The Reliability and Validity of a Modified Squat Test to Predict Cardiopulmonary Fitness in Healthy Older Men

Chiu-Ping Yeh,1,2 Hsien-Cheng Huang,3 Yaju Chang,4 Ming-De Chen,5 and Miaoju Hsu6,7

1Department of Physical Education, National Taiwan Normal University, Taipei, Taiwan
2Physical Educational Office, National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan
3Section of Cardiology, Department of Internal Medicine, Taipei City Hospital, Yangming Branch, Taipei, Taiwan
4Department of Physical Therapy and Graduate Institute of Rehabilitation Science, Chang Gung University, Taoyuan, Taiwan
5Department of Occupational Therapy, College of Health Science, Kaohsiung Medical University, Kaohsiung, Taiwan
6Department of Physical Therapy, College of Health Science, Kaohsiung Medical University, Kaohsiung, Taiwan
7Department of Rehabilitation, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan

Correspondence should be addressed to Miaoju Hsu; mjhsu@kmu.edu.tw

Received 31 August 2017; Accepted 16 November 2017; Published 2 January 2018

Academic Editor: Leonardo dos Santos

Copyright © 2018 Chiu-Ping Yeh et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Background. Shortcomings are noted in currently available cardiopulmonary field tests for the older adult and thus relevant research is still ongoing. Purpose. The purpose of this study was to investigate the reliability and validity of a modified squat test and to establish a regression model for predicting aerobic fitness in the older adult. Methods. Twenty-five healthy men aged 60 to 75 years completed this study. Each subject performed two modified squat tests with a prototype testing equipment and a maximal exercise test to determine maximal oxygen consumption. Recovery heart rates (HR) (0∼30, 60∼90, and 120∼150 seconds) were measured following the modified squat tests. The fitness indexes included the sum of recovery HR, recovery HR index, age-adjusted recovery HR index, and immediate HR. Results. The results revealed that the age-adjusted recovery HR index fitness had the highest intraclass correlation coefficients (ICC) of 0.9 and Pearson’s correlation coefficients of 0.71, which suggested the modified squat test can reasonably assess cardiopulmonary fitness for the older adult. The regression equation for estimating aerobic power was
\[ \dot{V}O_2_{max} = 16.781 + 16.732 \times (age-adjusted \ recovery \ HR \ index) + 0.02467 \times (physical \ activity \ level). \]

Conclusion. The modified squat test is a valid and reliable field test and thus can be an option to assess the cardiopulmonary fitness level of healthy older men in clinics or communities.

1. Introduction

Cardiopulmonary fitness, which is most accurately presented by maximal oxygen uptake (VO₂ max), is related to mortality in older adults. Laboratory maximal exercise tests with a treadmill or an ergometer can precisely evaluate VO₂ max, which is not always accessible due to expensive equipment and trained personnel being required [1, 2]. For practical purposes, field tests are developed and used to measure cardiopulmonary fitness. Based on the characteristics of the older adult, the common test modes of field tests are stepping and walking tests.

A three-minute stepping test is widely used to predict cardiopulmonary fitness in that heart rate (HR) responses immediately or during recovery after the stepping test are recorded and calculated. Different stepping frequency, bench height, test duration, the number of stages, and the scoring method have been developed for particular populations. For example, Petrella et al. [3] established a self-paced step test for the community-dwelling older adult, which is implemented at 40 cm height and requires stepping 20 times at different paces. A high correlation coefficient of 0.75∼0.94 is found between the observed and the predicted maximal oxygen consumption (VO₂ max). Though the self-paced step test appears to accurately estimate cardiopulmonary fitness in older adults, it is argued that stepping movements might cause orthopedics problems in knees as well as increase the fall risk to mobility-limited older adults [4]. Rikli et al. [5, 6]...
developed a two-minute self-paced test involving stepping in place, which is safer for the older adult. However, the relationship between this two-minute step-in-place test and maximal oxygen consumption is not established.

The walking test employs functional movements in nature and is easy to conduct. Particularly, the walking test is much safer than the stepping test and thus is more commonly used in senior people. Six-minute walking test and Rockport fitness walking test can reasonably predict cardiopulmonary fitness in the elderly [7, 8] while shortcomings are noted. Numerical studies have demonstrated that the 6 min walking test is not appropriate to evaluate changes in cardiorespiratory fitness in healthy older men who received endurance training for 24 weeks [9–12]. Moreover, a spacious walkway is needed. Therefore, research on developing new field tests of cardiopulmonary fitness for the older adult is still ongoing.

Inoue and Nakao developed a cardiopulmonary fitness test, a squat test, that is simple to administer in a confined space with minimum apparatus [13]. Participants should repeat squatting 30 times per min by bending of the legs until the hips meet with the heels. A significant correlation (\( r = 0.92 \) for women, \( r = 0.82 \) for men, \( p < .001 \)) between \( V_{\text{O}_2}\max \) and the fitness index of the squat test has been found in young adults. Considering difficulties to fully squat down in the older adult and the heavy loading of the knee joint during the squatting activity due to the nature of the movement, we modified the original squat test from full squatting to half-squatting in order to minimize possible injuries to knee joints. The purpose of this study was to evaluate the reliability and validity of the modified squat test and to construct a model for the estimation of aerobic fitness based on the modified squat test performance.

2. Method

2.1. Participants. Thirty-three healthy older subjects between the ages of 60 and 75 years participated in this study. Exclusion criteria included cardiovascular disease, metabolic disease, pulmonary disease, mental problems, and severe orthopedic diseases of the lower extremity. Informed consent was obtained from all participants. To assess potential risks of performing a maximal exercise test, the Physical Activity Readiness Questionnaire (PAR-Q) was administered and the resting 12-lead EKG was conducted and screened by a cardiologist. Before testing, body weight, height, body fat (TANITA, Taiwan), and Physical Activity Scale for the Elderly (PASE) score were recorded.

2.2. Experimental Protocol. All participants had to complete a maximal exercise test and two modified squat tests. The subject performed the first modified squat test, followed by the second modified squat test with oxygen consumption measured and then a maximal exercise test. An adequate rest was provided between the tests in order to allow heart rate and blood pressure to be returned to the level of baseline, which was defined as within 5 beats/minutes for heart rate and 5 mmHg for blood pressure.

2.3. Maximal Exercise Test. Aerobic capacity was measured by performing a treadmill exercise test using the Cornell-modified Bruce treadmill exercise protocol (Table 1). The protocol, which was used to determine the cardiopulmonary fitness of the elderly, consists of 2-min stages, beginning with 0 stage at 1.7 mph and 0% grade, gradually increasing intensity to stage 5 of the Bruce protocol [14, 15]. The 12–lead EKG was monitored during the test as well as the recovery stage. Heart rate was recorded every minute, and blood pressure and Borg’s rating of perceived exertion (RPE) on a scale of 6–20 were assessed every 2 minutes. Respiratory gas samples were analyzed breath-by-breath using a portable metabolic system (K4b², COSMED, Rome, Italy). The test was terminated based on American College of Sports Medicine (ACSM) guidelines for conducting a maximal exercise test [16, 17], with the age-predicted maximum heart rate calculated as \((208 - 0.7 \times \text{age})\) [18] and respiratory exchange ratio (RER) adjusted for 1.00 [19]. Aerobic power (\( V_{\text{O}_2}\max \)), HR\(_\text{max}\), maximal blood pressure, rating of perceived exertion (RPE) based on a 6–20 points’ Borg Scale, and the time of the exercise test were obtained.

2.4. Modified Squat Test. A custom-made lightweight equipment platform (Figure 1(a)) was developed to conduct the modified squat test. The vertical part of the testing equipment (Figure 1(b)) could be detached from the horizontal part so that the equipment could be easily carried. When performing the modified squat test, the subject started at a standing position with his elbows 90° flexed at the sides of the waist (Figure 2(a)), followed by squatting down to 45° knee flexion with both arms pushed out at the same time (Figure 2(b)), and then returned to the starting position (Figure 2(a)). The subject repeated the above-mentioned sequences at a rate of 104 cycles/min for 3 minutes, using a metronome. Recovery heart rates (HR) (0–30, 60–90, and 120–150 seconds) were counted following the modified squat test with using a stethoscope. Blood pressure and RPE were recorded at the end of the test. To compare with previous studies, we calculated several fitness indexes including immediate HR, the sum of recovery HR, and recovery HR index (18000/(HR\(_{0-30} + \text{HR}_{60-90} + \text{HR}_{120-150}) \times 2\) ). In addition, we developed a new index calculated as \((\text{recovery HR index}/\text{age})\). The indexes obtained from the modified squat test were determined as follows.

Table 1: Cornell-Modified Bruce Protocol.

| Stage | Min | Speed (mph) | Grade (%) |
|-------|-----|-------------|-----------|
| 0.0   | 2   | 1.7         | 0         |
| 0.5   | 4   | 1.7         | 5         |
| 1.0   | 6   | 1.7         | 10        |
| 1.5   | 8   | 2.1         | 11        |
| 2.0   | 10  | 2.5         | 12        |
| 2.5   | 12  | 3.0         | 13        |
| 3.0   | 14  | 3.4         | 14        |
| 3.5   | 16  | 3.8         | 15        |
| 4.0   | 18  | 4.2         | 16        |
| 4.5   | 20  | 4.6         | 17        |
| 5.0   | 22  | 5.0         | 18        |
Figure 1: Custom-made lightweight equipment. (a) Assembled testing device. (b) A diagram from a lateral view showing the upright part of the device can be detached from the horizontal part.

Figure 2: Movements of the modified squat test. (a) Starting position. (b) Ending position.

2.4.1. Immediate HR. After the termination of the modified squat test, heart rate measured from Polar was recorded immediately.

2.4.2. The Sum of Recovery HR. When the modified squat test was finished, cumulative heart beats were counted during 0~30, 60~90, and 120~150 seconds. The total number of recovery pulse counts was calculated as the sum of recovery HR.

2.4.3. Recovery HR Index. The fitness index was revised from the equation of Harvard step test [20]:

\[
\text{Recovery HR index} = \frac{\text{test duration of modified squat test (second) \times 100}}{\text{(the sum of recovery HR) \times 2}}
\]

2.4.4. Age-Adjusted Recovery Heart Rate. The fitness index was calculated according to the following equation:

\[
\text{Age-adjusted recovery heart rate} = \frac{\text{recovery HR index}}{\text{age}}
\]

2.5. Statistical Analysis. Test-retest reliability for the modified squat test was established by determining the intraclass correlation coefficient (ICC). The ICC values greater than 0.75 were considered as good reliability, those between 0.5 and 0.75 as moderate reliability, and those below 0.5 as poor reliability [21]. Pearson correlation analysis was used to evaluate the correlation between the fitness indexes of the modified squat test and the maximal exercise test performance. Correlation coefficients \( r \) higher than 0.6 were defined as high correlations, those between 0.3 and 0.6 as moderate correlations, and those
Table 2: Physical characteristics and baseline physiological parameters for the subject (N = 25).

|                          | Mean   | SD   |
|--------------------------|--------|------|
| Age (years)              | 65.16  | 4.90 |
| Weight (kg)              | 66.11  | 8.58 |
| Height (cm)              | 166.52 | 5.21 |
| BMI (kg/m²)              | 23.81  | 2.59 |
| Body fat (%)             | 20.57  | 5.73 |
| Heart rate rest (beats/min) | 73.80 | 11.69 |
| Systolic blood pressure (mmHg) | 128  | 14.59 |
| Diastolic blood pressure (mmHg) | 81.28 | 9.34 |
| Physical Activity Scale for the Elderly | 137.07 | 64.81 |

SD: standard deviation.

Table 3: Physiological responses to maximal exercise test (N = 25).

|                          | Mean   | SD   |
|--------------------------|--------|------|
| VO₂ max (ml/kg/min)      | 35.82  | 4.44 |
| RER                      | 1.05   | 0.11 |
| Time to exhaustion (min) | 12.80  | 2.00 |
| HR max (beats/min)       | 165.12 | 8.25 |
| Systolic blood pressure (mmHg) | 196.75 | 18.88 |
| Diastolic blood pressure (mmHg) | 88.00 | 10.49 |
| RPE                      | 17.28  | 1.24 |

SD: standard deviation.

under 0.3 as poor correlations [21]. To predict VO₂ max from the best fitness index, a stepwise multiple regression analysis was performed with physical activity level and physiological and anthropometric data (age, resting HR, height, weight, BMI, and percent of body fat) as independent variables.

3. Results

3.1. Participant Characteristics. Thirty-three male participants aged 60 to 75 years were recruited. Eight of these participants did not complete the maximal exercise test due to cardiac and/or balance problems and were excluded for data analysis. The baseline characteristics of the remaining 25 participants analyzed are presented in Table 2.

3.2. Maximal Graded Exercise Test. Physiological responses of the participant to the maximal exercise test are shown in Table 3. Twenty-five subjects completed the maximal exercise test without any abnormal ECGs or complications. The VO₂ and RER at baseline were 4.86 ± 1.03 (ml/kg/min) and 0.76 ± 0.10, respectively. The VO₂ and RER at maximal efforts reached 35.82 ± 4.44 (ml/kg/min) and 1.05 ± 0.11, respectively. The time to volitional exhaustion was within an optimal exercise time of 8 to 12 minutes as suggested by ACSM.

3.3. The Modified Squat Test. Table 4 presents the result of the two modified squat tests. As shown in Table 4, the intensity for the modified squat test was 20.72 ± 3.60 ml/kg/min, corresponding to 58.22 ± 10.00% of VO₂ max and 80.98 ± 10.92% of age-predicted maximal HR.

3.4. Reliability of Squat Test. All the modified squat test fitness indexes showed high test-retest reliabilities, with ICC values ranging from 0.77 to 0.90. As shown in Table 5, age-adjusted recovery HR index had the highest ICC value (0.90) among the four squat test indexes.

3.5. Validity of the Modified Squat Test. As shown in Table 6, a significant negative correlation was seen between the sum of recovery HR and VO₂ max, whereas significant positive correlations between the recovery HR index and age-adjusted recovery index and VO₂ max were found. Age-adjusted recovery HR index had the highest correlation with VO₂ max.

3.6. Prediction of VO₂ max Equation. Table 7 presents the result of the stepwise multiple regression analysis for prediction of VO₂ max. Age-adjusted recovery HR index and physical activity level were strongly correlated with VO₂ max and accounted for 63% of the variance. The prediction equation for VO₂ max from the modified squat test was

\[
\text{VO}_2\text{ max} = 16.781 + 16.732 \times (\text{Age-adjusted recovery HR index}) + 0.02467 \times (\text{physical activity level}).
\]

4. Discussion

Cardiopulmonary fitness is associated with risks of cardiovascular diseases [22–24]. With aging, maximal oxygen consumption declines at the rate of 1% per year [25]. Regular exercise has been considered to be a safe and effective strategy to delay the aging process. Evaluation of cardiopulmonary fitness is essential to assure that a safe exercise prescription is implemented for older people [26]. Considering the nature of physical characteristics of older individuals, we modified a squat test, which was originally designed for young healthy adults.

4.1. Reliability. The ICC analyses on the fitness indexes (the immediate HR, sum of recovery HR, recovery HR index, and age-adjusted recovery HR index) of the modified squat test revealed that the ICCs ranged from 0.77 to 0.90, suggesting high reliabilities according to the definition of reliability level proposed by Portney and Watkins [21]. Age-adjusted recovery HR index had the highest ICC among the four modified squat test fitness indexes, showing the best reliability. On the contrary, the immediate HR yielded the lowest ICC value (0.77). The older adult has greater variations in physiological responses to an exercise and slower adaptations to an exercise, which contributes to the lower ICC seen in the immediate HR fitness index.

Petrella et al. investigated the validity of the self-paced step test in older adults while the reliability was not conducted [3]. Kervio et al. assessed the reliability of the 6-minute walk test in 12 healthy old individuals [27]. In their study, six trials of the 6-minute walk test were performed. However, only the coefficient of variation (CV) instead of ICCs was reported. Fenstermaker et al. investigated the test-retest ICC reliability of the Rockport walking test on the fitness indexes of walking
Table 4: Parameters of the modified squat test (N = 25).

| Parameter                        | SI         | S2         |
|----------------------------------|------------|------------|
| Immediate HR (beats/min)         | 131.40 ± 17.85 | 134.04 ± 18.63 |
| Recovery HR 0–30 s (beats)       | 51.16 ± 9.59  | 58.36 ± 9.63  |
| Recovery HR 60–90 s (beats)      | 47.80 ± 8.27  | 48.60 ± 9.57  |
| Recovery HR 120–150 s (beats)    | 44.84 ± 8.01  | 45.96 ± 9.17  |
| Sum of recovery HR (beats)       | 149.80 ± 24.79 | 152.92 ± 27.45 |
| Recovery HR index                | 61.92 ± 11.81 | 60.70 ± 10.85 |
| Age-adjusted recovery HR index   | 0.96 ± 0.21   | 0.94 ± 0.18   |
| VO₂ (ml/kg/min)                  | —           | 20.72 ± 3.60  |
| Percentage of VO₂ max (%)        | 80.93 ± 10.88 | 82.53 ± 11.05 |
| SBP (mmHg)                       | 167.11 ± 17.27 | 164.27 ± 22.48 |
| DBP (mmHg)                       | 95.78 ± 8.21  | 88.18 ± 11.43 |
| RPE                              | 12.20 ± 1.44  | 12.48 ± 1.81  |

S1: the first modified squat test; S2: the second modified squat test with oxygen consumption measurement; —: not available.

Table 5: Test-retest reliability of the modified squat test (N = 25).

| Index                              | ICC  | Sum of recovery HR (beats) | Recovery HR index | Age-adjusted recovery HR index |
|------------------------------------|------|---------------------------|-------------------|-------------------------------|
| Immediate HR (beats)               | 0.77 | 0.88                      | 0.87              | 0.90                          |

Table 6: Correlations between the squat test indexes and VO₂ max (n = 25).

| S1                                | S2        |
|-----------------------------------|-----------|
| Immediate HR (beats/min)          | -0.52**   | -0.51*     |
| Sum of recovery HR (beats)         | -0.64**   | 0.64**     |
| Recovery HR index                 | 0.68**    |            |
| Age-adjusted recovery HR index     | 0.70**    | 0.71**     |

**p < .001; *p < .05; S1: the first modified squat test; S2: the second modified squat test with oxygen consumption measurement.

Table 7: The regression model for the modified squat test to predict VO₂ max.

| Regression coefficient (B) | SE   | Standardized regression coefficients (β) | p value |
|----------------------------|------|------------------------------------------|---------|
| Age-adjusted recovery HR index | 16.732 | 0.497 | .000 |
| Physical activity level     | 0.02467 | 0.130 | .000 |
| Constant                    | 16.781 | 3.203 | .011 |
| R²                          | 0.63  | 0.59 | |

SE: standard error; R²: coefficient of determination.

The self-paced step test used a step with 40 cm height, which may predispose older individuals to increased risk of falls during testing. In our study, moderate to high correlations between fitness indexes and VO₂ max, with the highest correlation of 0.7 seen in age-adjusted recovery HR index, suggested the modified squat test is a valid fitness test in the older individual and comparable to or even superior to other fitness field tests reported in previous studies. The modified squat test is convenient, has low cost, is safe to administer, and requires limited space and thus may be another option for assessing aerobic fitness for old healthy individuals.

4.2. Validity. Previous studies have developed several aerobic fitness tests for old individuals. Rikli and Jones investigated the validity of the 6 min walk test in older individuals by correlating the treadmill performance time reaching 85% of time, HR, and estimated VO₂ max [9]. The ICC values of Rockport walking fitness indexes ranged from 0.67 to 0.71. In our study, a high ICC of 0.90 for age-adjusted recovery HR index suggests that the reliability of the modified squat test is comparable or superior to the above-mentioned fitness tests.
The immediate HR fitness index had the worst validity among the fitness indexes. One contributory factor might be due to the aged autonomic nervous system. Immediate HR recovery is primarily a function of reactivation of the parasympathetic nervous system, while later recovery of HR is associated with gradual withdrawal of the sympathetic nervous system [30, 31]. Aging results in slower adaptations of the autonomic nervous system to the termination of exercise [32, 33]. In other words, it takes longer for older adults to recover their HR to the baseline. Therefore, fitness indexes using several recovery HRs would be more representative of the fitness level of the older individual.

### 4.3. Prediction of Equation

Kervio et al. reported that predicted $\dot{V}O_{2\text{max}}$ equation for older individuals from the 6-minute walk test parameters (distance, heart rate) and anthropometric value (age, weight, and height) accounted for 94% of the variance in $\dot{V}O_{2\text{max}}$, with a small subject number of 12 [27]. In the self-paced step test, stepping time, heart rate, age, BMI, and $O_2$ pulse were significantly associated with $\dot{V}O_{2\text{max}}$ and were chosen to establish the predictive formula, which can explain 72% to 86% of variance [3]. The correlation of the predicted $\dot{V}O_{2\text{max}}$ of the self-paced step test and the measured $\dot{V}O_{2\text{max}}$ was from 0.88 and 0.90 for low-fitness men and women and 0.83 and 0.94 for high-fitness men and women. In our study, the age-adjusted recovery HR fitness index had the highest validity among four fitness indexes calculated and thus was chosen to develop a prediction equation for aerobic power of the older individual. Factors which might affect $\dot{V}O_{2\text{max}}$ value such as age, resting HR, height, weight, body fat, and physical activity were taken into account for regression analysis to establish the prediction of $\dot{V}O_{2\text{max}}$. The predicted $\dot{V}O_{2\text{max}}$ using this model was highly correlated ($r = 0.79$) with measured $\dot{V}O_{2\text{max}}$ from the maximal exercise test. The predictive model based on age-adjusted recovery HR and physical activity explained 63% of the variances in $\dot{V}O_{2\text{max}}$. The variance explained by the prediction equation in our study appears to be lower than those in the 6 min walk test and the self-paced step test. However, only 12 subjects were recruited to develop the prediction equation from the 6 min walk test in Kervio et al. study. In the prediction model for the self-paced step test, $O_2$ pulse was used as one of predictive parameters. Petrella et al. indicated that $O_2$ pulse from the self-paced step test was strongly associated with $\dot{V}O_{2\text{max}}$ and improved the percentage variance to be explained in the prediction of $\dot{V}O_{2\text{max}}$ [3]. For clinical practice purposes, we did not include $O_2$ pulse in our model, which might contribute to the discrepancy. In addition, previous research stated that body composition, such as BMI, weight, or body fat, is a factor in the predictive equation of $\dot{V}O_{2\text{max}}$ [3, 9, 27]. However, in our study, body composition was excluded in the regression analyses. A small sample size and homogeneous body fat in our subjects might be contributory factors.

### 4.4. Suggestions for Future Applications of the Modified Squat Test

The exercise intensity for the modified squat test is approximately 60% of $\dot{V}O_{2\text{max}}$ and 81% of age-predicted maximal HR, corresponding to a moderate exercise workload. No discomfort or injuries during the testing were reported. The modified squat test is submaximal while appearing to be able to elicit substantiate physiological exercise responses to allow one's maximal aerobic power to be assessed safely and accurately. Moreover, it is interesting to note that most of the subjects expressed that they would practice the modified squat test as an exercise afterwards, suggesting the continuous movement of the modified squat test might potentially be developed as an interesting form of exercise. To serve this purpose, the prototype testing device used in this study should be further developed to provide adjustments of exercise workloads as well as feedback of exercise intensity. The prototype testing device could be manufactured with sensors monitoring HR and with a device indicating different rates of half-squatting. In addition, an electronic goniometer could well be integrated into the testing system to indicate the appropriate angle of squatting.

There are several limitations in this study. First, the sample size of this study was small. In addition, most of the subjects tended to be young older adults (aged < 70 years). Therefore, a larger sample size with individuals aged 70 years and beyond is required in future studies to enhance the application of the $\dot{V}O_{2\text{max}}$ prediction equation determined from the modified squat test. Second, the subjects of this study were all males. Whether the modified squat test is valid for healthy older females still needs to be confirmed.

### 5. Conclusions

The results reveal that the modified squat test is valid and reliable and can be an option for evaluating the fitness level in healthy elderly men in clinics or communities. The best index is age-adjusted recovery heart rate. The predicted equation for $\dot{V}O_{2\text{max}}$ is $16.781 + 16.732 \times \text{age-adjusted recovery HR} + 0.02467 \times \text{physical activity level (score of PASE questionnaire)}$.

### Conflicts of Interest

The authors declare no conflicts of interest.

### Acknowledgments

The authors would like to thank all of the participants who volunteered their time to participate in the study.

### References

[1] D. Hansen, N. Jacobs, S. Bex, G. D’Haene, P. Dendale, and N. Claes, "Are fixed-rate step tests medically safe for assessing physical fitness?" European Journal of Applied Physiology, vol. 111, no. 10, pp. 2593–2599, 2011.

[2] H. Bennett, G. Parfitt, K. Davison, and R. Eston, "Validity of submaximal step tests to estimate maximal oxygen uptake in healthy adults," Sports Medicine, vol. 46, no. 5, pp. 737–750, 2016.

[3] R. J. Petrella, J. J. Koval, D. A. Cunningham, and D. H. Paterson, "A self-paced step test to predict aerobic fitness in older adults..."
in the primary care clinic,” Journal of the American Geriatrics Society, vol. 49, no. 5, pp. 632–638, 2001.

[4] H.-J. Lee and L.-S. Chou, “Balance control during stair negotiation in older adults,” Journal of Biomechanics, vol. 40, no. 11, pp. 2530–2536, 2007.

[5] R. E. Rikli and C. J. Jones, “Development and validation of a functional fitness test for community-residing older adults,” Journal of Aging and Physical Activity, vol. 7, no. 2, pp. 129–161, 1999.

[6] J. E. Johnston, The Validation of a 2-Minute Step Test in Older Adults, California State University, Fullerton, Calif, USA, 1999.

[7] M. Leone, S. Duvergé, É. Kalinova, H. T. Bui, and A. S. Comtois, “Comparison of bioenergetics of walking during a multistage incremental shuttle walk test and a 6-min walk test in active older adults,” Aging Clinical and Experimental Research, vol. 29, no. 2, pp. 239–246, 2017.

[8] K. Kim, H.-Y. Lee, D.-Y. Lee, and C.-W. Nam, “Changes in cardiopulmonary function in normal adults after the Rockport 1 mile walking test: a preliminary study,” Journal of Physical Therapy Science, vol. 27, no. 8, pp. 2559–2561, 2015.

[9] K. L. Fenstermaker, S. A. Plowman, and M. A. Looney, “Validation of the rockport fitness walking test in females 65 years and older,” Research Quarterly for Exercise and Sport, vol. 63, no. 3, pp. 322–327, 1992.

[10] Y. Kubori, R. Matsuki, A. Hotta, T. Morisawa, and A. Tamaki, “Comparison between stair-climbing test and six-minute walk test after lung resection using video-assisted thoracoscopic surgery lobectomy,” Journal of Physical Therapy Science, vol. 29, no. 5, pp. 902–904, 2017.

[11] R. E. Rikli and C. J. Jones, “The reliability and validity of a 6-minute walk test as a measure of physical endurance in older adults,” Journal of Aging & Physical Activity, vol. 6, no. 4, pp. 363–375, 1998.

[12] M. G. Santana, C. A. B. de Lira, G. S. Passos et al., “Is the six-minute walk test appropriate for detecting changes in cardiorespiratory fitness in healthy elderly men?” Journal of Science and Medicine in Sport, vol. 15, no. 3, pp. 259–265, 2012.

[13] Y. Inoue and M. Nakao, “Prediction of maximal oxygen uptake by squat test in men and women,” Kobe Journal of Medical Sciences, vol. 42, no. 2, pp. 119–129, 1996.

[14] P. M. Okin, O. Ameisen, and P. Kligsfeld, “A modified treadmill exercise protocol for computer-assisted analysis of the ST segment/heart rate slope: methods and reproducibility,” Journal of Electrocardiology, vol. 19, no. 4, pp. 311–318, 1986.

[15] M. Hollenberg, L. H. Ngo, D. Turner, and I. B. Tager, “Treadmill Exercise Testing in an Epidemiologic Study of Elderly Subjects,” The Journals of Gerontology Series A, Biological Sciences and Medical Sciences, vol. 53A, no. 4, pp. B259–B267, 1998.

[16] A. C. O. S. Medicine, B. A. Franklin, M. H. Whaley, E. T. Howley, and G. J. Balady, Acm’s Guidelines for Exercise: Testing and Prescription, Lippincott Williams & Wilkins, Philadelphia, Pa, USA, 2000.

[17] American College of Sports Medicine, B. A. Franklin, M. H. Whaley, E. T. Howley, and G. J. Balady, Balady, Acm’s Guidelines for Exercise: Testing and Prescription, Lippincott Williams & Wilkins, Philadelphia, Pa, USA, 2000.

[18] H. Tanaka, K. D. Monahan, and D. R. Seals, “Age-predicted maximal heart rate revisited,” Journal of the American College of Cardiology, vol. 37, no. 1, pp. 153–156, 2001.

[19] E. Edvardsen, E. Hem, and S. A. Andersen, “End criteria for reaching maximal oxygen uptake must be strict and adjusted to sex and age: a cross-sectional study,” PLoS ONE, vol. 9, no. 1, Article ID e85276, 2014.

[20] E. N. Keen and A. W. Sloan, “Observations on the Harvard step test,” Journal of Applied Physiology, vol. 13, no. 2, pp. 241–245, 1958.

[21] L. G. Portney and M. P. Watkins, Foundations of Clinical Research: Applications to Practice, Prentice Hall Health, Upper Saddle River, NJ, USA, 2nd edition, 2000.

[22] D.-C. Lee, X. Sui, E. G. Artero et al., “Long-term effects of changes in cardiorespiratory fitness and body mass index on all-cause and cardiovascular disease mortality in men: the Aerobics Center Longitudinal Study,” Circulation, vol. 124, no. 23, pp. 2483–2490, 2011.

[23] R. Ross, S. N. Blair, R. Arena et al., “Importance of assessing cardiorespiratory fitness in clinical practice: a case for fitness as a clinical vital sign: a scientific statement from the american heart association,” Circulation, vol. 134, no. 24, pp. e653–e699, 2016.

[24] S. Gupta, A. Rohatgi, C. R. Ayers et al., “Cardiorespiratory fitness and classification of risk of cardiovascular disease mortality,” Circulation, vol. 123, no. 13, pp. 1377–1383, 2011.

[25] S. A. Hawkins and R. A. Wiswell, “Rate and mechanism of maximal oxygen consumption decline with aging,” Sports Medicine, vol. 33, no. 12, pp. 877–888, 2003.

[26] G. F. Fletcher, G. J. Balady, E. A. Amsterdam et al., “Exercise standards for testing and training: a statement for healthcare professionals from the American Heart Association,” Circulation, vol. 104, no. 14, pp. 1694–1740, 2001.

[27] G. Kervio, F. Carre, and N. S. Ville, “Reliability and intensity of the six-minute walk test in healthy elderly subjects,” Medicine & Science in Sports & Exercise, vol. 35, no. 1, pp. 169–174, 2003.

[28] A. D. Hughes and N. Chaturvedi, “Estimation of maximal oxygen consumption and heart rate recovery using the Tecumseh sub-maximal step test and their relationship to cardiovascular risk factors,” Artery Research, vol. 18, pp. 29–35, 2017.

[29] Y.-D. Tang, T. A. Dewland, D. Wencker, and S. D. Katz, “Post-exercise heart rate recovery independently predicts mortality risk in patients with chronic heart failure,” Journal of Cardiac Failure, vol. 15, no. 10, pp. 850–855, 2009.

[30] N. Du, S. Bai, K. Oguri et al., “Heart rate recovery after exercise and neural regulation of heart rate variability in 30–40 year old female marathon runners,” Journal of Sports Science and Medicine, vol. 4, no. 1, pp. 9–17, 2005.

[31] V. S. L. Droguett, A. D. C. Santos, C. E. de Medeiros, D. P. Marques, L. S. do Nascimento, and M. D. S. Brasileiro-Santos, “Cardiac autonomic modulation in healthy elderly after different intensities of dynamic exercise,” Clinical Interventions in Aging, vol. 10, pp. 203–208, 2015.

[32] U. Dimkpa and K. Ibhazehiebo, “Assessment of the influence of age on the rate of heart rate decline after maximal exercise in non-athletic adult males,” Clinical Physiology and Functional Imaging, vol. 29, no. 1, pp. 68–73, 2009.

[33] H. Njemanze, C. Warren, C. Eggert et al., “Age-related decline in cardiac autonomic function is not attenuated with increased physical activity,” Oncotarget, vol. 7, no. 47, pp. 76390–76397, 2016.