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ORIGINAL ARTICLE

Predictive models for the six-minute walk test considering the walking course and physical activity level

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ABSTRACT

BACKGROUND: In recent decades, space limitations in the clinical environment have forced health professionals to administer the six-minute walk test (6MWT) using a 20-m or even a 10-m course. However, course length and physical activity level (PAL) affect the test outcomes.
AIM: To develop a reference equation for the 6MWT that takes into account the effects of course length and PAL on the walking distance.
DESIGN: Cross-sectional study.
SETTING: Federal University of the State of Rio de Janeiro.
POPULATION: Two hundred fifteen healthy adults.
METHODS: All subjects performed the 6MWT on 10-, 20- and 30-m courses. Eight regression models were constructed considering the association between the six-minute walking distance (6MWD) and heart rate, perceived effort (scores from the Borg's Perceived Exertion Scale-BPES), PAL (classification according to the International Physical Activity Questionnaire, IPAQ), as well as anthropometric and demographic variables. The models were analyzed for the coefficients of determination (R^2) and statistical significance at $P<0.05$.
RESULTS: A nonlinear increase in the means of the 6MWDs obtained using the three course lengths was observed (591±70, 652±79 and 678±85 m for course lengths of 10, 20 and 30 m, respectively, with $P<0.001$). The 6MWD correlated positively with the following variables: sex (r=0.20), body height (r=0.30), IPAQ classification (r=0.14), ΔBPES rating (r=0.25) and Δheart rate (HR, r=0.23), with $P<0.001$ for all. In contrast, the 6MWD correlated negatively with age (r=-0.23) and Body Mass Index (BMI, r=-0.18), with $P<0.001$ for both. The regression model with the highest coefficient of determination (adjusted R^2=0.36) included the following variables: sex, age, BMI, course length (CL), BPES, HR, and IPAQ.
CONCLUSIONS: The length of the course strongly impacts individual performance on the 6MWT in a predominantly young adult population. Furthermore, IPAQ-assessed PAL is an important independent predictor of 6MWD.
CLINICAL REHABILITATION IMPACT: The incorporation of course length in the prediction of 6MWD allows the use of a prediction equation that includes the effects of different course sizes. PAL should be used in the prediction of 6MWD.

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KEY WORDS: Walk test; Exercise test; Reference values.

In recent decades, there has been considerable progress in assessing the dynamics of cardiorespiratory and metabolic integration. A growing interest in the six-minute walk test (6MWT) has been driven primarily by its simplicity and noninvasive nature.[1] The 6MWT is a low-cost, easily applied and reproducible test that assesses global conditions and integrates responses from the cardiopulmonary system, the systemic and peripheral circulation, neuromuscular units, and muscle metabolism and takes into account functional capacity, although it does not provide information specific to any particular system.[2, 3] It is better tolerated by patients and is more representative of activities of daily living (ADLs) than other walking tests.[4] The 6MWT is used for the evaluation of functional capacity in patients with chronic heart disease and lung disease, in the assessment of medical and rehabilitative interventions, and as a predictor of morbidity and mortality in many clinical conditions.[5]

The 6MWT is one of the most commonly used exercise field tests in clinical practice. Comprehensive guidelines for the test that define its inclusion criteria and provide instructions for execution and parameters for interpretation have been available since 2002.[2] Although the 6MWT is one of the most widely used submaximal tests of aerobic capacity in clinical practice, the course length (CL) used in the test has become an issue in recent years.[6-8] Reference equations for the 6MWT were established using courses varying from 20 m to 50 m in length.[6-8] Because shorter courses require more curves to cover the same distance, the six-minute walking distance (6MWD) may be affected by CL, primarily due to kinematic factors related to the participant's course during the test.[7, 8] A longer course requires subjects to spend less time reversing directions; moreover, it produces a learning effect in which the subjects exhibit better coordination due to reaching the ideal length of the course and overcoming anxiety, which results in a greater 6MWD.[8, 9] According to the American Thoracic Society (ATS), courses should be at least 30 m in length.[2] However, space limitations in primary care facilities have increased in recent decades due to population growth and new trends in architecture and urbanism, forcing health professionals to administer the 6MWT using courses 20 m or even 10 m in length.

The interpretation of the 6MWT is based on reference values that are obtained using equations that consider the anthropometric, demographic, and/or physiological variables of a population. However, since the 6MWT began to be used in cardiopulmonary rehabilitation, it has been found that there is no single resting variable — whether biochemical, clinical or functional — that can accurately predict individual performance on the 6MWT.[5] This observation is reinforced by the diversity of predictors that are included in the various predictive equations for 6MWD for the general population and for specific populations.[10-14] These variables include gender, age, body mass, body height, Body Mass Index (BMI), and heart rate (HR).[15] However, most published predictive equations show high variability in their predictive power, suggesting that other factors that are not typically considered as affecting test performance may play an important role in the distance covered; these factors include the physical activity level (PAL) of the individual.[16-20]

Many clinicians simply fail to use the 6MWT because they are unable to faithfully replicate the ATS guidelines in a primary care setting.[6] In view of this shortcoming, it is of great interest both in research and in clinical practice to find an equation that can be used to standardize the test results on courses less than 30 m in length. Thus, the objective of the present study was to develop a reference equation for the 6MWT that takes into account the effects of course length and PAL on the walking distance.

Materials and methods

Subjects

This was a cross-sectional study conducted between March 2016 and April 2018 in which 255 healthy participants aged ≥18 years were evaluated. The study participants came from a convenience sample in the city of Rio de Janeiro, Brazil, which had an estimated population of 6,688,927 inhabitants in 2018 and a clear predominance of women in the age group ≥18 years.[21] The individuals were recruited from the employees of the Federal University of the State of Rio de Janeiro and from the residents of a surrounding community. All participants selected for the study were healthy and able to walk and did not require any walking aids. The following exclusion criteria were used: any problem in walking or a requirement for the use of walking aids; history of cardiorespiratory, metabolic, neurological, or musculoskeletal disease; history of cardiac or thoracic surgery; smoking for more than 10 pack-years; resting HR>120 bpm; resting systolic blood pressure ≥180 mmHg or resting diastolic blood pressure >100 mmHg; use of medications that could affect muscle function, such as statins; BMI<18 kg/m^2 or >40 kg/m^2; report of respiratory or cold symptoms in the last three weeks; and individuals who were considered "very active" according to the short form of the International Physical Activity Questionnaire (IPAQ).[6, 15, 22]

The project was approved by the Research Ethics Committee of the Augusto Motta University Centre under number CAAE-52689716.5.0000.5235, and all participants signed a consent form. The entire protocol followed the recommendations for research on humans set forth in the Helsinki Declaration.

Anthropometry

Body mass and height were measured by standard techniques with the participants barefoot and wearing light clothing. Body mass was measured to the nearest 0.1 kg on a calibrated scale, and height was measured to the nearest 0.1 cm on a stadiometer. BMI was calculated as body mass in kilograms divided by height in meters squared (kg/m^2).

Physical activity level

The PAL in daily life was evaluated using the IPAQ short form, which evaluates the total energy expenditure in metabolic equivalent task (MET) and the time spent on daily activities.[22] These activities were divided into different intensities (vigorous, moderate, and light) for five domains: work; means of transport; household chores; recreation, sports, exercise, and leisure activities; and time spent sitting. All physical activities performed in minutes per week, estimated in METs/min, were added to obtain the total Physical Activity (PA) Score.[22] Participants were instructed to answer the questions based on the week prior to the IPAQ application date. According to the IPAQ, participants were categorized as sedentary (code =0), irregularly active (code =1), active (code =2), or very active (code =3).[22]

Spirometry

Spirometry was performed on the same day as the 6MWT using a Spirometer Pony FX (Cosmed Ltd., Milan, Italy) after a rest period of 10 minutes. The criteria of acceptance and reproducibility for spirometry followed the recommendations of the American Thoracic Society.[23] The values found were described as absolute values and as a percentage of the predicted values for the Brazilian population.[24] The following variables were analyzed: forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), and FEV_1/FVC ratio.

6MWT

The 6MWTs were conducted along a straight, long, flat course that was marked every 3 m; the delimitation of the circuit was indicated by signaling cones. Each participant performed three tests on the 10-, 20-, and 30-m courses, and the order of testing on the different CLs was randomized. The participants were familiar with the procedure, and standardized encouragement phrases were used at one-minute intervals during the 6MWT. There was a minimum rest interval of 30 minutes between tests.[2] The participants were instructed to discontinue the test if they felt dizzy or experienced leg cramps, chest pain, or intolerable dyspnea.[9] Oxygen saturation (SpO_2) was measured at the beginning and end of the test using a portable oximeter (Nonin Medical, Inc., Plymouth, MN, USA). HR was measured before and immediately after the 6MWT, and the difference between the measurements was calculated (ΔHR). The Borg's Perceived Exertion Scale (BPES) was applied at baseline and at 6 minutes of the 6MWT using a range from 0 (nothing at all) to 10 (extremely severe). Prior to BPES application, the examiner explained what the points meant. Subsequently, the difference in BPES at baseline and at six minutes (Δ BPES (0'-6') was calculated.

Statistical analysis

The data analysis was performed using JASP software 0.9.0.1 (Amsterdam, the Netherlands). An initial analysis was performed to verify the normality of the variables. For this, the Kolmogorov-Smirnov test was used together with a graphical analysis of the histograms. This revealed a Gaussian distribution of the data for all variables except age, which followed a non-normal distribution in accordance with the distribution of the population of the city of Rio de Janeiro. According to the distribution of the population of this city, our sample shows a clear predominance of young adults (Figure 1).[21] For the age variable, a natural logarithmic transformation [ln(Age)] was applied to permit the use of parametric tests. ANOVA followed by the Bonferroni *post-hoc* test was used in the comparison of the three-course distances (10, 20 and 30 m).

The Pearson correlation coefficient (r) was used to evaluate the association of 6MWD, ΔBPES, ΔHR, and ΔSpO_2 with the following variables: age, body mass, body height, BMI, IPAQ stage, ΔBPES, ΔHR and ΔSpO_2. Correlations between 0 and 0.25 (or 0 and -0.25) were considered to be small or non-existent, those between 0.25 and 0.50 (or -0.25 to -0.50) were considered to be reasonable, those between

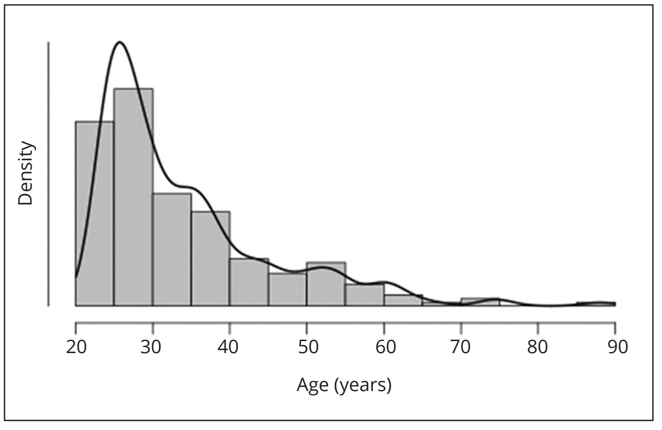

Figure 1.—Density histogram showing the distribution of the sample according to age; the age distribution is similar to that of the population of the city of Rio de Janeiro.

0.50 and 0.75 (or -0.50 to -0.75) were considered to be moderate to good, and those greater than 0.75 (or -0.75) were considered to be very good to excellent.[25] All variables (except ΔSpO_2) had correlations with 6MWD of $P<0.10$ and thus were used in the multivariate regression analysis.

Regression models were constructed from a basic model (null) considering the association between the 6MWD and the other variables, including gender, age, BMI and CL. The models were analyzed for the coefficients and their respective 95% confidence intervals, coefficients of determination (R^2) adjusted for the number of independent variables, and statistical significance at $P<0.05$. Calibration was verified using the calibration plot (measured *vs.* predicted outcomes), along with regression lines showing the slope and intercept and the limits of agreement (LoA) plot for each of the proposed models.[26]

Results

Sample characteristics

The general characteristics, pulmonary function parameters, and 6MWT results are shown in Table I. Of the 255

TABLE I.—*General characteristics, pulmonary function parameters, and six-minute walk test results.*

Variable	Participants, N.=215
Demographic data	
Male sex, %	90 (41.9)
Age, years	34.2±11.5
Body mass, kg	70.9±13.9
Body height, m	1.69±0.09
BMI, kg/m²	24.8±3.67
IPAQ stages	
Sedentary, %	58 (27)
Not regularly active, %	79 (36.7)
Active, %	78 (36.3)
Spirometry	
FVC, L	3.28±0.71
FVC, % predicted	100.5±14.6
FEV_1, L	3.83±0.89
FEV_1, % predicted	105.9±16.6
FEV_1/FVC, %	84.1±10.2
Six-minute walk test	
6MWD on the 10-m corridor, m	591±70
6MWD on the 20-m corridor, m	652±79
6MWD on the 30-m corridor, m	678±85
Δ BS (0’–6’)	3.50±1.91
Δ HR, bpm	34±22
Δ SpO_2, %	-0.02±2.45

Data are given as the mean±SD or number (%).
BMI: Body Mass Index; IPAQ: International Physical Activity Questionnaire; FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; 6MWD: 6-min walking distance; BPES: Borg’s Perceived Exertion Scale; HR: heart rate; SpO_2: oxygen saturation.

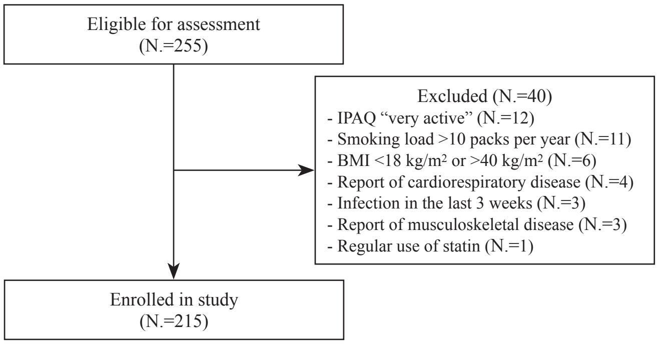

Figure 2.—Flow chart showing the stages of the recruitment process.

participants initially recruited for the study, 40 were excluded (Figure 2). Thus, the sample included 215 healthy participants, with a mean age of 34.2±11.5 years and a mean BMI of 24.8±3.67 kg/m², of which 41.9% were men. In this sample, 27%, 36.7% and 36.3% of the participants were considered to be sedentary, irregularly active, and active, respectively (IPAQ classification). All participants had spirometric data within the normal range.

Test performance

Regarding the 6MWT data, a nonlinear increase was observed between the means of the 6MWDs obtained in the three CLs studied (591±70, 652±79 and 678±85 m for CLs of 10, 20 and 30 m, respectively; Table I). In the comparison of the deltas between the average of distances of 10 m and 20 m (61.4 m), 10 m and 30 m (87 m), and 20 m and 30 m (25.6 m), we observed significant differences ($P<0.001$; Figure 3).

Regression diagnosis

Table II shows the correlations between clinical data and the measurements obtained during the 6MWT. 6MWD correlated positively with the following variables: body height (r=0.30), ΔBPES (r=0.25), ΔHR (r=0.23), sex (r=0.20), and IPAQ (r=0.14), with $P<0.001$ for all. In contrast, 6MWD correlated negatively with the variables ln(Age) (r=-0.23) and BMI (r=-0.18), with $P<0.001$ for both.

Prediction model and its overall performance

Table III shows the various regression models analyzed for the determination of the reference equation (final model). The overall performance of the null model (including sex, age, BMI, and CL;[2] adjusted R^2 value: 0.27) was significantly improved with the inclusion of IPAQ, HR, or BPES

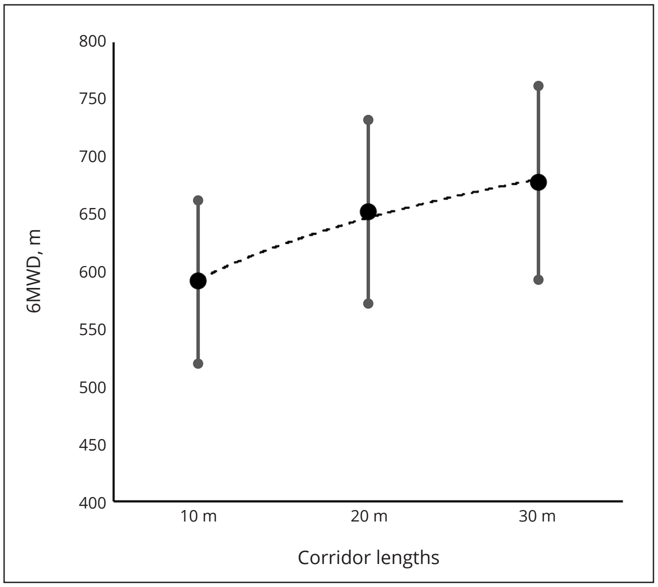

Figure 3.—Changes in 6-min walking distance (6MWD) when corridor lengths of 10, 20 and 30 meters were used.

Table II.—*Pearson's correlation coefficients between the clinical data and the six-minute walk test results.*

Variables	6MWD	Δ BDS	Δ HR	Δ SpO_2
Body height	0.30 * †	0.06	0.03	-0.02
Δ BPES	0.25 * †	-	0.15	0.04
ln(Age)	-0.23 * †	-0.17 * †	-0.12 * ^	0.03
Δ HR	0.23 * †	0.15 * †	-	0.02
Sex	0.20 * †	-0.05	0.02	-0.04
BMI	-0.18 * †	-0.04	-0.05	0.01
IPAQ stage	0.14 * †	-0.06	-0.03	0.03
Body mass	0.03	0.01	-0.03	-0.01
Δ SpO_2	0.05	0.04	0.02	-

6MWD: six-minute walking distance; BPES: Borg's Perceived Exertion Scale; HR: heart rate; SpO_2: oxygen saturation; ln: natural logarithm; BMI: Body Mass Index; IPAQ: International Physical Activity Questionnaire.
*These values show significant differences: ^P<0.05; †P<0.001.

(adjusted R^2 values of 0.29, 0.31, 0.31, respectively; all P<0.001). Further inclusion of pairs of those variables also significantly improved the overall performance over the null model (adjusted R^2 values ranging from 0.32 to 0.33; all P<0.001). Lastly, the final model, including sex, age, BMI, CL,[2] BPES, HR and IPAQ, showed a higher goodness-of-fit and prediction performance (adjusted R^2 value: 0.36; root mean squared error: 69.5 m). In this final model, the regression coefficient was 0.60 (correlation considered to be moderate to good).[25]

Figure 4 shows the regression plot for the final tested model. Regarding calibration, differences occurred within the LoA, with a random distribution over the mean in the final model for 6MWD (Figure 5). For the 6MWT data, the bias [$CI_{95\%}$] was -0.3 m [-5.6; 5.1], with an SD of±69.1 m. The respective lower and upper LoAs [$CI_{95\%}$] were -135.7 m [-144.9; -126.4] and 135.1 m [125.9; 144.4]. Only 1 (3%) participant was situated outside the LoA.

Discussion

This is the first study that incorporates CL in the prediction of 6MWD, which allows the use of an equation for different course sizes lower than 30 m. From a practical point of view, this finding is of great value in the face of the growing scarcity of testing space around the world. Although the ATS[2] recommends a 30 m walking distance, different lengths, including 100 feet, 15 m, 18 m, and 50 m, have been used;[20, 27-31] however, these studies did not consider including different CLs into a single prediction equation. Notably, our study incorporates PAL into the prediction of 6MWD using the IPAQ, which is an easily available and applicable questionnaire.

The 6MWT is well tolerated by people and is similar to normal ADLs because these are performed at submaximal effort levels.[29, 30] The planned distances differ by up to 30% among the various published reference equations for the 6MWTdistances differ by up to 30%.[2, 10-14, 32, 33] In Brazil, healthy individuals over 40 years of age typically walk greater distances than individuals in the United States and Europe. This could be because the daily lives of residents of countries in which lower socioeconomic conditions are more prevalent place.[19] In fact, Casanova *et al.*[19] showed that the highest 6MWD was reached by Brazilians, with a mean of 638±95 m, which is slightly lower than that observed in our study. Notably, unlike these authors, we included young adults, which explains, at least in part, the higher 6MWD mean noted in our study in the 30 m course.

A recent meta-analysis showed that in 24 of 25 studies evaluating the 6MWT, the test was performed along a straight course ranging from 15-82.3 m.[12] However, as shown by our results, the length of the course strongly influences the performance of an individual in the 6MWT, and the results of the test performed on 10, 20 or 30 m courses are not interchangeable. This may invalidate the use of 6MWT equations that were obtained on CLs different from that used to generate the equations. Indeed, Beekman *et al.*[6] observed that the 6MWT results from a 10 m course were 49.5 m shorter than results from a 30 m course in chronic obstructive pulmonary disease (COPD) patients. These findings are in line with our results, which

TABLE III.—*Linear regression models based on the variables that correlated with the 6-min walking distance.*

Variables	R	R^2	Adjusted R^2	Unstandardized ß (CI 95%)	*t*	F	P value	RMSE (m)
Null model	0.53	0.23	0.27			62		73.7
Intercept				910.1 (835.6 to 984.7)	24		<0.001	
Sex				50.6 (38.1 to 63.1)	7.94		<0.001	
ln(Age)				-60.7 (-80.9 to -40.5)	-5.91		<0.001	
BMI				-5.08 (-6.73 to -3.43)	-6.04		<0.001	
CL^2				0.10 (0.08 to 0.12)	11.5		<0.001	
Model #1 (IPAQ)	0.54	0.29	0.29			53.4		72.9
Intercept				890.6 (816.1 to 965.1)	23.5		<0.001	
Sex				48 (35.5 to 60.4)	7.55		<0.001	
ln(Age)				-58.4 (-78.4 to -38.4)	-5.72		<0.001	
BMI				-5.20 (-6.83 to -3.56)	-6.23		<0.001	
CL^2				0.10 (0.08 to 0.12)	11.7		<0.001	
IPAQ				13.8 (6.56 to 21)	3.74		<0.001	
Model #2 (HR)	0.56	0.31	0.31			58		72
Intercept				859.5 (784.5 to 934.6)	22.5		<0.001	
Sex				48.8 (36.6 to 61.1)	7.83		<0.001	
ln(Age)				-55.5 (-75.3 to -35.6)	-5.49		<0.001	
BMI				-4.74 (-6.36 to -3.12)	-5.74		<0.001	
CL^2				0.10 (0.08 to 0.12)	11.8		<0.001	
HR				0.72 (0.46 to 0.98)	5.54		<0.001	
Model #3 (BDS)	0.56	0.32	0.31			59.3		71.8
Intercept				842.7 (766.7 to 918.7)	21.8		<0.001	
Sex				50.9 (38.7 to 63.1)	9		<0.001	
ln(Age)				-49.4 (-69.4 to -29.3)	-4.84		<0.001	
BMI				-5.18 (-6.79 to -3.57)	-6.32		<0.001	
CL^2				0.10 (0.08 to 0.11)	11.49		<0.001	
BPES				8.95 (5.98 to 11.9)	5.93		<0.001	
Model #4 (HR, IPAQ)	0.57	0.33	0.32			52.3		71.2
Intercept				837.1 (762.1 to 912)	21.9		<0.001	
Sex				46 (33.8 to 58.1)	7.41		<0.001	
ln(Age)				-52.8 (-72.4 to -33.1)	-5.28		<0.001	
BMI				-4.85 (-6.45 to -3.25)	-5.95		<0.001	
CL^2				0.10 (0.08 to 0.12)	12		<0.001	
HR				0.74 (0.49 to 0.10)	5.78		<0.001	
IPAQ				14.7 (7.66 to 21.8)	4.09		<0.001	
Model #5 (BDS, IPAQ)	0.58	0.34	0.33			53.8		70.8
Intercept				817.3 (741.5 to 893.1)	21.1		<0.001	
Sex				48 (35.9 to 60.1)	7.78		<0.001	
ln(Age)				-46.1 (-65.9 to -26.3)	-4.57		<0.001	
BMI				-5.32 (-6.91 to -3.73)	-6.57		<0.001	
CL^2				0.10 (0.08 to 0.11)	11.6		<0.001	
BPES				9.41 (6.48 to 12.3)	6.31		<0.001	
IPAQ				15.5 (8.40 to 22.5)	4.30		<0.001	
Model #6 (BDS, HR)	0.58	0.34	0.33			55.2		70.5
Intercept				805.8 (729.7 to 881.9)	20.8		<0.001	
Sex				49.3 (37.3 to 61.3)	8.07		<0.001	
ln(Age)				-46 (-65.7 to -26.2)	-4.57		<0.001	
BMI				-4.87 (-6.46 to -3.28)	-6.03		<0.001	
CL^2				0.10 (0.08 to 0.12)	11.7		<0.001	
BPES				7.98 (5.04 to 10.9)	5.33		<0.001	
HR				0.63 (0.38 to 0.88)	4.90		<0.001	
Model #7 (BDS, HR, IPAQ)	0.60	0.36	0.36			51.7		69.5
Intercept				778.1 (702.2 to 854)	20.1		<0.001	
Sex				46.2 (34.3 to 58.1)	7.63		<0.001	
ln(Age)				-42.5 (-62 to -23)	-4.28		<0.001	
BMI				-5 (-6.57 to -3.44)	-6.28		<0.001	
CL^2				0.10 (0.08 to 0.11)	11.9		<0.001	
BPES				8.43 (5.54 to 11.3)	5.71		<0.001	
HR				0.65 (0.40 to 0.90)	5.13		<0.001	
IPAQ				16.1 (9.17 to 23)	4.57		<0.001	

R: regression coefficient; R^2: determination coefficient; RMSE: root mean square error; ln: natural logarithm; BMI: Body Mass Index; CL: corridor length; IPAQ: International Physical Activity Questionnaire; HR: heart rate; BPES: Borg's Perceived Exertion Scale.

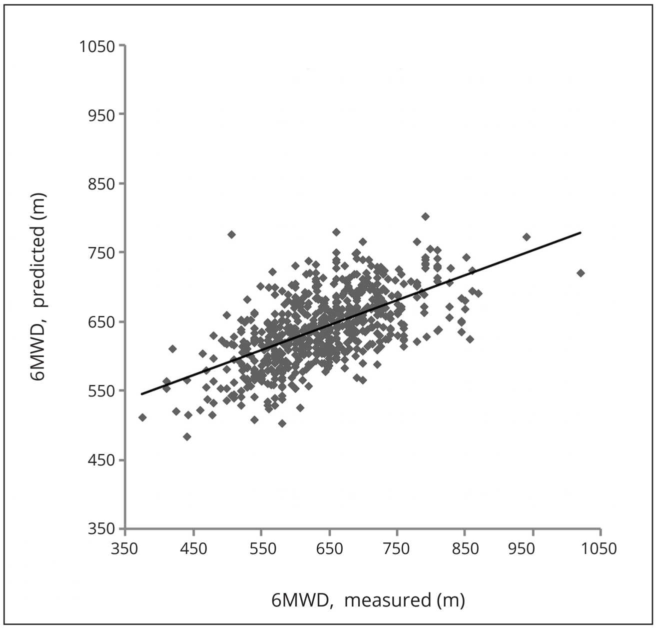

Figure 4.—Regression plot of the 6-min walking distance (6MWD) model (measured *vs*. predicted).

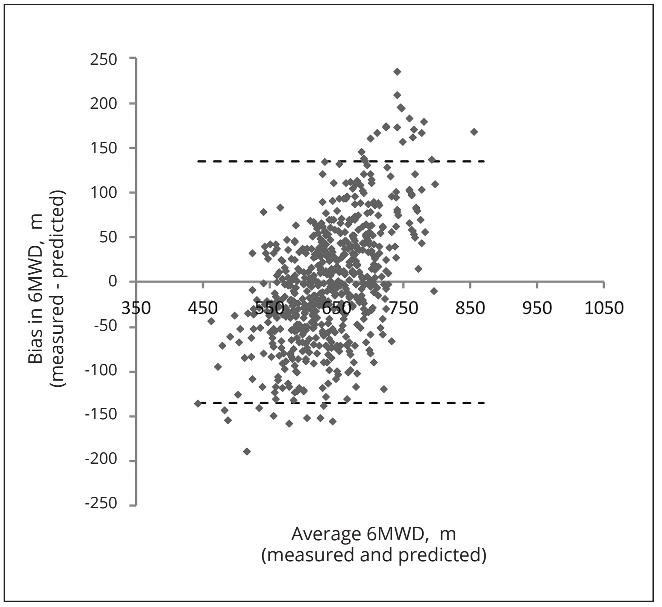

Figure 5.—Limits of agreement plots of the averaged values and the differences (measured-predicted values) of the 6-min walking distance (6MWD) model.

showed a lack of linearity in the growth between the distances traveled in the 10, 20 and 30 m courses.

In agreement with our findings, Ng *et al.*[29] observed that the highest 6MWD was recorded in the 30 m course when they assessed people aged ≥50 years for 10, 20 and 30 m. Interestingly, Enright *et al.*[34] have suggested that the lower 6MWD achieved on a 10 m course can be explained, at least in part, by the increase in the number of laps involved in a shorter walking path. Thus, it is speculated that more effort and time are required for the individual to make turns on a shorter course.[29] A longer course allows more space for acceleration and a higher maximum speed if the individual is capable. In a clinical study with 34 older adults, Macfarlane and Looney[35] showed that a distance of 2.2 to 3.2 m was required to accelerate from rest to a constant walking speed, while a distance of 1.8 to 1.9 m was required to decelerate from constant speed to rest. In addition, the length of the walkway may affect the chosen walking strategy, which would influence the individual's self-selected walking pace.[29]

Most studies that have developed reference equations for the 6MWT excluded elite athletes, but did not objectively measure individual PALs.[30] However, there has been increasing interest in the detection of low aerobic capacity and peripheral endothelial dysfunction, which are strongly associated with a sedentary life.[36] In the present study, the PAL in daily life assessed by IPAQ was positively correlated with the 6MWD and remained as its independent predictor in the complete model. In line with our findings, Zou *et al.*[9] noted that the 6MWD was significantly different among physically active and sedentary individuals. However, counterintuitively, these investigators only included age and height as predictors of 6MWD in their equations. In another study, Zou *et al.*[37] observed a greater 6MWD in active subjects compared to non-active subjects. Physical exercise has a positive correlation with muscle strength.[38] On the other hand, a sedentary lifestyle usually alters muscle metabolism, muscle mass, and physical capacity, which could explain why the 6MWD traveled by sedentary subjects was significantly lower than the 6MWD travelled by physically active subjects in our study.[20, 31, 37, 38]

Since heart rate increases in proportion to exercise intensity, a greater difference in HR between baseline and immediately after the end of the test may indicate higher effort expenditure during the test. As the 6MWT is effort-dependent, this explains the positive correlation we observed between HR and 6MWD. In line with our results, Britto *et al.*[15] published the first Brazilian multicenter study to construct a reference equation, presenting the variation of HR in their regression analysis. More recently, Zou *et al.*[37] observed that height and the difference in HR before and after the 6MWT were the most significant predictors of 6MWD. However, HR has been criticized because it is not always an adequate predictor for 6MWD due to submaximal cardiac performance, the wide range in standardized HR measurements, and the use of medications that may influence its measurement.[15] This may be a limitation when using predictive equations that include HR for patients with cardiovascular diseases.

In addition to the length of the course, our final model to explain 6MWD included sex, age, BMI, BPES, HR and IPAQ, showing an adjusted R^2 of 0.36 (regression coefficient =0.60). Consistent with these findings, a meta-analysis showed that the two variables most frequently included in 43 reference equations were age and gender and that R^2 values ranged from 0.04 to 0.78, with a median of 0.46.[13] The inclusion of BMI clearly strengthens the equation because six-minute walk work (6MWW) is the product of 6MWD and body mass, and 6MWW increases with obesity.[30] Another important variable in our model is BPES because the physical sensations that a person experiences during PA correspond to the perceived rate of exertion.[29] BPES follows the same rationale as HR because it is also proportional to exercise intensity.[39] One limitation of using HR in regression models is the fact that individuals in whom a high HR is detected immediately after a 6MWT may represent physically less fit participants.[9] However, PAL was included in our regression model and did not show collinearity with the difference in HR before and after the 6MWT.

Some implications should be highlighted about the inclusion of PAL in our final model to explain 6MWD. The use of PAL to predict 6MWD addresses the diversity of people's lifestyles in the contemporary world, making performance comparisons in the 6MWT inadvisable without regard to whether the person is physically sedentary or active.[31] Some studies have reported an association between PA and functional capacity in diseased populations.[20, 40, 41] It is suggested that the functional capacity of a sedentary individual is equivalent or close to that of an unhealthy individual, and this reinforces the importance of PAL in the functional capacity prediction model.[40, 41] In addition, PAL can be directly influenced by rehabilitation programs (RP) for various clinical conditions, especially those that cause damage to muscle function. In fact, several recent studies have shown improvements in PA and sedentary behavior after a comprehensive RP.[42-45] Thus, the inclusion of PAL in the 6MWD equation addresses the possible effects of lifestyle on the expected functional capacity due to participation in rehabilitation programs. Ultimately, this may provide relevant information for clinicians in pre-and postassessments of their patients because, although the comparisons are necessarily made at different PALs, the PAL is accounted for in each assessment.

Limitations of the study

A critical analysis of the results and their limitations is relevant. First, the average age of our participants was relatively low. This is explained by the difficulty of recruiting healthy elderly people, a difficulty that was also encountered in several other studies. However, the age distribution of our sample is similar to that of the population of the city of Rio de Janeiro,[21] where the study was conducted. Future studies could be directed at the recruitment of older adults with the goal of elaborating equations that are more appropriate for this age group. Second, the learning effect may have negatively impacted our results because each participant was required to perform the test three times. However, randomization of the test sequences and the inclusion of rest periods of 30 minutes between trials were implemented to help reduce the learning effect. Furthermore, the order in which the participants performed the three courses of the 6MWT did not systematically affect the results due to the randomized double-crossover design and because all participants performed all the tests at the three distances. Third, the univariate correlations in our study were considered to be small or reasonable similar to other studies.[13] However, our final regression model has an adjusted determination coefficient value much higher (R^2=0.36) than any bivariate correlations between the independent variables ($r \leq 0.30$, $R^2 \leq 0.09$) and the 6MWD. This strongly suggests that information between the independent variables and the 6MWD that cannot be captured in a bivariate analysis can improve the explanation of the 6MWD if considered simultaneously in the same model.

Conclusions

The present study shows that CLs of 10, 20 and 30 m strongly impact individual performance during the 6MWT, and thus, the incorporation of this variable in the prediction equation may allow the execution of the test in restricted spaces. Additionally, IPAQ-assessed PAL is an independent predictor of 6MWD. The presented equation solves a practical problem and applies to individuals in various health contexts. Although this study was performed with a sample predominantly composed of young adults, these findings may have implications for the performance of the 6MWT in a variety of chronic diseases and clinical situations of cardiopulmonary and neurological rehabilitation. Further studies are needed to validate the proposed equation in different patient populations.

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