EVALUATION OF A STEP-TEST FOR ASSESSING THE CARDIORESPIRATORY CAPACITY OF WORKERS IN THAILAND: A PILOT STUDY

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The aim of this pilot study was to evaluate the accuracy of a simple step-test procedure supplemented by the measurement of heart rate (HR) (STEP1) to assess the cardiorespiratory capacity i.e., maximal oxygen consumption ($\dot{V}O_2$max) of Thai workers. The subjects comprised 18 men and 17 women. Their ages varied from 19 to 20 years and all were physically active. The subjects performed three tests: a submaximal incremental cycle-ergometer (CYCLE) test supplemented by HR recordings and respiratory gas exchange, and two step-tests (STEP1 and STEP2). In the STEP1 test HR was recorded continuously. The STEP2 test included the measurements of HR and respiratory gas exchange. For the male subjects the mean difference of the estimated $\dot{V}O_2$max values obtained from the CYCLE and STEP1 test was 15% ($p<0.05$). With the female subjects the mean $\dot{V}O_2$max values were equal when predicted according to the CYCLE and STEP1 tests. The present STEP1 test is not sufficiently accurate to predict the $\dot{V}O_2$max of Thai men. The results of this pilot study need to be confirmed with larger samples of subjects with various backgrounds in terms of individual characteristics and occupations.

Keywords: submaximal test; maximal oxygen cosumption; heart rate; cycle ergometer; physical load

INTRODUCTION

Heavy dynamic physical work is still common in many industrial and service jobs (Hasle et al., 1985; Intaranont and Vanwonterghem, 1993; Yoopat et al., 1998). In addition to demanding muscular exertion, hot and humid work environments in tropical regions set strenuous loads on the cardiorespiratory capacity and thermal regulation of workers (Gogh, 1990; Juengprasert, 1995*)*. Furthermore, unbalanced relationships between job demands and individual capacities may lead to serious health and safety risks (Ramsey et al., 1983; Rutenfranz et al., 1990).

Workers engaged in jobs in forestry, agriculture, building, installation, transportation, manual sorting, cleaning, and in some special safety occupations, such as fire fighters, police officers, and soldiers, are regularly exposed to heavy muscular load (e.g., Ilmarinen, 1984; Louhevaara, 1995). In these types of jobs the cardiorespiratory (aerobic) capacity of workers is the determining factor with regard to the performance and productivity of daily tasks (Ramsey et al., 1983; Åstrand, 1960). Therefore, reliable assessments of cardiorespiratory capacity is often relevant for preventing overstrain and unhealthy consequences among workers. One of the major problems in performing research related to occupational health and safety in developing countries, such as Thailand, is the lack of financial resources. Because of this, reliable results based on laboratory tests with sophisticated equipment and large sample populations are often quite limited. One solution to this problem might

be the development of a simple and sufficiently reliable field test for assessing the cardiorespiratory capacity of workers. In tropical conditions, outdoor screening tests like a 2-km walking test (Laukkanen, 1993) are unreliable and also not feasible. The only indoor test for the assessment of cardiorespiratory capacity of an individual or a group of individuals that can be performed without expensive equipment is a step-test (Malville et al., 2001; Heyward, 1998).

The aim of the present pilot study was to evaluate the reliability, physiological characteristics and feasibility of a simple step-test supplemented with HR measurements to assess the cardiorespiratory capacity of workers in Thailand. In order to reach this aim, two submaximal step-test procedures were evaluated. The step-tests were performed similarly, but they were supplemented with recording of HR and respiratory gas exchanges or merely of HR. The estimated maximal oxygen consumption of the simple step-test procedure was compared to those obtained from a submaximal cycle-ergometer test in which HR and respiratory gas exchange were continuously registered.

METHODS

Subjects

The healthy volunteer subjects consisted of 18 men (mean age 19 SD 2 years) and 17 women (mean age 20 SD 2 years) (Table 1). The subjects were physically active in terms of soccer, basketball and judo. The subjects were carefully informed of the procedures of the study and any possible health risks before they voluntarily signed an informed consent form as required by the Thai Ethics Committee.

Test procedures

Before the exercise tests were done the subjects were given a clinical health examination supplemented using an electrocardiogram while the subjects were lying in a supine position. Their height, body mass, blood pressure and oral temperature were measured. The subjects then completed a questionnaire, which queried physical activity levels, participation in competitions, injuries, diseases, use of alcohol, tobacco and drugs, and some information on occupational work loads were inquired.

The following three different laboratory test procedures were randomly completed by the subjects:

1. A submaximal incremental cycle-ergometer test supplemented by HR recordings and respiratory gas exchange measurements (CYCLE),
2. A submaximal step-test supplemented by HR recording (STEP1), and
3. A submaximal step-test supplemented by HR recording and respiratory gas exchange measurements (STEP2).

STEP2 was identical to STEP1 with exception of measuring the physiological response. Therefore STEP2 can be estimated as a validation of the simplified STEP1 method.

Before the commencement of each test the subjects were given a rest period of 2 minutes during which they were asked to remain in a sitting position while familiarizing themselves to measuring equipments. After the test, their recovery was followed for 5 minutes while they remained in a sitting position. The total duration of each test was about 20 minutes. The tests were performed in temperate conditions (ambient temperature 22 °C, the relative humidity < 65%). The subjects wore shorts and a T-shirt for the tests.

Table 1. Characteristics of the subjects. The values are mean ± SD.

Gender	N	Age (years)	Body mass (kg)	Body Height (cm)
Male	18	18.7 ± 2.1	66.7 ± 13.2	171 ± 7.9
Female	17	19.6 ± 1.9	59.6 ± 9.0	161 ± 6.8

Cycle-ergometer (CYCLE) test

The CYCLE test was continuous and incremental. The subjects maintained a steady pedalling rate of 50 rounds/min which was controlled by a metronome. A two minutes rest period while sitting on the cycle-ergometer was followed by a warm up period of 2 minutes with an external load of 50 W. The load was then increased by 25 W every second minute until the set HR target was reached. The target HR was 90% or 85% of the age-specific average maximal HR (220–age beats/min) for male and female subjects, respectively (Mesquita et al., 1996).

Step- (STEP1 and STEP2) tests

The step-test procedure used was modified and developed from earlier procedures (Brouha, 1943; Heyward, 1998). The step-tests consisted of stepping up and down a box at a constant pace of 25 cycles per minute, while being controlled by a metronome. The stepping period lasted for 12 minutes. The height of the box was individually set at the level of 15% of each subject's height, and varied from 22.5 to 28.5 cm. The adjustment of different box heights was done by using a standard box with the height of 22 cm, to which plates with various thickness levels of 0.5 or 1 cm were then added to achieve the appropriate box height level for each individual.

Measurements and equipment

In the CYCLE, STEP1 and STEP2 tests, HR was continuously recorded and the average of every minute was registered by using the BHL6000 system (Bauman & Haldi, Switzerland).

In the CYCLE and STEP2 tests, the cardiorespiratory responses were recorded every 30 sec with an Oxycon 4 gas analyzer (Mijnhardt, Holland). The analyzed responses were respiratory frequency, tidal volume, volume of ventilation, oxygen consumption ($\dot{V}O_2$), the production of carbon dioxide, and the respiratory exchange ratio. The calculation of $\dot{V}O_2$ was based on the oxygen concentration levels determined by a polarographic oxygen cell and, consequently, the production of carbon dioxide on an infra-red cell.

In the CYCLE test, $\dot{V}O_2$max was extrapolated according to the individual linear regression equations between $\dot{V}O_2$ and HR (Louhevaara et al., 1980; Åstrand and Rodahl, 1986). The used estimated maximal HRs were based on the formula: 220–age beats/min.

In the STEP2 test, $\dot{V}O_2$max was calculated according to linear regression equation between HR and $\dot{V}O_2$ measured every 30 seconds.

In the STEP1 test, the estimation of $\dot{V}O_2$max was done according to steady state HR, and by applying the following equation (von Döbeln et al., 1967):

$$\dot{V}O_2max\,(ml/min/kg) = 1.29\,[SQR\,L/(HR-60)]\,e^{-0.00884\cdot T}$$

L   = load (kgm/min)
HR   = heart rate at the end of exercise (beats/min)
T   = age (years)
SQR   = square root
e   = Napierian logarithm for age T

The physical load of the step-tests was calculated following Heyward (1998) including the positive load (climbing phases) and the negative load (stepping down) where less solicited muscles were active using less energy.

$$L = [(N \times BH \times BM) + 1/3(N \times BH \times BM)]$$

N   = number of cycles/min
BH   = box height (m)
BM   = body mass (kg)

Statistics

The submaximal responses of the CYCLE, STEP1 and STEP2 tests were described with means and standard deviations. The estimated $\dot{V}O_2$max of the CYCLE test was based on linear regression analysis. The differences between the estimated $\dot{V}O_2$max values of the CYCLE, STEP1 and STEP2 tests were tested with paired-samples *t* test. The differences were considered statistically significant when *p*<0.05.

RESULTS

In the submaximal incremental CYCLE test, the correlation between measured $\dot{V}O_2$ and HR was significant (*p*<0.01) for both male and female subjects (0.93 and 0.84, respectively), and the set target HR levels were attained without subject-related or technical problems.

The highest submaximal $\dot{V}O_2$ values of the male subjects were 2.8 (SD 0.5) l/min in the CYCLE test and 1.8 (SD 0.4) l/min in the STEP2 test. The corresponding values for the female subjects were 1.8 (SD 0.5) and 1.3 (SD 0.3) l/min, respectively. The steady-state HRs for both male and female

Table 2. Heart rate (HR) and ventilatory gas exchange for the male and female subjects during the two last minutes of the CYCLE and STEP2 tests, and HR for the STEP1 test. VE = pulmonary ventilation, $\dot{V}O_2$ = oxygen consumption, $\dot{V}CO_2$ = the production of carbondioxide, R= the respiratory exchange ratio, $\dot{V}O_2$max= maximal oxygen consumption. Upper and lower values in the rows for each measurement indicate the mean and standard deviation, respectively.

	Male (N=18)			Female (N=17)		
	CYCLE	STEP2	STEP1	CYCLE	STEP2	STEP1
Measured						
HR (beats/min)	176	132	132	171	141	141
	8	11	11	4	18	18
VE (l/min)	81	40	-	49	29	-
	18	10	-	12	7	-
$\dot{V}O_2$ (l/min)	2.8	1.8	-	1.8	1.3	-
	0.5	0.4	-	0.5	0.3	-
$\dot{V}CO_2$ (l/min)	2.7	1.4	-	1.6	1.0	-
	0.5	0.4	-	0.5	0.2	-
R	1.0	0.8	-	0.9	0.7	-
	0.1	0.1	-	0.1	0.0	-
Estimated		*			*	
		*	*		*	NS
$\dot{V}O_2$max (l/min)	3.4	3.8	2.9	2.3	2.6	2.4
	0.5	0.6	0.4	0.5	0.8	0.4
		*			NS	
		NS	*		NS	NS
$\dot{V}O_2$max (ml/min/kg)	52.0	58.0	44.0	39.0	44.0	41.0
	9.4	11.0	5.5	8.7	12.0	5.3

* Significant difference between the tests, *p*<0.05. NS shows no significant difference.

subjects was equal in both STEP1 and STEP2 tests (Table 2).

    The estimated mean $\dot{V}O_2$max for the male subjects obtained in the STEP1 test was on the average 15% lower than of the CYCLE test (2.9 vs. 3.4 l/min, $p<0.05$) (Table 2). The corresponding difference between STEP1 and STEP2 tests was 24% ($p<0.05$) (Table 2). The correlation between $\dot{V}O_2$max values of the CYCLE and STEP1 tests was 0.71 ($p<0.01$) (Figure 1).

    With the female subjects, the estimated mean $\dot{V}O_2$max values for the STEP1 and CYCLE tests were equal. Also the estimated mean $\dot{V}O_2$max values obtained from the STEP1 and STEP2 tests were equal (Table 2). The correlation between the $\dot{V}O_2$max values of the CYCLE and STEP1 tests was 0.94 ($p<0.01$) (Figure 2).
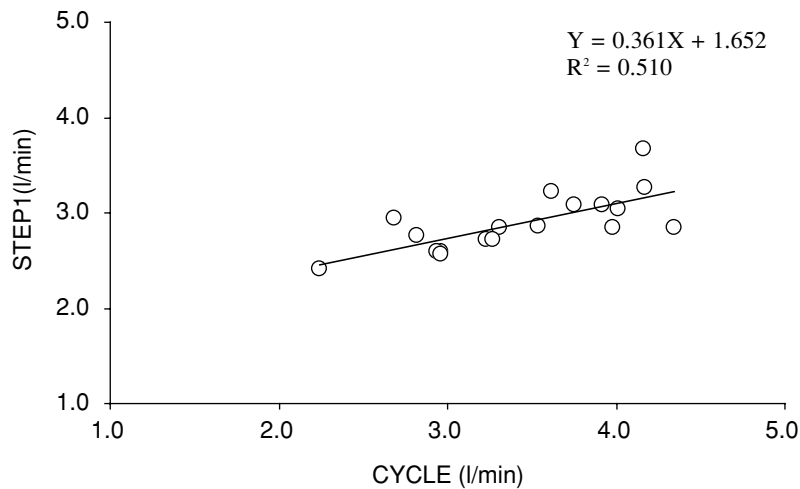
$$Y = 0.361X + 1.652$$
$$R^2 = 0.510$$

Fig.1. Correlation of $\dot{V}O_2$max between the CYCLE and STEP 1 tests in male subjects.

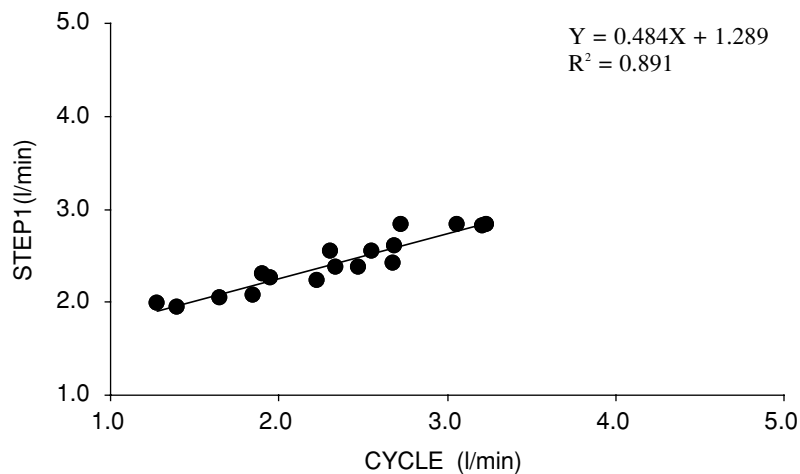$$Y = 0.484X + 1.289$$
$$R^2 = 0.891$$

Fig.2. Correlation of $\dot{V}O_2$max between the CYCLE and STEP 1 tests in female subjects.

DISCUSSION

In submaximal incremental tests on a cycle-ergometer where $\dot{V}O_2max$ prediction is based on HR responses, the over- and under-estimations of approximately 10 % for a group level are common and acceptable (Kilbom, 1990). The main difficulty is to predict the maximal HR due to large individual HR variations in all age groups (Kilbom, 1990; Wasserman et al., 1999). An acceptable reliability can be reached if submaximal HR is sufficiently high at the end of the test (about 90% of average age-specific maximal HR) (Fletcher et al., 1998). Then, the $\dot{V}O_2max$ may be predicted via a linear regression equation (Louhevaara et al.,1980; Åstrand and Rodahl, 1986). Louhevaara et al., (1980) observed differences which varied from -13% to +9% when estimated (extrapolated) and directly measured $\dot{V}O_2max$ values on a cycle-ergometer were compared to the group level. The differences were similar to those reported earlier by Åstrand and Ryhming (1954) and Glassford et al. (1965). The mean over-estimation of the $\dot{V}O_2max$ was 28% with the use of the ACSM protocol (Swain and Wright, 1997), and that was comparable to the 26% previously reported by Greiwe et al., (1995). It can therefore be assumed that the estimated $\dot{V}O_2max$ values of this study for the male and female subjects are of the same range in accuracy.

The STEP1 test significantly under-estimated the $\dot{V}O_2max$ of the male subjects in the group level (15%) when compared to the CYCLE test.

With the female subjects, the STEP1 test gave similar results as the CYCLE test at the group level. Presumably, the main reason for the difference between genders was that the mean HR of the male subjects was ,on the average, 10 beats/min lower than that of the female subjects in the STEP1 test.

The reasons for problems in accuracy in submaximal cycle-ergometer and step-test procedures have been discussed in a number of studies (Wasserman et al., 1999; Noonan and Dean, 2000). The main problems were the influence of an individual's body mass on the load (Spiro et al., 1977) and individual sensibility for various types of physical activity (Glassford et al., 1965). The effects of various test protocols have also been discussed; pedalling speed (50-80 rounds/min) (Swain and Wright, 1997), the duration of incremental tests: short (Fairshter et al., 1983) or long, to reach as maximal a HR as possible (Balgos et al., 1996). In addition, the prediction of $\dot{V}O_2max$ can be done through continuous intermittent protocols (Howley et al., 1995). Usually, all studied test features have both advantages and disadvantages, and the overall best test protocol for a submaximal exercise test for assessing $\dot{V}O_2max$ seems impossible to find. In every case, the use of a cycle-ergometer and incremental test procedure seemed to give more reliable results than the use of a step bench and a single steady-state load (Wasserman et al., 1999; Fitchett, 1985).

In order to confirm the results of this study, larger samples of subjects, with various leisure time activity levels, occupational backgrounds and individual characteristics such as age and body mass are needed in future studies. The inter-individual differences in the gender population, more pronounced in the female population, should be handled with care in order to find out if the low capacity has a biological or a functional background. It is not common in Thailand to perform studies on female workers. From the methodological side, it might be possible to introduce some incremental principles for a simple step-test to answer the question marks of overestimation or underestimation from steady state and non-steady state protocols. Furthermore, the linear regression equations often seem to over-estimate the $\dot{V}O_2$ max values compared to the values obtained from direct maximal exercise tests. One solution might be the application of logarithmic equations as HR tends to level-off at near maximum work levels (Heyward, 1998; Yoopat et al., 1998).

Finally, the specific Thai anthropologic, physiologic and socio-cultural specificity should be taken into account as well when designing test protocols. Food and other living conditions may have implications on the test performance and the cardiorespiratory responses.

CONCLUSIONS

The results of the present pilot study justified the following conclusions:

1. The STEP1 test which was based on a single steady-state load and a continuous recording of HR was not reliable with young Thai men, and it cannot be used for assessing the $\dot{V}O_2$max of Thai workers.

2. The STEP1 test seemed to predict the $\dot{V}O_2$max of young Thai women accurately at both the group and individual levels.

3. The main reason for the difference between genders in accuracy when predicting the $\dot{V}O_2$max with the STEP1 test was probably too low of a work load for the male subjects.

4. The present results must be confirmed with larger samples of subjects of different ages and occupational backgrounds. Also, the development of test protocol for more adjustable increments during the step tests is needed.

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