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ORIGINAL RESEARCH

Reference values for the bilateral heel-rise test

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Abstract
Background: The bilateral heel-rise test is an instrument that evaluates the performance of the triceps surae. Normative parameters need to be established for the use of the heel-rise test in clinical practice.
Objective: To determine the reference values for the bilateral heel-rise test.
Methods: This cross-sectional study assessed healthy subjects using the bilateral heel-rise test. We analyzed the number of repetitions, time (in seconds), and repetition rate (repetitions/second) during execution of the heel-rise test, until the point of voluntary fatigue. The estimates were stratified by age and gender. Multiple linear regression was performed to define the reference equation for the bilateral heel-rise test.
Results: A total of 147 individuals were included. The median age was 37 years (IQR 28–46). It was observed that the number of repetitions decreases with age, with a higher number of repetitions in male participants compared to female participants. Gender, body mass index, and maximum activity scores predict 14% of the number of plantar flexions performed in the bilateral heel-rise test. Age and adjusted activity scores predict 18% of the repetition rate in the bilateral heel-rise test.
Conclusion: The bilateral heel-rise test reference values for an adult population were defined as scores above the 25th percentile for number of repetitions, time, and repetition rate. The number of heel-rise test repetitions that corresponds to the 25th percentile, according to age and gender, is as follows: age 20–29, 65 repetitions for men and 45.5 for women; age 30–39, 62.75 men and 41.5 women; age 40–49, 67.25 men and 45 women; and age 50–59, 54 men and 39.25 women.

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Introduction

The strength and endurance of the triceps surae muscle arBeloe essential for walking, maintaining balance, and performing activities of daily living.[1–3] Some health conditions can result in specific changes in this muscle.[4–6] Therefore, it is important to appropriately measure the strength and endurance of the triceps surae as a means of monitoring changes that may influence the functional performance of individuals. Several methods have been used to assess the strength and endurance of this muscle, such as dynamometers, isokinetic dynamometers, or functional tests including the heel-rise test (HRT). The HRT is used to quantify clinical conditions that affect the triceps surae, such as peripheral arterial disease (PAD),[9–11] Achilles tendon injury,[12,13] stroke,[14] chronic venous insufficiency,[5,15] and health conditions related to old age.[16] The HRT evaluates various properties of the triceps surae, such as strength, endurance, fatigue, muscle function, and performance.[7,15,17] It involves repeated concentric-eccentric muscle action[1,7,8] and has been shown to be clinically relevant in the quantification of triceps surae endurance.[5,7,8] The test was initially proposed as a unipedal test.[7,8] However, Pereira et al.[10] evaluated a sample of subjects with PAD and found that the bipedal test was more reliable, resulting from mitigation of balance changes in the individual. The bilateral HRT is a feasible and reproducible test in clinical practice that is useful for evaluating the task of plantar flexion in standing.[10]

There is evidence that demographic, anthropometric, and ethnic factors can influence performance in the HRT.[5,18,19] Thus, a limitation of the bilateral HRT in clinical practice exists in that, currently, there are no normative parameters for any population, which limits the interpretation of results. Bilateral HRT reference values may be used as a basis for research and clinical practice in the evaluation of healthy subjects and patients with specific health conditions. Therefore, the aim of this study was to determine bilateral HRT reference values.

Methods

This is a cross-sectional study, approved by the Ethics Committee of Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil (CAAE – 0439.0.203.000-11). After reading and signing the consent form, an initial assessment was conducted to collect clinical and demographic data on the participants, specifically weight, height, blood pressure (BP), and heart rate (HR) at rest. Individuals were asked about the presence of health conditions and current medications. After that, the Human Activity Profile (HAP) questionnaire was administered in interview form. Upon completion of the interview, the bilateral HRT was conducted. All measurements were taken on the same day.

The sample group consisted of healthy adults, regardless of gender and ethnicity, recruited from the general community. Inclusion criteria were: (1) individuals aged between 20 and 60 years, (2) body mass index (BMI) classified as normal or overweight (18.5–29.9 kg/m^2), (3) no orthopedic or neurological problems limiting plantar flexion, (4) absence of chronic venous insufficiency (varicose veins, edema, and lipodermatosclerosis), and (5) no adverse health conditions at the time of the test, such as flu, fever, etc. Subjects were excluded if they were unable to understand and/or perform the procedures, presented clinical instability, exhibited BP greater than 200/110 mmHg or HR greater than 120 bpm at rest,[20] or presented with a HR greater than 85% of the maximum heart rate expected for age (220 beats per minute minus age) during the test.

Tests were conducted at the Cardiovascular and Metabolic Rehabilitation sector of a clinical hospital in Brazil. A pilot study was conducted to verify the reliability of the bilateral HRT with ten healthy individuals evaluated by three examiners. The interval between assessments was seven days. The reliability of the measures, both intra- and inter-examiner, from the bilateral HRT, demonstrated a high reproducibility ($ICC_{2,1\_inter\text{-}examiner}$ = 0.98, 95% CI 0.90–0.99; $ICC_{2,1\_intra\text{-}examiner\_1}$ = 0.98, 95% CI 0.91–0.99; $ICC_{2,1\_intra\text{-}examiner\_2}$ = 0.99, 95% CI 0.99–1.00; $ICC_{2,1\_intra\text{-}examiner\_3}$ = 0.99, 95% CI 0.99–1.00). All subjects were evaluated by a trained examiner.

The bilateral HRT was performed in a standing position, with the participant standing barefoot and bipedally.[10] The participant remained supported by their dominant hand on the wall, with the elbow in semi-flexion to maintain balance. Methodology was implemented such that the individual performed plantar flexion with maximum range across all repetitions. The first flexion was executed using the full range of motion, up to the point of support by the metatarsophalangeal joints. At full flexion, the examiner marked the maximum height reached by the participant's head on an instrument with adjustable height. The examiner was responsible for first demonstrating the test to the participant and guiding the participant in leaning their head on the instrument attached to the wall during every plantar flexion. This ensured that the individual performed plantar flexion using full range of motion in every repetition. During the test, the individual performed the maximum number of plantar flexions possible, until the point of voluntary fatigue, as fast as possible, with the examiner timing the execution of the test. A verbal command was given at the beginning of the test, and during performance of the test, no form of encouragement was given. The examiner registered the number of repetitions performed and the total time for execution of the test (Fig. 1). The variables analyzed were number of plantar flexions performed during the bilateral HRT, total time (seconds), and repetition rate (repetitions per second).

The Human Activity Profile (HAP) was used to characterize the physical activity level of the sample and to investigate its possible influence on bilateral HRT performance.[21,22] The HAP contains 94 items, categorized according to the International Classification of Functioning, Disability and Health, investigating domains of activity and participation. The arrangement of items in the profile is established on the basis of energy cost; lower numbers require less energy expenditure, and as the number increases, so does the relative energy expenditure. For each item, there are three possible answers: ''still doing'', ''stopped doing'', or ''never done''. The HAP was translated and adapted to the Brazilian population in 2006 by Souza et al.[23] Based on each response, the primary scores are calculated: the Maximum Activity Score (MAS) and the Adjusted Activity Score (AAS). The MAS directly corresponds to the number of the activity with the highest oxygen demand that

Figure 1 Execution of the bilateral HRT.

the individual continues to participate in, without requiring mathematical calculation. The AAS is calculated with subtraction of the number of activities that the respondent has marked as no longer participating in, prior to the last marked as 'still doing', from the MAS.

Statistical analysis

Descriptive analysis was calculated. The estimates were stratified by age and gender. To evaluate the distribution of data, the Kolmogorov–Smirnov test was used. Bilateral HRT results are expressed stratified by gender and age group as 10th, 25th, 50th, 75th and 90th percentiles.[24] In this study, scores between the 25th and 75th percentile were considered within the normal range. Therefore, scores below the 25th percentile were interpreted as below average.[25] Pearson or Spearman correlation coefficients were used to define the explanatory variables (age, BMI, MAS, and AAS), for use in the multiple linear regression model for bilateral HRT outcome prediction. The explanatory variables were included when $p < 0.20$. Multiple linear regression (using a backward elimination method) was performed to define the reference equation for the bilateral HRT in the given sample. Two regression models were used; one for the total number of plantar flexions and another for bilateral HRT repetition rate. Based on the multiple linear regression analysis, an explanatory model for each dependent variable was chosen. The Mann–Whitney *U* test was used in comparison of bilateral HRT performance outcomes between the genders. An alpha of 5% was taken as the significance level. The Statistical Package for Social Sciences (SPSS 15.0, Chicago, IL, USA) was used for the analysis.

A sample calculation of 10 individuals in each age group was performed, on the assumption that an *n* of 10 $(K+1)$, where *K* is the number of explanatory variables, was sufficient to perform a multiple linear regression analysis. Following initial participant recruitment, a new calculation was completed from partial results of the analysis. This defined a minimum number of 80 individuals for the sample (10 per age group and gender), assuming an alpha of 5% and power of 80%. An additional sample calculation from a pilot of 40 individuals was done to examine whether the *n* studied was representative of the population. *n* performed the calculation $= \{(Z_{\alpha/2} \cdot \sigma)/E\}^2$. In the case of unknown sample (as there is no study-based bilateral HRT), calculate the sigma of a pilot. The *n* calculation based on population representativeness was 133, according to the formula $(1.96 \times 11.74/2)$, where 11.74 is the standard deviation of the pilot study and 2 is acceptable error. The additional sample size calculation demonstrated that the *n* collected from 147 subjects was appropriate.

Table 1 A comparison of characteristics and bilateral HRT performance outcomes between genders, expressed as median and interquartile range (25–75%). BMI is presented as mean ± standard deviation.

	Men ($n = 69$)	Women ($n = 78$)	*p*
Number of plantar flexions (repetitions)	82 (64–121.50)	56.50 (44.50–81.25)	<0.0001
Repetition rate (repetitions/second)	1.19 (0.96–1.59)	1.11 (0.89–1.37)	0.06
Time (s)	62 (46–102)	53 (40–71.25)	0.007
Age (years)	36 (28–45.50)	37 (28.75–49)	0.62
BMI (kg/m^2)	25.03 ± 2.85	22.97 ± 2.66	<0.0001
MAS	92 (89–94)	88 (85–92)	<0.0001
AAS	92 (89–94)	87 (84–91)	<0.0001

kg, kilogram; m, meters; BMI, body mass index; kg/m^2, kilogram/meter^2; MAS, Maximum Activity Score; AAS, Adjusted Activity Score; *p*, significance level.

Results

The study included 147 individuals with a median age of 37 (IQR 28–46) years and a mean BMI of 23.94 (SD 2.93) kg/m^2. Of the cohort, 69 (46.9%) were male, and 78 (53.1%) were female. All subjects reached the point of voluntary fatigue during the course of the bilateral HRT. No complications were observed during the test. According to the HAP questionnaire results, 144 (98%) individuals were considered active and 3 (2%) moderately active. The descriptive analysis of the sample group is presented in Table 1. The comparison of the characteristics and the performance on the bilateral HRT between genders showed statistically significant differences in both total time and total number of plantar flexions. However, no such difference was observed with respect to the repetition rates (Table 1).

The multiple linear regression models for total number of plantar flexions and the measured bilateral HRT repetition rate exhibited low coefficient of determination ($R^2 = 0.14$ and $R^2 = 0.18$, $p < 0.001$) (Table 2).

When considering the results from the entire sample, the mean number of plantar flexion repetitions was 71 (IQR 50–108), the total time required for the test was 57 (IQR 42–80) s, and the average measured repetition rate was 1.16 (IQR 0.9–1.48) plantar flexions per second. A descriptive analysis of the performance on the bilateral HRT, stratified by age and gender, is presented in Table 3. Finally, Table 4 presents data on the total number of plantar flexions performed in the test, stratified by gender and age group, expressed as 10th, 25th, 50th, 75th, and 90th percentiles.

Discussion

The aim of this study was to establish the bilateral HRT reference values. Daily living and walking require submaximal effort levels,[26] and thus, the endurance of the triceps surae plays a major role in effectively performing these activities.[27,28] Therefore, the total number of plantar flexions is the most effective bilateral HRT variable for making inferences on the endurance of the triceps surae. Normative values for the bilateral HRT should be used for future evaluation of people with specific health conditions such as peripheral arterial disease and chronic venous insufficiency. During the bilateral HRT, a muscle stretch-shortening cycle (SSC), derived from the combination of elastic energy and myoelectric power, is observed. This physiological mechanism aims to increase the mechanical efficiency of movement. The effect of the SSC, and in turn mechanical efficiency, may vary according to the speed of contraction.[29] Therefore, when considering the bilateral HRT reference values, both the total number of repetitions, and the measured repetition rate, should be considered. Participant characteristics (gender, age, BMI, and physical activity level) were not able to predict the performance outcomes for the bilateral HRT. There may be others factors that determine performance in the bilateral HRT. As the coefficient of determination in regression analysis was poor, result variation ranges (interquartile range 25–75%) in the bilateral HRT were established for reference values.

A study by Jan et al.[18] proposed the requirement for definition of normative parameters for the HRT. The authors evaluated 180 subjects, aged 21–80 years ($R^2 = 0.57$ and $p < 0.001$) and observed differences in performance outcomes for the HRT between genders and different age groups.[18] However, the authors included only sedentary individuals in the sample, and performed the test unilaterally with flexion repetition rate dictated by audible cues. According to Pereira et al.,[10] bipedal support is a more reliable methodology in the HRT, as this mitigates effects of balance disorders.[10] Of the 180 participants in the Jan et al.[18] study, 172 (95.6%) finished the trial due to loss of balance, while only 4.4% reached voluntary exhaustion. Controlling HRT repetition rate, in the Jan et al.[18] study, may have been responsible for the smaller variability of the data and greater coefficient of determination observed.

In the present study, the flexion repetition rate was not pre-determined, leading to greater data variability, as a product of physiological variation in different age groups. We suggest that standardization of speed during the bilateral HRT is not clinically feasible, as testing at lower speeds may result in a ceiling effect in physically active individuals. On the other hand, higher speeds may prove a hindrance for people with low levels of physical activity and limiting health conditions. Thus, a self-imposed repetition rate enables the bilateral HRT to be more universal. Another important consideration about the HRT is its potential in the assessment of patients with vascular disease. Individuals with peripheral arterial disease and chronic venous insufficiency have difficulty standardizing a repetition rate of plantar flexion.

In our study, differences in performance outcomes from the bilateral HRT were observed between genders, with the exception of the repetition rate variable. Notably, BMI, MAS, and AAS were different between genders. Despite this

Table 2 Linear regression analysis, examining the entire sample, for the dependent variables 'number of plantar flexions' and 'repetition rate' in the bilateral HRT.

Dependent variable	Explanatory variables	R^2	Constant	*B*	Beta
Number of plantar flexions	Sex	0.14*	95.24	−31.87	−0.30
	BMI			−3.89	−0.21
	MAS			1.47	0.13
Repetition rate	Age	0.18*	−0.73	−0.006	−0.17
	AAS			0.025	0.33

BMI, body mass index; MAS, Maximum Activity Score; AAS, Adjusted Activity Score; p, significance level; R^2, coefficient of determination.
* $p < 0.001$.

Table 3 Descriptive analysis of performance outcomes on the bilateral HRT, with the sample stratified by age group and gender, expressed as median and interquartile range (25–75%).

Age group	Male ($n = 69$)				Female ($n = 78$)			
	n	Number of plantar flexions	Time (s)	Repetition rate	n	Number of plantar flexions	Time (s)	Repetition rate
20–29	20	85 (65.0–118.7)	54.5 (46–74)	1.55 (1.2–1.76)	20	56.5 (45.5–86)	49.5 (35.2–60.5)	1.25 (0.94–1.6)
30–39	22	82 (62.7–135)	76.5 (41.7–106)	1.15 (0.94–1.59)	21	70 (41.5–96.5)	58 (41–74.5)	1.06 (0.77–1.38)
40–49	14	83 (67.2–143)	67 (46–158.7)	1.07 (0.94–1.51)	19	56 (45–71)	53 (40–84)	1.15 (0.79–1.3)
50–59	13	79 (54–115)	64 (46–126)	1.05 (0.81–1.17)	18	54.5 (39.2–73.2)	52.5 (40–73.7)	0.97 (0.84–1.35)

Table 4 Data for the total number of plantar flexions in the bilateral HRT, stratified by gender and age group, expressed as 10th, 25th, 50th, 75th, and 90th percentiles.

Age group (in years)	Number of plantar flexions				
	P10	P25	P50	P75	P90
20–29					
M	53.2	65	85	118.75	160.6
F	37.6	45.5	56.5	86	123.9
30–39					
M	45	62.75	82	135	221.4
F	27.6	41.5	70	96.5	119.4
40–49					
M	40	67.25	83	143	210.5
F	41	45	56	71	131
50–59					
M	42.8	54	79	115	173.4
F	28.7	39.25	54.5	73.25	118.7

M, male; F, female; P10, 10th percentile; P25, 25th percentile; P50, 50th percentile; P75, 75th percentile; P90, 90th percentile.

difference, this finding is not clinically relevant, as both male and female groups exhibited a normal BMI and were considered active in the HAP questionnaire. When considering performance outcomes for the HRT, gender differences were observed in both this study and that conducted by Jan et al.[18] Typically, the male sample group exhibited a greater absolute number of flexions, repetition rate, and a longer overall time to voluntary exhaustion. Previously, it has been shown that the muscle strength and endurance of the triceps surae in a female population was less than that of a male group, due to a smaller muscle cross-section,[30] which may explain the difference in performance on the HRT.

In a study by Lunsford et al.,[8] 203 healthy subjects (122 men and 81 women), aged between 20 and 59 years, were evaluated using the HRT. No statistically significant differences in performance outcomes between genders were observed. As with this study, the methodology was unilateral; however, as in the study by Jan et al.,[18] repetition rate was dictated audibly. The average number of plantar flexions was 27.9 ± 11.1 (minimum of 6 and a maximum of 70). In this study, male subjects had a 32% higher body mass than women. Thus, men could generate greater force, but concomitantly exhibited greater mass. Gender body mass differences may justify the lack of statistical difference for performance outcomes of the HRT, in the Lunsford et al.[8] study.

This study identified individual physical activity levels with the HAP questionnaire. The HAP takes into account not only recreational activities, but also personal day-to-day activities requiring specific energy expenditures. Specifically, individuals with no health conditions limiting test execution were selected, and therefore, the sample was characterized by individuals considered either 'active' or 'moderately active' by the HAP questionnaire.

The bilateral HRT reference values in an adult population were defined in this study. However, we did not define reference values in an elderly sample, limiting the clinical relevance of this study in an elderly stratum. This may be considered a limitation of the present study. Considering the existence of large numbers of elderly patients with health conditions, future studies are required to define parameters for the bilateral HRT in this population.

Conflicts of interest

The authors declare no conflicts of interest.

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