

Reference equations for the performance of healthy adults on field walking tests^{*}, ^{**}

Equações de referência para os testes de caminhada de campo em adultos saudáveis

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Abstract

Objective: To develop regression equations for predicting six-minute and incremental shuttle walk distances (6MWD and ISWD, respectively), based on demographic characteristics, anthropometric variables, and grip strength. **Methods:** We evaluated 6MWD and ISWD in 98 healthy adults. Height, weight, and grip strength were also assessed. Using data from 90 of the participants (40 males; 60 ± 9 years of age), we devised linear equations adjusted for age, gender, height, and weight, and we developed alternate models that included grip strength. We prospectively applied the equations in the 8 remaining participants (4 males; 59 ± 10 years), who had been randomly separated from the initial sample. **Results:** Age, gender, height, and weight collectively explained 54.5% and 64.9% of the variance in 6MWD and ISWD, respectively, whereas age, height, weight, and grip strength collectively explained 54.4% and 69.0% of the respective variances. There was no significant difference between the measured and predicted 6MWD using equations with and without grip strength (14 ± 57 vs. 13 ± 67 m). Similar results were observed for ISWD (25 ± 104 vs. 25 ± 93 m). **Conclusions:** Grip strength is a determinant of ISWD and 6MWD; however, it could not improve the power of equations adjusted by demographic and anthropometric variables. The validity of our models including grip strength should be further evaluated in patients with skeletal muscle dysfunction.

Keywords: Walking; Exercise; Reference Values; Exercise test.

Resumo

Objetivo: Desenvolver equações de regressão para a previsão das distâncias caminhadas nos testes de caminhada de seis minutos e *incremental shuttle walk test* (DTC6 e ISWD) baseadas em atributos demográficos, antropométricos e força de preensão manual. **Métodos:** Avaliamos a DTC6 e ISWD em 98 adultos saudáveis. Estatura, peso e força de preensão manual foram também avaliados. Equações ajustadas para idade, gênero, estatura e peso e equações, incluindo também a força de preensão manual, foram desenvolvidas dos dados de 90 participantes (40 homens; 60 ± 9 anos). Aplicamos prospectivamente as equações em 8 participantes (4 homens; 59 ± 10 anos) randomicamente selecionados da amostra inicial. **Resultados:** Idade, gênero, altura e peso explicaram coletivamente 54,5% e 64,9% da variância da DTC6 e ISWD, respectivamente, ao passo que idade, altura, peso e força de preensão manual explicaram coletivamente 54,4% e 69,0% da variância da DTC6 e ISWD, respectivamente. A diferença entre a DTC6 prospectivamente avaliada e prevista não foi significativa usando equações com e sem força de preensão manual (14 ± 57 m vs. 13 ± 67 m). Resultados semelhantes foram observados para a ISWD (25 ± 104 m vs. 25 ± 93 m). **Conclusões:** A força de preensão manual é um determinante para DTC6 e ISWD; entretanto, não foi capaz de aumentar o poder das equações ajustadas por variáveis demográficas e antropométricas. A validade de nossos modelos incluindo a força de preensão manual deve ser avaliada em pacientes com disfunção muscular esquelética.

Descritores: Caminhada; Exercício; Valores de referência; Teste de esforço.

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Introduction

Walking tests, such as the six-minute walk test (6MWT) and incremental shuttle walk test (ISWT),^(1,2) are economically accessible and offer the advantage of operational simplicity. These tests are well established and have become widely used measures of exercise capacity in patients with any of a number of chronic diseases.

The 6MWT, which is of a fixed duration, is influenced by external factors, such as motivation and the amount of effort expended. Therefore, the instructions and level of encouragement given should be carefully standardized.⁽¹⁾ On the 6MWT, the pace is determined by the subject, and the distance covered therefore varies widely, even among healthy individuals.⁽³⁻⁶⁾ However, on the ISWT, there is a controlled, progressive increase in pace every 60 s.⁽²⁾ Both tests are safe when performed appropriately and have been used, with no adverse effects, in thousands of patients with heart or lung disease.⁽¹⁾

Various demographic, anthropometric, and physiological factors can influence the total distance covered on field walking tests, such as the six-minute walk distance (6MWD) and the incremental shuttle walk distance (ISWD). Shorter individuals and women have shorter strides and consequently cover less distance. Elderly and obese individuals often have low lean body mass and therefore also cover shorter distances. The 6MWD has been reported to be below average in unmotivated individuals, those with cognitive deficits, and those with arthritis or other musculoskeletal disorders.^(3,7) Other factors that can influence the 6MWD include symptoms of depression, impaired health-related quality of life, medication use, systemic inflammation, and impaired pulmonary function.⁽⁷⁾

To our knowledge, only three studies have formulated reference equations to predict the 6MWD and ISWD in Brazilian individuals.⁽⁸⁻¹⁰⁾ Iwama et al.,⁽⁹⁾ who evaluated 6MWDs in 134 healthy Brazilians (73 women) ≥ 13 years of age, found that age and gender collectively explained 30.0% of the variance in 6MWD. Priesnitz et al.⁽⁸⁾ evaluated a convenience sample of 188 healthy Brazilian children and adolescents (92 males) between 6 and 12 years of age, recruited from three elementary schools. The authors found that age, height, weight, and absolute difference between pre- and post-6MWT HR correlated significantly with 6MWD, collectively explaining

36.6% of the 6MWD variance. Jürgensen et al.⁽¹⁰⁾ evaluated ISWD in 131 Brazilian individuals. Using a predictive model, the authors showed that age, height, weight, and gender collectively explained 50.3% of the ISWD variance. In a recent multicenter study, the predictive equations varied widely across centers (adjusted $R^2 = 0.09-0.73$) and explained $< 30\%$ of the 6MWD variance at four of the centers evaluated.⁽¹¹⁾

The assessment of grip strength (GS) has broad clinical applicability, because it is a low-cost, simple, rapid, and noninvasive method,^(12,13) providing an indicator of general health and overall muscle function.⁽¹²⁾ Various authors have found GC to correlate significantly and positively with 6MWD and ISWD, especially in patients with COPD.^(7,14-16) In healthy elderly individuals, GS has been identified as a determinant of 6MWD.⁽⁷⁾

The use of faulty reference equations can result in mistakes related to the interpretation of the level of physical fitness and the improvement in walking distance after interventions in patients with chronic diseases. Therefore, the purpose of this study was to develop regression equations for predicting the 6MWD and ISWD, based on demographic characteristics, anthropometric variables, and GS. We also attempted to determine whether GS correlates with ISWD and 6MWD.

Methods

We evaluated 98 healthy subjects—all over 40 years of age—some recruited from among employees of the Federal University of São Paulo, located in the city of Santos, Brazil, and others recruited from among residents of the surrounding community, through newspaper advertisements. Subjects completed a questionnaire regarding physical activity, and those determined to engage in such activity for less than 30 min/day were classified as sedentary.⁽¹⁷⁾ On the basis of their BMI, the subjects were stratified into the following categories: underweight (< 18.5 kg/m²); normal weight (18.5-24.9 kg/m²); overweight (25-29.9 kg/m²); and obese (≥ 30 kg/m²). All of the subjects selected for study were healthy and ambulatory (having no cardiorespiratory, metabolic, neuromuscular, or musculoskeletal disease and requiring no walking aids). Subjects with abnormal post-

bronchodilator lung function were excluded,⁽¹⁸⁾ as were those classified as obese. We randomly selected 8 individuals—one man and one woman from the 40–49, 50–59, 60–69, and ≥ 70 year age brackets, respectively—to serve as test subjects, and we developed reference equations based on data related to the remaining 90 participants. To verify the reliability of our reference equations, we applied them in the 8 test subjects. The study design was approved by the Human Research Ethics Committee of the Federal University of São Paulo, and all subjects gave written informed consent.

Weight and height were measured by standard techniques, with the subjects wearing light clothing and no shoes. Weight was measured to the nearest 0.1 kg with a calibrated scale, and height was determined to the nearest 0.5 cm with a stadiometer. The BMI was calculated as weight in kilograms divided by height in meters squared (kg/m^2). Pulmonary function and bronchodilator reversibility tests were performed using a hand-held spirometer (Spiropalm; COSMED, Rome, Italy), in accordance with American Thoracic Society criteria.⁽¹⁸⁾

The 6MWT and ISWT were each administered twice, on alternate days. Before and after each test, we assessed HR, blood pressure, breathlessness, and leg fatigue. To minimize the learning effect, we allowed an interval of at least 30 min between tests.^(1,19) The 6MWT was carried out in accordance with American Thoracic Society recommendations.⁽¹⁾ The test consisted of walking unaided, as fast as possible, for 6 min in a corridor 27–30 m in length. Every 60 s, raters provided standardized verbal encouragement, as follows: “You’re doing well” and “Keep up the good work”. The ISWT was carried out with the method described by Singh et al.⁽²⁾ The test consisted of walking a 10-m course at a progressive pace. Walking speed was controlled by a series of sounds indicating the moment the subject should change directions around the cone. Every 60 s, another sound indicated the moment at which the subject should increase the pace. When the subject was unable to reach the closest cone (i.e. was > 0.5 m from the cone) by the time the signal sounded, the rater ended the test, which could also be terminated by the subject for any reason. Because the ISWT was developed to assess functional exercise capacity in patients with lung disease, the original

protocol consists of 12 stages (total distance, 1,020 m). However, because we were applying the test in healthy subjects, we extended it to 15 stages (1,500 m), in order to avoid the ceiling effect.

The dominant hand was defined as that favored in carrying out daily activities. The participants were asked about hand preference for activities such as writing, eating, and carrying objects. We assessed the GS of the dominant hand with a Jamar dynamometer (TEC, Clifton, NJ, USA), using the method described by Mathiowetz et al.⁽¹²⁾ Subjects were seated with one arm raised parallel to the trunk, shoulder in neutral rotation, elbow flexed 90° , and forearm in a neutral position. During the test, we allowed hyperextension of the wrist up to 30° and ulnar deviation up to 15° . We took three measurements, 30 s apart. The greatest of the three measurements was used in the data analysis.

The statistical analysis was performed with the Statistical Package for the Social Sciences, version 12 (SPSS Inc., Chicago, IL, USA). Data are presented as mean and standard deviation or as median and interquartile range. We employed the Kolmogorov-Smirnov test to evaluate normality of data distribution, Pearson’s or Spearman’s correlation coefficient to study correlations between variables, and unpaired t-test to determine intergroup differences in numerical data. We also used stepwise multiple linear regression analysis to identify the dependent variables that were the best predictors of 6MWD and ISWD. Age, gender, height, and weight were included in the regression models. Alternate models were constructed to include GS. Gender interaction terms were included for age, height, weight, and GS. Correlations between ISWD and GS and between 6MWD and GS were determined using the z statistic (MedCalc™, version 11.1.1; MedCalc Software, Mariakerke, Belgium). Sample size was estimated on the basis of the number of variables to be entered into the multiple regression analysis and the minimum number of observations required. The minimum sample size was calculated to be at least 50 subjects. Multicollinearity in the models was avoided by excluding variables with variance inflation factors > 4 . We evaluated the measured 6MWD and ISWD in comparison with the predicted

distances derived from our equations. The level of statistical significance was set at 5%.

Results

The characteristics of the 90 subjects (40 males) are summarized in Table 1. All of the subjects had normal lung function. The age distribution of our sample was as follows: 40-49 years ($n = 20$); 50-59 years ($n = 21$); 60-69 years ($n = 26$); and ≥ 70 years ($n = 23$). Mean BMI was within the overweight range (28 ± 3 kg/m²). Approximately 52% of the subjects were classified as sedentary. The GS, 6MWD, and ISWD values were greater in males than in females (43 ± 7 vs. 28 ± 5 kg, 641 ± 63 vs. 540 ± 72 m, and 600 ± 91 vs. 417 ± 103 m, respectively; $p < 0.001$ for all).

The univariate analysis showed that 6MWD correlated significantly with age ($r = -0.35$), height ($r = 0.58$), BMI ($r = -0.47$), and GS (Figure 1a), whereas ISWD correlated significantly with age, height, and BMI ($r = -0.36$, $r = 0.66$, and $r = -0.48$, respectively; $p < 0.05$ for all), as well as with GS (Figure 1b). The correlation coefficient for ISWD and GS was significant higher than that obtained for 6MWD and GS (z statistic = 2.05; $p = 0.03$). Age, gender, height, and weight collectively explained 54.5% and 64.9% of the variance in 6MWD and ISWD, respectively (Table 2). In the alternate models, age, height, weight, and GS collectively explained 54.4% and 69% of the variance in 6MWD and ISWD, respectively (Table 3). No interactions with gender were detected.

Table 1 – General characteristics of the subjects.

Characteristic	Mean \pm SD
	($n = 90$)
Age, years	60 \pm 9
Weight, kg	69 \pm 12
Height, m	1.60 \pm 0.09
BMI, kg/m ²	26 \pm 4
FEV ₁ , %pred	111 \pm 13
FVC, %pred	109 \pm 11
FEV ₁ /FVC, %	85 \pm 6
GS, kg	33 \pm 9
1st 6MWD, m	567 \pm 75
2nd 6MWD, m	572 \pm 83
1st ISWD, m	451 \pm 133
2nd ISWD, m	474 \pm 131

BMI: body mass index; GS: grip strength; 6MWD: six-minute walk distance; ISWD: incremental shuttle walk distance.

The validation sample comprised the 8 test subjects (means: age, 59 \pm 10 years; height, 1.65 \pm 0.08 m; weight, 74 \pm 12 kg; and BMI, 27 \pm 4 kg/m²). For those 8 subjects, the mean 6MWD was 588 \pm 71 m, corresponding to 102 \pm 9% and 102 \pm 11% of the predicted values calculated with equations including and excluding GS, respectively. The difference between the measured and predicted 6MWD values was not significant, with or without GS (13 \pm 67 m and 14 \pm 57 m, respectively; $p > 0.05$). The mean ISWD was 515 \pm 150 m, corresponding to 105 \pm 15% and 105 \pm 18% of the predicted values calculated by the equations with and without GS, respectively. The difference between the measured and predicted ISWD

Table 2 – Predictive model for incremental shuttle and six-minute walk distances in healthy subjects, using demographic and anthropometric attributes.

Variable	Incremental shuttle walk distance				Six-minute walk distance			
	Partial R ²	Coefficient	SE	p	Partial R ²	Coefficient	SE	p
Constant	-	34.608	255.310	-	-	299.296	185.784	-
Age, years	0.041	-4.384	0.997	< 0.001	0.047	-2.728	0.725	< 0.001
Weight, kg	0.100	-2.949	0.788	< 0.001	0.112	-2.160	0.574	< 0.001
Height, m	0.443	553.336	157.264	< 0.001	0.346	361.731	114.438	0.002
Gender*	0.065	114.387	28.771	< 0.001	0.038	56.386	20.936	0.009
		Total R ² = 0.649				Total R ² = 0.543		

*Factor gender: men = 1; women = 0.

Reference equations employed in this model:

Incremental shuttle walk distance = 34.608 - (4.384 vs. age) - (2.949 vs. weight) + (553.336 vs. height) + (114.387 vs. gender); standard error of the estimate = 79.4 m

Six-minute walk distance = 299.296 - (2.728 vs. age) - (2.160 vs. weight) + (361.731 vs. height) + (56.386 vs. gender); standard error of the estimate = 57.7 m.

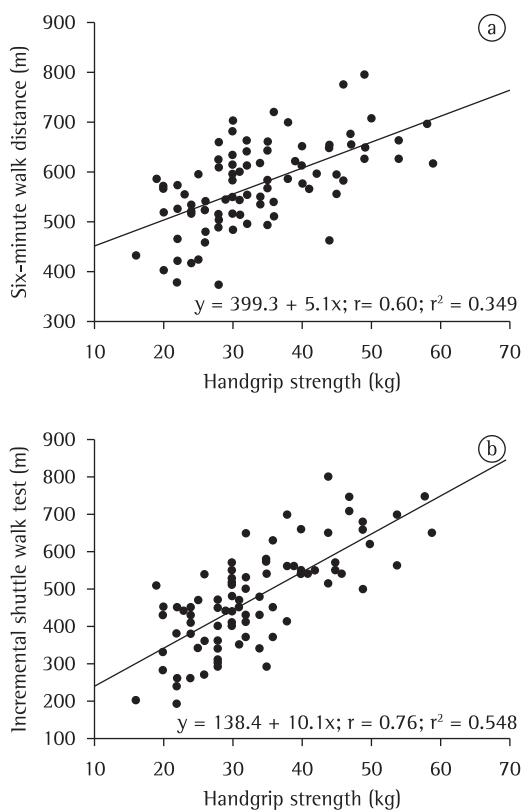


Figure 1 - Correlation of grip strength with six-minute walk distance (a) and incremental shuttle walk distance (b).

values was also not significant, with or without GS (25 ± 93 m and 25 ± 104 m, respectively; $p > 0.05$).

Discussion

To our knowledge, the present study is the first to develop GS-based reference equations for predicting ISWD and 6MWD in healthy, fully ambulatory subjects. We found that GS played an important role in predicting 6MWD and ISWD in healthy older adults, explaining large proportions of the total variances in these variables. Although GS correlated strongly with 6MWD and ISWD, it correlated more significantly with ISWD.

In our study, age, gender, weight, and height were identified as independent predictors of ISWD and 6MWD. These results are quite similar to those previously described for older Brazilians adults.^(9,10) The influence of gender on walking distance might be attributable to the fact that men have greater absolute muscle strength,

muscle mass, and height than do women. The negative influence of advanced age on ISWD might be explained by the gradual reduction in muscle mass, muscle strength, and maximal oxygen uptake that typically occurs in parallel with aging.⁽²⁰⁾ Height has a strong influence, which might be attributable to the greater stride length in taller individuals, stride length being a major predictor of gait speed.⁽²¹⁾ However, findings related to the question of whether body weight correlates with 6MWD and ISWD have been inconsistent across studies.⁽⁵⁻⁷⁾ Nevertheless, it is likely that, because of its curvilinear nature, this correlation has defied detection in linear regressions.^(7,10,22)

In the present study, the inclusion of GS did not improve the power of commonly used reference equations based on anthropometric and demographic attributes. This could be attributed to the great influence that age, weight, height, and gender has on GS. However, it is possible that the equations including GS would be more appropriate for the evaluation of patients with muscle depletion. In such cases, muscle strength would be considered, and the predicted performance on the 6MWT and ISWT might more accurately represent the functional capacity of the patients. Further studies are needed in order to assess the validity of these equations in patients who are more debilitated and have skeletal muscle dysfunction, such as those with lung diseases, especially COPD, cystic fibrosis, and bronchiectasis, in which there is typically pronounced muscle loss.

We found that GS correlated strongly with ISWD and 6MWD, more so with ISWD. Studies that have evaluated the validity of these walking tests in patients with chronic disease have found GS to be significantly correlated with 6MWD and ISWD.^(14,16) Similar results have been described in healthy individuals.^(4,7) The fact that muscle strength and body weight had a greater influence on the ISWD than on the 6MWD might be attributable to the incremental nature of the ISWT, in which the pace is progressively increased at each stage. It is likely that individuals walk with intensity above the lactate threshold during a large portion of the test, which results in greater recruitment of glycolytic muscle fibers.⁽²³⁾ One study assessed the ventilatory and HR variability thresholds in healthy subjects performing the ISWT and recognized indices

Table 3 – Predictive model for the incremental shuttle and six-minute walk distances in healthy subjects using demographic and anthropometric attributes and grip strength.

Variable	Incremental shuttle walk distance (m)				Six-minute walk distance (m)			
	Partial R ²	Coefficient	SE	p	Partial R ²	Coefficient	SE	p
Constant	-	-243.867	183.135	-	-	109.764	141.888	-
Age, years	0.038	-2.833	0.872	0.002	0.045	-1.794	0.675	0.004
Weight, kg	0.066	-3.259	0.716	< 0.001	0.088	-2.383	0.555	< 0.001
Height, m	0.047	575.101	126.924	< 0.001	0.062	423.110	98.337	< 0.001
Grip strength, kg	0.538	6.321	1.171	< 0.001	0.348	2.422	0.908	0.009
		Total R ² = 0.690				Total R ² = 0.543		

*Factor grip strength: men = 1; women = 0.

Reference equations employed in this model:

Incremental shuttle walk distance = -243.867 - (2.833 vs. age) - (3.259 vs. weight) + (575.101 vs. height) + (6.321 vs. grip strength); standard error of the estimate = 74.6 m

Six-minute walk distance = 109.764 - (1.794 vs. age) - (2.383 vs. weight) + (423.110 vs. height) + (2.422 vs. grip strength); standard error of the estimate = 57.8 m.

of transition between moderate and intense exercise.⁽²⁴⁾ However, on the 6MWT, the pace is controlled by the subject and an aerobic steady state is achieved.⁽²⁵⁾ This suggests that the exercise intensity is at or below the lactate threshold in most cases, which results in a lower demand for glycolytic muscle fiber recruitment.⁽²³⁾ In agreement with this, Pelegriano et al.⁽²⁶⁾ found the 6MWD to be similar in COPD patients with and without lean body mass depletion, indicating that skeletal muscle has a limited influence on 6MWD. However, during the test, the patients with such depletion presented significantly greater HR and sensation of leg fatigue. Therefore, muscle mass and muscle function both seem to have a more consistent influence on ISWD than on 6MWD.

Various chronic diseases have systemic manifestations. One major manifestation of such diseases is peripheral skeletal muscle dysfunction. Although reductions in muscle mass and strength occur in parallel, the correlation between these variables is not linear. Therefore, muscle depletion can occur even in patients with normal body mass and BMI. For example, patients of the same gender with the same anthropometric characteristics would be expected to cover the same distance on field walking tests, after adjustment for anthropometric and demographic attributes, based on reference equations. However, peripheral muscle strength (i.e., the degree of muscle depletion) can differ significantly between individuals. To predict performance on walking tests, muscle strength, widely

recognized as a determinant of cardiorespiratory fitness, should be taken into account.

Our results have clinical implications. Traditionally, GS has been used in evaluating the physical condition of the upper limbs. However, more recently, GS has been assessed in various clinical situations. For example, Ling et al.⁽²⁷⁾ showed that GS was a major predictor of all-cause mortality in adults > 85 years of age. Al Snih et al.⁽²⁸⁾ followed a population-based sample of 2,488 noninstitutionalized men and women ≥ 65 years of age, 507 of whom died within the first five years of the study. The authors found that GS was strongly correlated with mortality. Poorer performance on the timed walk test, as well as diabetes mellitus, hypertension, and cancer, were also found to be significant negative predictors of five-year survival. Previous studies have demonstrated a significant positive correlation between GS and body cell mass.⁽²⁹⁾ Taekema et al.⁽³⁰⁾ found that lower GS was correlated with poorer scores for functional, psychological, and social health domains. The authors also showed that lower baseline GS was predictive of an accelerated decline in cognition and in the ability to perform activities of daily living. Therefore, the determination of GS could be useful for identifying elderly patients at risk for such a decline. As an index of general health and muscle strength, GS shows promise. Given the low cost of dynamometry, it is reasonable to include this variable in regression models designed to predict the distance covered on walking tests.

The main limitation of the present study was the use of a convenience sample, which might

have introduced a selection bias. However, this type of sample has often been used in studies evaluating reference values for the total distance walked on field walking tests.^(3-7,10) The GS values, in combination with demographic and anthropometric attributes, did not increase the R^2 values of the standard equations. This might be attributable to the fact that GS was consistently correlated with age, height, and weight, or there might have been multicollinearity among variables in the alternate models, which could also explain that finding. However, the variance inflation factor values were < 4 , indicating that there was no such multicollinearity in the alternate models.

We conclude that GS is a determinant of the total distance covered on the 6MWT and ISWT. However, the inclusion of GS did not appreciably improve the power to predict 6MWD and ISWD in comparison with that of equations including only demographic and anthropometric attributes. Nevertheless, reference equations including muscle function could be useful for interpreting the walk performance of patients with skeletal muscle dysfunction.

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