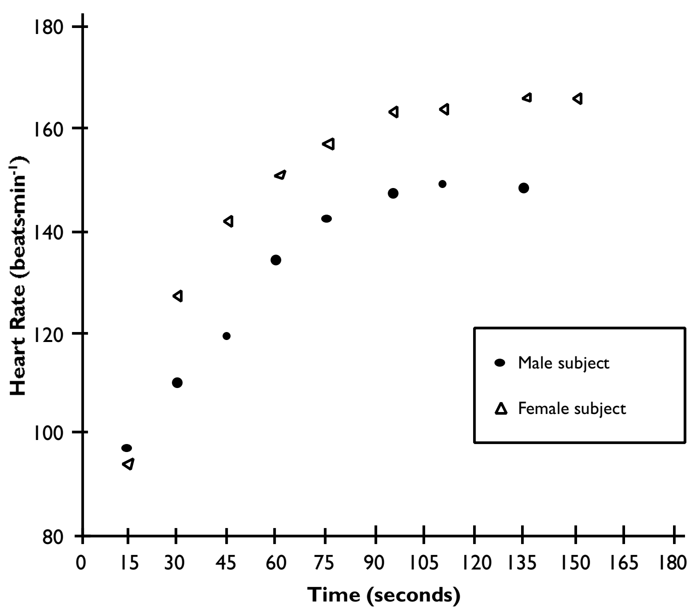


Fig. 3 Heart rate response during stair climbing for a typical Male and Female subject.



was significantly fitter and younger than the development group. This could have resulted in the larger variance between the female groups.

Table II compares the directly measured and predicted VO_{2max} in the validation group of subjects. The individual differences between the predicted and directly measured VO_{2max} values ranged from as low as 0.3 to a high of 11.1 ml·kg^{-1}·min^{-1}. These values were equivalent to 0.7 to 22.1% of the individual's directly measured VO_{2max}. However, the mean group differences between the directly measured and predicted VO_{2max} were small, about 0.2 and 2.7 ml·kg^{-1}·min^{-1} in the male and female cohorts, respectively. This is about 0.4 to 6.2% and would be considered as acceptable for such field tests for determining cardiorespiratory fitness. For example, in the 2-km walk test of Oja et al[18], differences between directly measured and predicted VO_{2max} varied from 0.9 to 4.3 ml·kg^{-1}·min^{-1} or 3.3 to 11.7%. In the Canadian Home Fitness Step Test, Shephard et al[9] reported that the discrepancy compared with directly measured aerobic power in young adults averaged about 10%.

Statistical analysis revealed significant correlation between directly measured VO_{2max} and the predicted VO_{2max} derived from the regression equations in male and female cohorts of both the development ($r = 0.76$ and 0.70, $p < 0.01$ respectively) and validation groups ($r = 0.81$ and 0.90, $p < 0.01$ respectively). These correlations are favorable given the small number of subjects in the validation sample. It is possible that the correlation would have been higher if the directly measured VO_{2max} had been conducted on a stepping ergometer[19]. Furthermore, the paired t-test analysis showed no significant difference between the directly measured and predicted mean VO_{2max} values in both male and female validation groups ($p = 0.936$ and 0.306). In addition, the total error (E) for the validation sample was 4.9 and 6.3 ml·kg^{-1}·min^{-1} in males and females respectively, which compared favorably with the corresponding E of 5.4 and 3.8 ml·kg^{-1}·min^{-1} in the development group (see Table III). All these suggest that the regression formulae to predict aerobic power from the stair-climb test are valid.

Strengths and limitations of the stair-climb test

This stair-climb test has many advantages compared with other commonly available fitness tests. The stair-climb test is simple to conduct and does not require specialised equipment like a bicycle ergometer or other equipment such as bench steps. Heart rate can be easily determined via palpation or use of heart rate monitors while timing of the climb requires only a normal watch (with accuracy to one second). Furthermore, the test can be conducted as a self-test without the need for any expert knowledge. Another advantage of the stair-climb test is that it is a submaximal effort test as compared to the 2.4-km run test[20,21] and of a much shorter duration than the 2-km walk test[18]. Both the 2.4-km run and 2-km walk tests are presently being conducted on a regular basis by the Singapore Sports Council to determine the cardiovascular fitness levels of Singaporeans, as part of the Council's efforts to promote healthy living through regular exercise. The stair-climb test offers the public another attractive opportunity to measure their fitness level at their leisure.

While it has many advantages, the stair-climb test does have its limitations. Firstly, it is well-accepted that a duration of at least 2-3 minutes is necessary to consider an activity to be predominantly aerobic in nature. Thus it may be argued that the stair-climb test duration (range of CT: 83 – 171 s) may not be sufficiently long enough to be able to induce an "aerobic state" for some, if not all the participants. While we agree that the test duration may be short, we however observed that the heart rate monitored during the stair-climbing test tended to plateau at about the 90-second mark in many of the subjects. It is very possible that the warm-up of about five minutes prior to the test could have helped subjects to reach steady state at about 90 seconds, and before completing the climb. A graphical illustration of a typical male and female subject's heart rate response during stair climbing is provided in Fig. 3. Moreover, it was a deliberate intention that the stair-climb test be designed to suit the type of stairs commonly available in HDB flats, most of which are twelve or more storeys in height.

Secondly, the stair-climb test can physiologically be very intense. In this study, the average male and female in the development group attained a peak heart rate of 154 and 165 beats·min^{-1} at the end of the climb respectively. These values are 86.3 and 92.5% of the maximum heart rate attained in the laboratory. Such high heart rates may be difficult to count accurately, necessitating the use of heart rate monitors. Furthermore, although not measured in this study, it has been shown that blood pressure can reach a high level during vigorous stepping exercises as compared to horizontal walking[22]. It is therefore strongly advised that individuals with hypertension should avoid the stair-climb test. For obvious reasons, those with musculoskeletal problems which may be exacerbated by stair-climbing (for example osteoarthritis of the knee) are also advised to avoid the stair-climb test. It is worth noting that there were no serious injuries or medical complications during the conduct of the study.

The stair-climb test was designed to help Singaporeans measure their level of fitness on a regular basis. It is hoped that this would enhance adherence to exercise. While it has been shown that the stair-climb test can be used to measure cardiorespiratory fitness fairly accurately, it remains to be seen whether the test is able to detect changes due to fitness improvements. Further research would be needed to address this issue.

CONCLUSION

A simple stair-climb test was developed to enable adult Singaporeans to assess their cardiorespiratory fitness. This simple test requires minimal equipment and is easy to self-administer. This would enable Singaporeans to assess their cardiorespiratory fitness whenever they wish to, and would help to motivate them to exercise regularly. It could also encourage Singaporeans to use the stairs near to their homes for exercise.

Table II. Comparison between Directly Measured (DM) and Predicted (P) VO_{2max} (in ml·kg^{-1}·min^{-1}) from the Stair-climb Regression Equations in Males (N = 11) and Females (N = 7).

Subjects	VO_{2max} P	VO_{2max} DM	Difference (P - DM)	Percentage Difference*
Males				
1	43.7	35.8	7.9	22.1
2	46.9	48.8	-1.9	3.9
3	42.0	39.1	2.9	7.4
4	43.4	46.5	-3.1	6.7
5	45.0	41.5	3.5	8.4
6	44.0	44.3	-0.3	0.7
7	54.0	48.0	6.0	12.5
8	48.4	50.3	-1.9	3.8
9	51.8	50.0	1.8	3.6
10	52.5	55.0	-2.5	4.5
11	54.8	65.9	-11.1	16.8
Mean	47.86	47.75		
SD	4.68	8.15		
Females				
1	37.9	33.0	4.9	14.8
2	42.1	45.6	-3.5	7.7
3	42.2	45.0	-2.8	6.2
4	41.0	36.7	4.3	11.7
5	42.0	51.9	-9.9	19.1
6	42.3	53.1	-10.8	20.3
7	41.0	42.0	-1.0	2.4
Mean	41.21	43.90		
SD	1.56	7.39		

* in relation to Directly Measured VO_{2max}

Table III. Mean (SD) Predicted VO_{2max} (P) from the Stair-climb Test vs Directly Measured VO_{2max} (DM) in the Laboratory of the Development and Validation Groups of Subjects.

	VO_{2max} P	VO_{2max} DM	Difference (P - DM)	Total Error (E)
Development Group				
Males *(N = 56)*	43.04 (6.46)	43.06 (8.45)	-0.03 (5.45)	5.40
Females *(N = 47)*	36.48 (3.74)	36.52 (5.36)	-0.04 (3.85)	3.81
Validation Group				
Male *(N = 11)*	47.86 (4.68)	47.75 (8.15)	0.12 (5.18)	4.94
Female *(N = 7)*	41.21 (1.56)	43.90 (7.39)	-2.69 (6.16)	6.30

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REFERENCES

1. Ministry of Information and the Arts, Singapore. Singapore 1998. Singapore: The Ministry, 1999.
2. Singapore Sports Council. National Sports Participation Survey 1997. Singapore: The Council, 1998.
3. Nagle FJ, Balke B, and Naughton JP. Gradational step tests for assessing work capacity. J Appl Physiol 1965; 20:745-8.
4. Holland GJ, Hoffmann JJ, Vincent W, Mayers M, Caston A. Treadmill vs Steptreadmill Ergometry. Physician Sportsmed 1990; 18(1):79-85.
5. Ilmarinen J, Rutenfranz J, Knauth P, Ahrens M, Kylian H, Siuda A, Korallus U. The effect of an on the job training program - stair climbing - on the physical working capacity of employees (German). Eur J Appl Physiol 1978; 38(1):25-40.
6. Loy SF, Holland GJ, Mutton DL, Snow J, Vincent WJ, Hoffmann JJ, Shaw S. Effects of stair-climbing vs run training on treadmill and track running performance. Med Sci Sports Exerc 1993; 25(11):1275-8.
7. Bruce FM, Floyd WF, Ward JS. Oxygen consumption and heart rate during stair climbing. J Physiol 1967; 191(2):90-2.
8. Jetté M, Campbell J, Mongeon J, Routhier R. The Canadian Home Fitness test as a predictor of aerobic capacity. Can Med Assoc J 1976; 114:680-2.
9. Shephard R J, Thomas S, Weller I. The Canadian Home Fitness Test: 1991 Update. Sports Med 1991; 11(6):358-66.
10. Sykes, K. Chester step test. Journal of Occupational Health. Jan, 1995.
11. Balke B, Ware P. An experimental study of physical fitness of air force personnel. US Armed Forces Med J 1982; 675-88.
12. Hausswirth C, Bigard AX, Le Chevalier M. The Cosmed K4 telemetry system as an accurate device for oxygen uptake measurements during exercise. Int J Sports Med 1997; 18 (6):449-53.
13. Lohman TG. Skinfolds and body density and their relation to body fatness: a review. Human Biol 1981; 53:181-225.
14. Ong TC, Sothy S P. Exercise and cardiorespiratory fitness. Ergonomics 1986; 29(2):273-80.
15. Shvartz E, Reibold RC. Aerobic Fitness Norms for Males and Females Aged 6 to 75 Years: A Review. Aviat Space Environ Med 1990; 61:3-11.
16. Jackson AS, Beard EF, Wier LT, et al. Changes aerobic power in men, ages 25-70 yr. Med Sci Sports Exerc 1995; 27(1):113-20.
17. Jackson AS, Wier LT, Ayers GW, Beard EF, Stuteville JE, Blair SN. Changes aerobic power in women, ages 20-64 yr. Med Sci Sports Exerc 1995; 28(2):884-91.
18. Oja P, Laukkanen R, Pasanen M, Tyry T, Vuori I. A 2 km Walking Test for Assessing the Cardiorespiratory Fitness of Healthy Adults. Int J Sports Med 1991; 12:356-62.
19. Ben-Ezra V, Verstraete R. Stair climbing: an alternative exercise modality for firefighters. J Occup Med 30(2):103-5.
20. Cooper KH. The aerobics way. New York: M Evans and Co, 1977.
21. Giam CK, Teh KC. Sports medicine, exercise and fitness: a guide for everyone. Singapore: PG Publishing, 1988.
22. Benn SJ, McCartney N, McKelvie RS. Circulatory response to weight lifting, walking, and stair climbing in older males. J Am Geriartr Soc 1996; 44(2):121-5.