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PREDICTION OF MAXIMAL OXYGEN UPTAKE BY SQUAT TEST IN MEN AND WOMEN

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INDEXING WORDS

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SYNOPSIS

To examine the reproducibility of simple tests including step, squat and double quick tests, the respective tests were performed twice in 242 college women. The step test for 1, 2 or 3 min and the squat test for 1 or 1.5 min were adopted as simple endurance tests with superior reproducibility. Then 30 men (18-26 yr) and 32 women (18-34 yr) participated in a maximal O_2 uptake ($\dot{V}O_{2max}$) test and the simple endurance tests. The scores (the sum of heart beats for 30-60, 90-120, 150-180 seconds in a sitting posture following the exercise) in the respective simple endurance tests were significantly correlated (*P<0.001*) with $\dot{V}O_{2max}$ per kilogram body weight in the men and women. For example, the equation relating $\dot{V}O_{2max}$ to the score (X) of the squat test for 1.5 min in men was: $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) = -0.261X + 85.19 (r=-0.820, *P<0.001*). The discrepancies between $\dot{V}O_{2max}$ predicted by using the respective estimation equations and that determined by the direct method were 6.3% (by the step test for 3 min) ~ 8.1% (by the squat test for 1 min) in men and 4.7% (by the step test for 2 min) ~ 6.1% (by the squat test for 1 min) in women. Significant

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correlations were observed between the respective scores in the simple endurance tests ($P<0.001$) and between % body fat and the scores ($P<0.01$) in both men and women, but not for height vs. the scores. These results suggest that $\dot{V}O_{2max}$ can be estimated not only by the step test for 1, 2 or 3 min but also the squat test for 1 or 1.5 min.

INTRODUCTION

Recently, the establishment of exercise habits has been recommended for the maintenance and promotion of health. In order to promote motivation to exercise, methods need to be established so that exercising persons can self-evaluate their fitness easily and accurately. Thus, we have proposed simple methods for evaluating leg muscle endurance [17,18] and total oxygen uptake during exercise [7,8].

It is well known that aerobic fitness relates closely to high-density lipoprotein concentration [14], thermoregulation to cold and heat [1,2], and cardiopulmonary function variables [3,6]. It seems that aerobic fitness is the most important fitness for maintaining and promoting health. Although aerobic fitness of individuals can be accurately determined by direct measurement of maximal oxygen uptake ($\dot{V}O_{2max}$), the determination is quite exhausting and occasionally dangerous to the individual. Therefore, an estimation of $\dot{V}O_{2max}$ from simple submaximal procedures has been of interest for many years. Simple tests such as the step test [4,5,10,15] and the shuttle run test [12,13] have been developed for evaluating $\dot{V}O_{2max}$ of large groups. However, these indirect methods need either considerable space or some equipment. Therefore, a more simple test is needed which average people can easily perform by themselves in a confined space with no equipment.

We examined whether or not the squat test can be used as a simple endurance test that yields a higher correlation with $\dot{V}O_{2max}$ and higher reproducibility than a step test.

METHODS

Reproducibility of simple tests

To examine reproducibility on a pre-experimental basis, 62 college women aged 18-22 years participated in the simple tests that included squat, double quick and step tests as described below. Other college women (n=180) took part in only one of these tests. Each subject tried each test twice on separate days within a week after familiarizing themselves with the testing procedure. All tests were conducted in a gymnasium during the month of May. The air temperature in the gymnasium varied between 20 ℃ to 25 ℃.

Squat test: In this test, the subject maintained a distance of about 30 cm between the feet, and repeated squatting 30 times per min by bending of the legs until the hips came into contact with the heels, for 0.5, 1.0, or 1.5 minute (*Squat-$T_{0.5}$, Squat-$T_{1.0}$, Squat-$T_{1.5}$*).

Double quick test: In this test, the subject continued to stamp the legs up and down on the same spot at a frequency of 90 times a minute for 20 or 30 seconds (*Double-q_{20}, Double-q_{30}*). Each leg was raised until the thigh became parallel to the floor, with the arms swinging naturally.

Step test: This test was carried out by stepping up and down on a stool at a rate of 30 steps per min for 1, 2 or 3 minute (*Step-T_1, Step-T_2, Step-T_3*). The height of the stool was 45 cm for men and 35 cm for women. The subjects were requested to extend their knees completely, both on the stool and on the floor.

The three simple tests were performed at the respective constant rhythm in accordance with a metronome. Following each exercise each subject sat on the stool for 3 minutes, while pulse beats for 30-60, 90-120, 150-180 seconds were measured by both palpations of a radial artery by an observer and a carotid artery by the subject. The sum of the pulse beats for the three periods was recorded. However, only when discrepancies between the recordings by the observer and subject were less than five beats, the recordings by the observer were adopted as data. To survey the reproducibility for each simple test, % difference between the respective recordings of each test performed twice on separate days was calculated from the following equation:

% difference = (larger recording / smaller recording - 1.00) x 100

Relationship between score of simple endurance test and $\dot{V}O_{2max}$

Thirty men ranging in age from 18 to 26 years and 32 women ranging in age from 18 to 34 years served as volunteer subjects. The men's mean age was 21.9

(SD 2.4) years, mean height 170.3 (6.2) cm, mean body weight 63.7 (8.2) kg, mean % body fat 15.5 (5.3) and mean $\dot{V}O_{2max}$ 50.3 (7.2) ml · kg^{-1} · min^{-1}. The women's mean age, height, weight, % body fat and $\dot{V}O_{2max}$ were 21.6 (3.6) years, 157.7 (4.0) cm, 52.1 (5.2) kg, 21.5 (6.0) %, and 42.4 (6.8) ml · kg^{-1} · min^{-1}, respectively. They performed the simple endurance tests that had shown superior reproducibility. They also performed a $\dot{V}O_{2max}$ test. Before participation in the study, each subject received a physical examination that included measurement of blood pressure and an electrocardiogram at rest and during a 3-min step test. All medical results were normal. All subjects were informed of potential risks involved in participating in the study and gave their written consent. All tests were performed in a room at an ambient temperature of 23±1 ℃ and relative humidity of 50±5 %.

Simple endurance test: All subjects carried out *Squat-T_1*, *Squat-$T_{1.5}$*, *Step-T_1*, *Step-T_2* and *Step-T_3* twice on separate days in the order indicated. Each subject rested for at least 15 min between the respective tests. Although all procedures were the same as previously described above, heart beats were measured by polygraph using chest leads instead of pulse beats. The mean value for the sum of heart beats during three periods in the two trials was defined as the individual's score for each test.

$\dot{V}O_{2max}$ test: $\dot{V}O_{2max}$ was determined on a treadmill kept at a 6-degree-angle. Each subject ran to exhaustion for 7-10 minutes after the start of exercise. During the test, heart rate was continuously recorded via electrocardiogram (CM_5 lead). A gas sample for the last one-minute of exercise was collected in a Douglas bag. Expired gases were analyzed for O_2 and CO_2 concentration with a Roken-type gas analyzer. The volume of expired gas was measured by a dry gas meter and corrected to standard temperature and pressure (dry) conditions. $\dot{V}O_{2max}$ was determined when heart rate and respiratory quotient for the last one-minute of exercise was over 180 beats · min^{-1} and 1.15, respectively.

To determine whether the simple endurance tests with superior reproducibility can be applied as predictors of $\dot{V}O_{2max}$ per kilogram of body weight, 1) the relationship between $\dot{V}O_{2max}$ and each score from a simple endurance test was examined by regression analysis, and partial correlation coefficients among $\dot{V}O_{2max}$ and scores of various simple endurance tests were

also calculated by multiple regression analysis. Next, 2) the relationships between respective scores from the simple endurance tests were examined by regression analysis. Moreover, 3) $\dot{V}O_{2max}$ estimated from regression equations introduced in 1) process was compared with that measured directly. Discrepancies between the results were represented as a percentage error as follows:
% error = (|observed $\dot{V}O_{2max}$ - estimated $\dot{V}O_{2max}$| / observed $\dot{V}O_{2max}$) x 100

RESULTS

Table I shows % difference for evaluating the reproducibility of the simple tests. The % differences in *Squat-$T_{0.5}$*, *Double-q_{20}* and *Double-q_{30}* were significantly (*$P<0.01$*) larger than in *Step-T_3* which showed the smallest value among all the tests. The differences associated with the selected simple endurance tests were relatively small, however, averaging less than 6 %.

Table I. Percentage differences of the respective simple tests performed twice in women.

Simple test	n	% differences
Step-T_1	84	5.7±4.4
Step-T_2	83	5.4±4.3
Step-T_3	82	4.7±3.7
Squat-$T_{0.5}$	82	6.4±4.8*
Squat-$T_{1.0}$	96	5.3±4.4
Squat-$T_{1.5}$	83	5.8±4.7
Double-q_{20}	78	6.7±5.1*
Double-q_{30}	88	6.4±4.4*

% difference between the respective recordings of each test performed twice on separate days was calculated from the following equation, % difference = (larger recording / smaller recording - 1.00) x 100. Values of % difference are means± SD. *$P<0.05$ from the % difference in *Step-T_3*.

Figure 1 shows the relationship between scores from the *Squat-$T_{1.5}$* and $\dot{V}O_{2max}$ in men. As every other simple endurance test, the scores from the *Squat-$T_{1.5}$* were correlated significantly with $\dot{V}O_{2max}$ (*P<0.001*). The constants for the regression lines and the correlation coefficients between $\dot{V}O_{2max}$ and the scores from the simple endurance tests are indicated in Table Ⅱ, as well as % error between $\dot{V}O_{2max}$ estimated by using the regression equation and $\dot{V}O_{2max}$ measured directly. All the scores from the simple endurance tests were significantly (*P<0.001*) correlated with $\dot{V}O_{2max}$ in men and women. The scores from the respective tests had significant partial correlation coefficients to $\dot{V}O_{2max}$ (*P<0.01*). There were no significant differences between the respective % errors for each sex, although the women tended to have smaller average values.

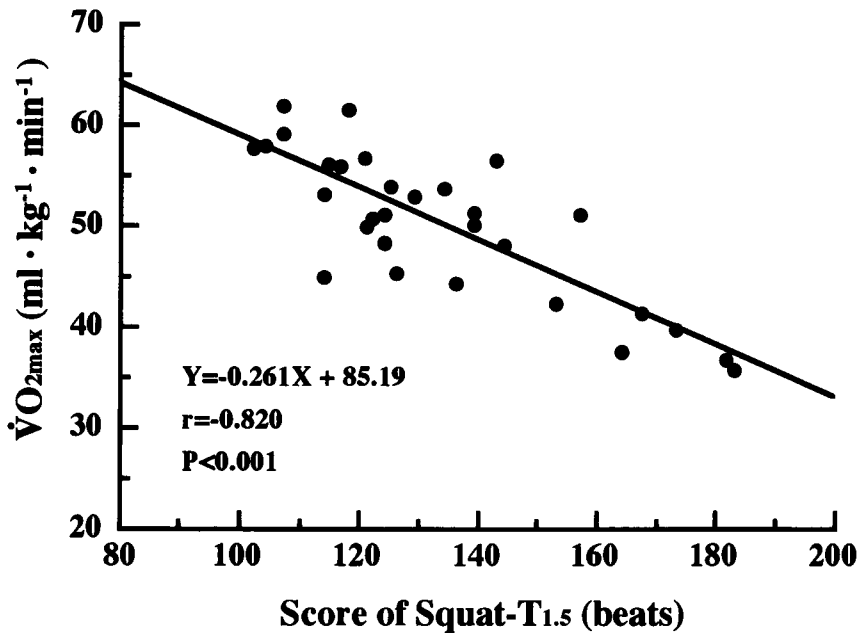

Figure 1. Relationship between scores of squat test for 1.5 min (*Squat-$T_{1.5}$*) and maximal oxygen uptake ($\dot{V}O_{2max}$) per kilogram body weight in men.

Table II. Relationships between $\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1}) and scores from the simple endurance tests, and % error between observed and predicted $\dot{V}O_{2max}$ in men (n=30) and women (n=32).

	Simple endurance test	Constants of equation (a)	(b)	r	% error
Men	*Step-T1*	-0.250	84.40	-0.813	6.9±5.6
	Step-T2	-0.240	86.87	-0.833	6.7±3.9
	Step-T3	-0.224	87.20	-0.849	6.3±4.1
	Squat-T1.0	-0.256	82.69	-0.739	8.1±6.2
	Squat-T1.5	-0.261	85.19	-0.820	6.3±5.4
Women	*Step-T1*	-0.243	73.61	-0.882	5.8±5.1
	Step-T2	-0.230	75.76	-0.936	4.7±2.7
	Step-T3	-0.214	75.78	-0.917	5.1±4.2
	Squat-T1.0	-0.277	77.64	-0.877	6.1±5.8
	Squat-T1.5	-0.253	77.90	-0.920	5.0±4.7

(a) and (b) are constants of first order equation. In the case of *Squat-T1.5* in women, for example, $\dot{V}O_{2max} = aX + b = -0.253X + 77.90$, where X is the score. r, correlation coefficient. % error was calculated from the following equation, % error = (|observed $\dot{V}O_{2max}$ - estimated $\dot{V}O_{2max}$| / observed $\dot{V}O_{2max}$) x 100.

Table III shows the correlation coefficients between the respective scores from the simple endurance tests for both men and women. Significant correlations ($P<0.001$) were observed between the respective simple endurance tests in both men and women, although r-values for women tended to be somewhat higher. Significant correlations ($P<0.01$) were observed between % fat vs. the score from each simple endurance test in both men (r=0.62, 0.53, 0.61, 0.58, and 0.72 in *Step-T1*, *Step-T2*, *Step-T3*, *Squat-T1.0*, and *Squat-T1.5*, respectively) and women (r=0.61, 0.59, 0.54, 0.62, and 0.60). No significant correlations were found between height vs. the score in men and women.

Table Ⅲ. Correlations between scores from the respective simple endurance tests in men and women.

		1	2	3	4	5
Men	1. *Step-T1*		0.880	0.874	0.596	0.738
	2. *Step-T2*			0.934	0.694	0.801
	3. *Step-T3*				0.714	0.816
	4. *Squat-T1.0*					0.895
	5. *Squat-T1.5*					
Women	1. *Step-T1*		0.913	0.886	0.923	0.940
	2. *Step-T2*			0.966	0.866	0.934
	3. *Step-T3*				0.877	0.924
	4. *Squat-T1.0*					0.939
	5. *Squat-T1.5*					

DISCUSSION

Astrand and Ryhming [4] prepared a nomogram, with which $\dot{V}O_{2max}$ can be estimated from heart rate for the last one-minute of exercise in a 6-min step test. They reported that the % error between the $\dot{V}O_{2max}$ estimated by using the nomogram and that measured directly was 6.8 %. Margaria *et al.* [15] also found that the % error was within 10 % using their nomogram. Ishiko [9] pointed out that in 17 male field athletes, the correlation coefficient between the $\dot{V}O_{2max}$ and the score of the Harvard step test was -0.696 ($P<0.01$), although the % error was not presented. McArdle *et al.* [16] also observed a similar correlation coefficient between $\dot{V}O_{2max}$ and the step test in an experiment involving 41 female undergraduates. In this study, not only the step test but also the squat test showed less % error and superior correlation coefficients compared to the studies cited. Furthermore we found significant correlations between the respective scores from the simple endurance tests, and significant partial correlation coefficients among $\dot{V}O_{2max}$ and the scores from the respective simple endurance tests. Our results suggest that average people can estimate their aerobic fitness by themselves by performing a squat test and subsequently measuring their pulse

rate.

Three reasons can be provided for the relatively higher correlations found: 1) subjects were selected from a wide range of $\dot{V}O_{2max}$, 2) each simple endurance test was conducted twice on separate days and the average of the scores was treated as an actual score, 3) the simple endurance tests were conducted in a room, in which the temperature and humidity were controlled at comfortable levels. Our results support the proposal that aerobic fitness can be satisfactorily estimated by not only the step test reported previously [4,5,9,10,15,16] but also by the squat test, even for the 1 min performance. These findings coincided with those of Virginia and Gwendolyn [19] who reported that the one minute step test could be used as a means for the estimation of cardiovascular fitness.

However, among the weight lifters (n=10) who did squat exercises regularly, the estimated values of $\dot{V}O_{2max}$ by the squat test were overestimated and the % error was significantly larger than that for the step test. The respective % errors were 8.0±4.5% and 14.9±8.1% for *Step-*T_2 and *Squat-*$T_{1.5}$, respectively. These findings suggest that for those persons who perform squat exercises regularly the step test is recommended as a means of the estimation of $\dot{V}O_{2max}$. Double quick tests were deemed less satisfactory due to lesser reproducibility. The difficulty for every subject to raise their legs in the same way poses a problem.

Body fatness yielded a relatively high correlation coefficient with the score of each simple endurance test, whereas height did not. Our results regarding body fat vs..test score concurred with the findings by Leblanc *et al.* [11] who reported a significant correlation between % body fat and $\dot{V}O_{2max}$ per kilogram body weight.

Pooled correlation coefficients for men and women were -0.645, -0.702,-0.688, -0.715 and -0.820 for the *Step-T1*, *Step-*T_2, *Step-*T_3, *Squat-*$T_{1.0}$ and *Squat-*$T_{1.5}$, respectively. The squat test correlations slightly exceeded those for the step tests. The reason may be that the load employed in the step test was mainly imposed by body weight and the height of the step. Thus, the relatively heavier men stepped higher (45 cm height stool vs. 35 cm high stool) and they performed more work than the women. The following equation was developed to

predict $\dot{V}O_{2max}$ from the score (X) of *Squat-$T_{1.5}$* regardless of sex:

$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1}) = -0.275X + 83.94

We conclude that the squat test can be used as a means for prediction of $\dot{V}O_{2max}$ per kilogram body weight. To use the squat test for this particular purpose, it is very important to make sure that the exercise has been learned and practiced, that the subjects get enough rest before the test, and that the test is conducted under comfortable environmental conditions. Although the squat test has several advantages as described above, attention should be paid to the muscle or knee-joint pain. The transient muscle pain during the squat test was found in the subjects, so that subjects suffering from knee-joint problem should be excluded from the test.

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