Development of a 12-min Treadmill Walk Test at a Self-selected Pace for the Evaluation of Cardiorespiratory Fitness in Adult Men

Masaki Nakagaichi and Kiyoji Tanaka

1) Doctoral program of Health and Sport Sciences, University of Tsukuba
2) Institute of Health and Sport Sciences and Center for Tsukuba Advanced Research Alliance (TARA), University of Tsukuba

Abstract. The direct measurement of true maximal oxygen uptake (VO_{2max}) and oxygen uptake corresponding to anaerobic threshold (VO_{2AT}) is not always practical, especially in middle age and older populations. Therefore, the purpose of this study was to develop a simple test that could accurately estimate cardiorespiratory fitness using a submaximal treadmill walking protocol for middle age, older, sedentary individuals and patients with chronic disease. Subjects for this study were 42 men (44.9 ± 15.7 years), which included 17 patients with coronary heart disease (57.0 ± 9.6 years). VO_{2peak} and VO_{2AT} were measured using a treadmill protocol (VO_{2peak}: 38.4 ± 11.6 ml/kg/min, VO_{2AT}: 22.9 ± 7.4 ml/kg/min). This simple test assessed the total distance covered in 12 minutes on the treadmill at an intensity corresponding to either 1) 11 on the Borg scale of ratings of perceived exertion (RPE11), 2) 13 on the Borg scale of ratings of perceived exertion (RPE13), or 3) “Optimal” by subjective judgment. The correlation coefficients between VO_{2peak} or VO_{2AT} and total distance at the three intensities (RPE11: 950 ± 100 m, RPE13: 1080 ± 140 m Optimal: 1050 ± 110 m) were statistically significant, ranging from 0.72 to 0.85. The test-retest reliability coefficient on 12 subjects was 0.98. The oxygen uptake (VO_{2}) was measured during the three walk tests on 15 subjects. There were no significant changes in submaximal VO_{2} values from min 4 to min 12 (RPE11: 19.8 ± 4.7 ml/kg/min, RPE13: 24.1 ± 4.9 ml/kg/min, Optimal: 23.1 ± 4.8 ml/kg/min) in any of the three tests. Similarly, the three submaximal VO_{2} values did not differ from the VO_{2AT} value (21.2 ± 8.3 ml/kg/min) obtained in the initial maximal test. These results suggest that the 12-min submaximal treadmill walk test (STWT) is a valid method for the assessment of VO_{2peak} and VO_{2AT}. Therefore, the STWT could be a useful performance test for evaluating cardiorespiratory fitness in middle age, older, sedentary individuals and patients with chronic disease.

Keywords: cardiorespiratory fitness, ratings of perceived exertion, self-selected pace walking, simple test

Introduction

Cardiorespiratory fitness is an integral component of health-related physical fitness. It is very important to evaluate an individual’s cardiorespiratory fitness correctly because it is a valuable index of health status and an indicator of training intensity during exercise. Maximal oxygen uptake (VO_{2max}) and oxygen uptake corresponding to anaerobic threshold (VO_{2AT}) are the accepted criteria for measuring cardiorespiratory fitness and functional capacity (Farrell et al., 1979; McArdle et al., 1981; Taylor et al., 1955). However, the assessment of VO_{2max} or VO_{2AT} requires sophisticated equipment and highly trained staff. Owing to the expense, the time required, and the risks associated with maximal exercise, direct measurement of VO_{2max} and/or VO_{2AT} is not practical in health-fitness clubs or for testing large populations.

These limitations have led to the development of indirect methods to evaluate cardiorespiratory fitness or predicted VO_{2max} (Åstrand and Ryhming, 1954; Cooper, 1968; Fox, 1973; Kline et al., 1987; Nakagaichi et al., 1996; Siconolfi et al., 1982). More simple and more feasible field tests of cardiorespiratory fitness have been introduced in recent years. Some are based upon maximal performance in a field test. Other protocols have used the heart rate (HR) at submaximal work loads to predict VO_{2max} or provided an estimate of VO_{2max} from multiple regression equations. Cooper’s 12-min run/walk test is, perhaps, the most widely-known field test. Cooper (1968) reported that the distance covered in 12 minutes correlated highly with VO_{2max} (r=0.90). Using young boys and adult men, other researchers have found correlations ranging from 0.65 to 0.90 between run/walk distance and VO_{2max} (Doolittle and Bigbee, 1967; Maksud and Coutts, 1971; Nakagaichi et al., 1996). However, the 12-min run/walk test has not always been practical to
performed for middle age, older, sedentary, or severely deconditioned individuals because it requires a maximal or near maximal effort.

Submaximal tests are usually based upon the measurement of HR at one or more work loads, such as Åstrand-Ryhming test (Åstrand and Ryhming, 1954) or modifications of Åstrand-Ryhming test (Fox, 1973; Glassford et al., 1965; Siconolfi et al., 1982). These tests usually assume an essentially linear relationship between HR and VO2 for various intensities of light to heavy exercise. There are, however, several limitations associated with these submaximal protocols. Specifically; 1) In some subjects, the HR-VO2 relationship becomes actually asymptotic at heavier work loads, which indicates that a larger than expected increase in VO2 occurs per unit increase in HR; 2) the slope of HR-VO2 line differ considerably among individuals; 3) there is a considerable variability (± 10 beats per minute) in the HRmax of individuals of the same age; 4) even under highly standardized conditions, the variation in submaximal HR is about ± 5 beats per minute at the same exercise load; and 5) medications may alter the HR response (American College of Sports Medicine [ACSM], 1995; Davies, 1968; Maritz et al., 1961; McArdle et al., 1981; Rowell et al., 1964; Tanaka et al., 1990). Thus, submaximal tests using the HR response during exercise have several limitations. As a result, the practical utility of these maximal and submaximal field tests may be questioned on the basis of three main limitations: 1) accuracy and validity of the prediction; 2) ease, convenience and safety of the testing protocol; and 3) generalized application to a broad population.

In an attempt to avoid these limitations, the purpose of this study was to develop a 12-min submaximal treadmill walk test (STWT) that requires only a moderate, submaximal level of exertion, that demonstrates acceptable accuracy in evaluating an individual's cardiorespiratory fitness, and that is easy to administer. The unique aspect of this method of evaluating an individual's cardiorespiratory fitness is that the distance covered in 12 minutes is completed at a self-selected pace using ratings of perceived exertion.

Methods

Subjects

Forty-two men served as subjects for this study. Of the 42 subjects, 17 were patients with coronary heart disease (CHD) and 25 subjects were apparently healthy individuals. The patients were participants in a hospital supervised physical conditioning program and they had been medically cleared for a symptom-limited graded exercise test (GXT). The subjects were informed of the nature, purpose, and risks involved in the study before giving their informed consent.

Twelve-minute submaximal treadmill walk test

This walk test was designed to indirectly evaluate an individual's cardiorespiratory fitness based upon the total distance covered in 12 minutes on a treadmill. Each participant performed the test at three different intensities; 1) corresponding to 11 on the 6-20 Borg scale of ratings of perceived exertion (RPE11: “fairly light”) (Borg, 1973), 2) corresponding to 13 on the Borg RPE scale (RPE13: “somewhat hard”) (Borg, 1973), or 3) corresponding to “Optimal” based upon the subject’s perception of the work rate necessary for continued health and well-being. The order of the three tests was randomized across the subjects on separate days. In order to find the test-retest reliability, 12 men randomly selected from the original sample performed one of the three tests on a separate day (RPE11, n=4; RPE13, n=4; Optimal, n=4). The treadmill incline was always set at 5% while the initial walking speed was set at 60 m/min. Following 2 minutes of warm-up walking at 60 m/min, the subject was allowed to control the walking speed at any time according to subject's preference (Appendix 1). Because the exercise intensity at lactate threshold (LT) or AT level has been associated with an RPE value of 11
to 13, independent of training state (Ceci and Hassmen 1991; Demello et al., 1987; Hetzler et al., 1991; Purvis and Cureton, 1981; Seip et al., 1991; Tanaka, 1991), we selected those ratings as the appropriate exercise intensities for this study. The VO\textsubscript{2} during the walking test was measured on 15 men, selected randomly from the original 42 subjects.

The treadmill we used was Mizuno Exer Track (Aerobic Exerciser 8800). Walking distance was automatically calculated from the number of revolutions and the length of treadmill belt. All metabolic measurements of expiratory gases were determined by standard techniques using open-circuit spirometry with a Fukuda Sangyo IS-6000 System. Electrocardiograms were recorded continuously using a Fukuda Denshi Dinascope 501 for measurement of exercise HR.

### Statistical analyses
Relationships between 12-min walk distance (RPE\textsubscript{11}, RPE\textsubscript{13}, and Optimal) and VO\textsubscript{2peak} or VO\textsubscript{2AT} were examined using the Pearson product-moment correlation. One-way analysis of variance (ANOVA) with repeated-measures and Scheffe's post-hoc procedures were performed to clarify the differences among: 1) the average distance covered in 12 minutes at the three intensities; 2) the average VO\textsubscript{2} recorded each minute for 12 minutes; and 3) the average VO\textsubscript{2} measured during the STWT from min 4 to min 12 and the VO\textsubscript{2AT} values. Statistical significance was accepted at the 0.05 level.

### Results
The physical characteristics of subjects were presented in Table 1. As expected, results of the one-way ANOVA indicated that there were significant differences in the average distance covered for 12 minutes at each of the three intensities. When the Scheffe post-hoc procedure was applied, significant differences were found between RPE\textsubscript{11} and RPE\textsubscript{13} and between RPE\textsubscript{11} and Optimal for the average distance covered in 12 minutes.

The test-retest reliability coefficient for 12-min walk distance was significantly high (r=0.97, n=12) (Fig. 1).

Table 2 shows the relationships between an individual's cardiorespiratory fitness (VO\textsubscript{2peak} and VO\textsubscript{2AT}) and the 12-min walk distance at the intensities of RPE\textsubscript{11}, RPE\textsubscript{13} and Optimal. Correlation coefficients between VO\textsubscript{2peak} or VO\textsubscript{2AT} and 12-min walk distance at the three intensities were statistically significant, ranging from 0.72 to 0.85 (Table 2). The standard error of estimation (SEE) of the linear regression equation for estimating VO\textsubscript{2peak} and VO\textsubscript{2AT} from the distance covered in 12 minutes ranged from 6.15 to 8.13 ml/kg/min (16.0 to 21.1%) and from 4.25 to 4.75 ml/kg/min (18.5 to 20.8%), respectively (Figs. 2–4).

The VO\textsubscript{2} responses during the STWT at the intensity of RPE\textsubscript{11}, RPE\textsubscript{13} and Optimal are presented in Fig. 5. During the STWT at each intensity, VO\textsubscript{2} did not change from min 4 to min 12. From these results, we concluded that the VO\textsubscript{2} from min 4 to min 12 reflected a

### Table 1 Physical characteristics of the subjects

<table>
<thead>
<tr>
<th></th>
<th>All subjects n=42</th>
<th>Patients n=17</th>
<th>Healthy men n=25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>44.9 ± 15.7</td>
<td>57.0 ± 9.6</td>
<td>36.7 ± 13.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166.3 ± 5.6</td>
<td>163.2 ± 3.3</td>
<td>168.3 ± 5.7</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65.8 ± 6.5</td>
<td>64.6 ± 5.0</td>
<td>66.6 ± 7.4</td>
</tr>
<tr>
<td>VO\textsubscript{2peak} (ml/kg/min)</td>
<td>38.4 ± 11.6</td>
<td>28.8 ± 6.9</td>
<td>44.9 ± 9.4</td>
</tr>
<tr>
<td>VO\textsubscript{2AT} (ml/kg/min)</td>
<td>22.9 ± 7.4</td>
<td>17.4 ± 8.8</td>
<td>26.7 ± 6.9</td>
</tr>
<tr>
<td>STWT RPE\textsubscript{11} (m)</td>
<td>950 ± 100</td>
<td>880 ± 80</td>
<td>1000 ± 90</td>
</tr>
<tr>
<td>STWT RPE\textsubscript{13} (m)</td>
<td>1080 ± 140*</td>
<td>980 ± 90*</td>
<td>1150 ± 120*</td>
</tr>
<tr>
<td>STWT Optimal (m)</td>
<td>1050 ± 110*</td>
<td>960 ± 60*</td>
<td>1110 ± 100*</td>
</tr>
</tbody>
</table>

*Significantly different from the mean 12-min walk distance at RPE\textsubscript{11} (P<0.05)
physiological steady state. Between min 4 and min 12, the average VO₂ values at the intensity of RPE11, RPE13 and Optimal were 19.8 ± 4.7, 24.1 ± 4.9 and 23.1 ± 4.8 ml/kg/min, respectively. When a one-way ANOVA was used to compare differences among the average VO₂ values and VO₂AT values (21.2 ± 8.3 ml/kg/min), no significant differences were found (Fig. 6).
Discussion

We have attempted to develop a submaximal walking test that evaluates cardiorespiratory fitness without requiring the direct assessment of physiological responses such as HR and VO₂. This test is unique in that it allows the individual to self-regulate their walking speed corresponding to an RPE11, RPE13 or Optimal intensity. The validity and reliability of this test was initially thought to be a concern due to the fact that exercise intensity was determined by subjective perception only. However, the correlation coefficients between VO₂peak or VO₂AT and distance covered in 12 minutes were statistically significant, ranging from 0.72 and 0.85 in the entire population. Even when the data of only CHD patients were analyzed, correlation coefficients of 0.52 to 0.85 were obtained. The

Fig. 4 Scatter diagrams and linear regression lines describing the relationships between 12-min walk distance (Optimal) and VO₂peak (upper figure), and between 12-min walk distance (Optimal) and VO₂AT (lower figure).

Fig. 5 Mean changes in VO₂ during the STWT (upper figure: RPE11, middle figure: RPE13, lower figure: Optimal). Means with asterisks are significantly different from the other means at the 0.05 level.
development of a submaximal walk test

fig. 6 comparison among mean VO2 values observed during the last 8 minutes in the STWT at the RPE11, RPE13, and Optimal and VO2AT.

magnitude of these correlation coefficients observed in the current study is similar to or higher than the range presented by numerous other investigators (Åstrand and Ryhming, 1954; Cooper, 1968; Fox, 1973; Glassford et al., 1965; Kline et al., 1987; Nakagaichi et al., 1996; Siconolfi et al., 1982; Tanaka et al., 1990). In addition, reproducibility of this test was very high (r=0.97, n=12). The SEE of VO2peak and VO2AT predicted from the distance walked in the submaximal tests ranged from 6.15 to 8.13 ml/kg/min and from 4.25 to 4.75 ml/kg/min, respectively, both of which are equivalent to approximately 20% error. Mastropaolo (1970) and Hermiston and Faulkner (1971) have observed that the SEE of VO2max is generally above ± 10% even when VO2max is predicted from many measurement values (VO2, HR, and so on) at submaximal exercise in young adult men. Due to the increased variability associated with advancing age, the slightly larger SEE’s observed in this study are not surprising. The validity of the STWT was similar to or higher in degree than other submaximal tests. The STWT demonstrated acceptable accuracy in evaluating an individual’s cardiorespiratory fitness. In this study, three different STWT were carried out. As a result, the validity of the STWT at an intensity corresponding to RPE13 is best recommended.

A major advantage of this test is that it is possible for the subject to self-regulate the walking speed at RPE11, RPE13, or Optimal. Our findings are consistent with a number of studies which have shown that the RPE can be used to help monitor training intensity (ACSM, 1995). Several recent studies have shown a strong relationship between RPE and blood lactate in submaximal test. This relationship does not appear to be affected by gender (Purvis and Cureton, 1981), training state (Demello et al., 1987; Seip et al., 1991), or mode of exercise (Ceci and Hassmen, 1991; Hetzler et al., 1991). In the present study, LT or AT appeared at an RPE of approximately 11 to 13. In this study, there were no significant differences among the three VO2 values and VO2AT. Our results suggest that as expected, the STWT was established at about LT or AT level. Therefore, exercise intensity was regulated correctly by subjective perception only.

The exercise intensity may be the most important consideration of the four basic factors encompassing an exercise program; exercise mode, frequency, duration, and intensity. The recommended intensity of exercise prescription for middle age, older, sedentary individuals, or patients with chronic disease should be no higher than LT or AT level (ACSM, 1995; Kim et al., 1992; Tanaka et al., 1989). Tanaka et al. (1989) reported that aerobic conditioning at an intensity corresponding to LT together with an appropriate dietary regimen is considered optimal for inducing changes in various anthropometric and physiological parameters. Kim et al. (1992) suggested that exercise at the LT level is optimal for untrained or sedentary individuals because it provides sufficient stress to enhance the cardiorespiratory system. However, exercising for a prolonged time above LT may be too stressful and invoke physiological fatigue. Moreover, moderate exercise (LT or AT level) is more likely to help participants avoid injuries that are closely rated to high-intensity exercise (above LT or AT level) and to avoid potential cardiovascular events (ACSM, 1995; Pollock, 1988; Willmore and Costill, 1994). Therefore, it is likely that the STWT, in which the exercise intensity is summarized to the LT or AT level, is safer for middle age, older, sedentary individuals, and patients with chronic disease. Using the STWT, it is possible to evaluate an individual’s cardiorespiratory fitness easily and accurately. This information can be used to design effective exercise prescription, for the development and maintenance of cardiorespiratory fitness.

The validity of the STWT was similar to or higher in degree than that of other submaximal tests. In addition, the exercise intensity of the STWT was in the range recommended as the optimal intensity of exercise prescription for middle age, older, sedentary individuals or patients with chronic disease. Thus, the STWT is a useful performance test for evaluating cardiorespiratory fitness.

Acknowledgments. This research was supported partly by Tanaka project of Tsukuba Advanced Research Alliance (TARA) University of Tsukuba.

Appendix 1. Testing protocol of 12-min submaximal treadmill walk test (STWT).
Testing protocol aimed at maintaining RPE13 (“Somewhat hard”)

1. This test has been designed to indirectly evaluate your cardiorespiratory fitness based upon attaining a walking distance which you feel to be “somewhat hard”.

2. Exercise time is 12 minutes. Inclination of the treadmill belt is always set at 5%. Initial walking speed is set at 60 m/min. —— Warm-up!

3. When 2 minutes have elapsed after you have started the walking, the instructor will ask you “May I increase the speed?” If you agree to an increase in speed, please answer immediately by saying either “a little” or “a lot.” On the other hand, if you feel it is better not to increase the speed, please answer “leave it as it is.”

   “a little”: an increase in the speed within the range of 20-30 m/min
   “a lot”: an increase in the speed within the range of 30-50 m/min

4. Every minute, the instructor will indicate “Please decide on a speed that you feel comfortable with.” Then, please answer by saying either “a little,” “a lot,” or “leave it as it is.”

   “a little”: an increase or a decrease in the speed within the range of 5-10 m/min
   “a lot”: an increase or a decrease in the speed within the range of 15-30 m/min

5. When 12 minutes have elapsed, the instructor will confirm the distance covered in 12 minutes. Walking speed is set at 60 m/min. —— Cool-down!

References


Davies CTM (1968) Limitations to the prediction of maximum oxygen intake from cardiac frequency measurements. J Appl Physiol 24: 700-706


Fox EL (1973) A simple, accurate technique for predicting maximal aerobic power. J Appl Physiol 35: 914-916


individual's maximal oxygen intake. Ergonomics 4: 97-122

Received: September 9, 1998
Accepted: October 15, 1998
Correspondence to: Masaki Nakagaichi, Institute of Health and Sport Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8574, Japan