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Original Research

Conceptual framework for the associations between trunk and lower limb muscle parameters and physical performance in community-dwelling older women

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ABSTRACT

Background: Muscle status plays an important role in the achievement of good physical performance. However, which muscle group and muscle parameters are associated with different physical tasks is not well defined.
Objective: To determine the association between trunk and lower limb muscles and physical performance in community-dwelling older women.
Methods: 118 older women, underwent an evaluation of physical performance, i.e., gait speed, Timed Up and Go (TUG), 5-times stand-to-sit (5TSST), forward and lateral step, and tandem gait, as well as a muscle performance evaluation with an isokinetic dynamometer to obtain the peak torque (PT), rate of torque development (RTD), and torque steadiness (TS) of the trunk, hip, knee, and ankle.
Results: There were associations between physical performance and muscle variables. However, each physical task was associated with different muscle parameters. Gait speed is the motor task that requires the least muscle strength (i.e., PT), whereas 5TSST, forward and lateral steps require PT, RTD, and TS of different muscle groups. Lower limb muscles RTD also plays a role in TUG and gait speed performance. The ability to control a submaximal torque is mainly required for forward and lateral stepping tasks. The PT of trunk muscles is also important for better performance of clinical tests.
Conclusion: This conceptual framework may be a guide for the understanding of the association between physical performance and trunk and lower limb muscle functional parameters in older women and may help future longitudinal research to confirm causality and assist physical therapists in decision-making.

Introduction

The aging process is associated with the decline of physical performance, which increases the risk of falls in the older population. Falls have been considered as a public health problem, because they increase the risk of negative health outcomes, like fractures, loss of independence, depression, social restrictions, hospitalization, institutionalization, and death.[1] The impairment of physical function performance has been associated with reduced muscle lower limb strength.[1-4] To create a physical therapy program targeting enhancement of physical performance through muscle improvement, the assessment of specific muscle groups may be needed.

However, besides muscle strength, other muscle variables, i.e., rate of torque development (RTD) and torque steadiness (TS),[5,6] should be taken into consideration to better understand the muscle contribution to physical function in older adults. The RTD is defined as the capacity to rapidly generate torque at the beginning of muscle contraction (200 to 300 ms).[5] Neural factors seem to have a greater influence on RTD in the initial phase of muscle contraction (< 40 ms) and maximum muscle strength seems to have more influence in the later stages of muscle contraction (> 90 ms).[7] On the other hand, TS is defined as the ability to maintain a submaximal contraction at a given torque level,[8] which means that a greater torque contraction variability may be associated with motor control deficit, increasing the risk for physical performance impairment in older adults.[8]

Preventing impairment of physical function and loss of independence

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is an essential goal among health care professionals to help older adults achieve a successful aging process and good quality of life. To the best of our knowledge, no study has so far proposed a conceptual framework for trunk and lower limb muscle roles regarding tests widely used in the Geriatric and Gerontological clinical practice and recommended by the World guidelines for falls prevention and management for older adults,[9] the American Geriatrics Society,[10] and European Working Group in Sarcopenia in Older People.[11] Previous studies have suggested assessing the ability of older adults to perform challenging tasks, such as step tests and tandem gait.[4,12] Although previous studies have shown that there are sex differences related to functionality and risk of falls,[13-15] recruiting and engaging older men in research remains challenging.[16,17] Therefore, this study aimed to verify the association between the trunk and lower limb muscles and physical performance in community-dwelling older women.

Methods

Design

This was a cross-sectional observational study with 118 community-dwelling older women, who were recruited in public squares, churches, community centers for older adults, and during events for older adults under the organization of the University of São Paulo, Brazil (Ribeirão Preto). The study was approved by the Ethics Committee for Research on Human Beings (CAAE: 62,209,916.5.0000.5440) and all participants gave written informed consent to participate. The authors conducted the study at the University of São Paulo (Ribeirão Preto) from March 2018 to July 2019.

The assessments were performed in two occasions, with an interval of 2 to 7 days between them. On the first day of evaluation, data were collected through interviews to characterize the sample, followed by the physical function tests, which were assessed in random order: habitual gait speed, Timed Up and Go (TUG), five times stand-to-sit test (5TSST), forward and lateral step tests, and tandem gait. Finally, familiarization with isometric muscle strength assessments on the isokinetic dynamometer (Biodex System 4 Pro; Biodex Medical Systems, Shirley, NY) was performed to minimize learning effects. On the second day of evaluation, after allowing enough time for muscular recovery from the familiarization session, muscle performance assessment was performed.

Participants

The criterion of eligibility was being independent and autonomous women aged 60 years and older. The exclusion criteria were: a low score on the 10-point Cognitive Screener (10-CS) according to the educational level ($<$ 8 points),[18] musculoskeletal or neurological conditions that could interfere with the performance in the functional tests, cardiovascular or metabolic conditions that would contraindicate physical activities, dizziness, visual complaints that would jeopardize the execution of daily activities (self-report), and loss of protective sensation in the feet.[19,20] The withdrawal criteria included those women who were not able to perform the muscle and clinical tests.

Outcome measures

Data were collected through interviews to characterize the sample. We collected information related to age, height, weight, number of comorbidities (self-report), number of medications being used, presence of fear of falling (possible replies: 1 = yes or 2 = no), number of falls in the previous 6 months, and level of physical activity (International Physical Activity Questionnaire—IPAQ short version).[21]

Physical performance tests

The procedures of the physical tests have been previously detailed, and the methods can be found in the online material.[22] Habitual gait speed was measured in m/s; the TUG, 5TSST, and tandem gait measured in seconds; and forward and lateral step tests in centimeters.

All tests were administrated by the same trained evaluator, who explained and demonstrated each task to be performed and then scored the participants. In addition, two other evaluators provided assistance during the assessments to prevent falls. The order of test execution was randomized for each participant.

Muscle assessments

Isometric muscle assessments on the isokinetic dynamometer (Biodex System 4 Pro; Biodex Medical Systems, Shirley, NY) were performed on the first day to allow familiarization with the test and minimize learning effects. The isokinetic dynamometer was connected to an electromyography module (EMG System do Brasil Ltda, São José dos Campos, SP, Brazil) to increase the sampling frequency to 2000 Hz. Isometric contractions were selected to ensure that peak torque (PT) would not be influenced by changes in the lever arm or the length-tension relationship of the muscle during the contraction.[23] Furthermore, they are also considered as safer and more reproducible, because older adults may have a range of motion limitations, presence of pain, and greater compensations when performing concentric contractions.[24] On the second day of evaluation, the muscle assessments were performed. The PT, RTD, and TS of the trunk and lower limb muscle groups were evaluated. Only the muscles of the dominant lower limb were evaluated. The dominant lower limb was defined as the limb of choice to kick a ball.

The PT protocol of evaluation of each muscle group consisted of three maximum voluntary isometric contractions of 5 s duration and with 30 s of rest between them. The same protocol used to obtain the PT was used to obtain the RTD. RTD was calculated from the periods from the torque onset to 30 and 200 ms.[5] The isometric PT and RTD of each muscle group were normalized by body mass to reflect the functional performance of the muscles according to the body mass of the individual.[5]

To obtain the TS of each muscle group, we used the PT obtained in the three initial contractions, with the target torques of 10 % and 50 % of the PT. Thus, to obtain the TS, after the completion of the three maximum voluntary isometric contractions, the participants performed, in random order, two voluntary submaximal contractions at 10 % of PT and two voluntary submaximal contractions at 50 % of PT, each lasting 15 s and with rest of 30 s, with visual feedback (dynamometer monitor positioned 1.5 m from the participant, signaling the target torque) and constant verbal stimulus to keep the contraction in the target torque as stable as possible. The lower the score, the better the TS. The TS was considered as the standard deviation (SD) of the torque obtained in the central 10 s of submaximal contractions (absolute TS), disregarding the initial and final 2.5 s of the contractions.[25,26]

We evaluated the flexor and extensor trunk muscles; hip flexor, extensor, adductor, and abductor muscles; knee flexor and extensor muscles; and ankle plantar flexor and dorsiflexor muscles. The positioning protocol to assess PT,[27] RTD, and TS[5,6,27] was previously described. In summary, the semi-standing position was adopted to evaluate the trunk extensors and flexors, with hip flexed at 70° relative to the vertical position. The hip abductors and adductors were assessed in the lateral decubitus position, with the limb to be tested upwards at 15° of hip abduction. The hip flexors and extensors were assessed in the supine position. Knee flexors and extensors were assessed with the participant sitting and the hip flexed at 90°. The plantar flexors and ankle dorsiflexors were assessed with the participant sitting, with the hip of the limb to be tested flexed at 70° and the knee at 45°.

Statistical analysis

Means and standard deviations or frequencies and percentages for participants' characteristics and muscle variables were summarized. Multiple linear regression analysis, adjusted for age, height, and level of physical activity, was performed to investigate associations between physical performance (dependent variables) and muscle parameters, i.e., PT, RTD, and TS (independent variables). Due to the non-normal distribution, data were transformed following the two-step method proposed by Templeton.[28] Prior to the analysis, all necessary assumptions were verified, including the absence of multicollinearity (variance inflation factor < 10), absence of outliers, Cook's Distance <1, independence of residuals (Durbin-Watson between 1.5 and 2.5), normal standardized residuals, homoscedasticity, and linear relationship between independent and dependent variables. However, for step forward and lateral tests, the data did not exhibit normal standardized residuals and homoscedasticity; therefore, *bootstrapping* (5000 bootstraps; 95 % CI BCa) was applied. The significance level was set at 0.05. Data analysis was performed using the IBM SPSS 25.0 software (SPSS Inc.).

Results

General features

A total of 118 older women (mean age 68.8 years) were included in the study (Table 1). The majority had a moderate level of physical activity (66 %), with the mean value of gait speed higher than 1.0 m/s and TUG lower than 10 s, which reflects good physical performance. The mean values of PT, RTD30 ms, RTD200 ms, TS10 %, and TS50 % of the trunk and lower limb muscle groups are presented in Table 2.

Physical performance and muscle strength

Detailed information about the results of the linear regression analysis is in the online material. The results indicate that a higher PT of the hip flexors, a better ability to maintain a submaximal muscle contraction of 10 % of the trunk flexors, and a better ability to rapidly generate torque of the hip adductors and knee flexors (i.e., RTD 30 ms and 200 ms) are associated with faster gait speed (Table 3).

For TUG, a higher PT of the trunk flexors and extensors, hip flexors and extensors, and ankle plantar flexors was associated with a faster time to complete the test. Additionally, a better capacity of the hip extensors and adductors, and knee flexors, to generate torque quickly (i.e., RTD 30 ms and 200 ms) was associated with a faster speed to complete the test, suggesting that the rapid activation of these muscles may be necessary for this task. Also, TUG was associated with TS10 % of the hip extensors, indicating that the better ability to maintain a submaximal muscle contraction resulted in better performance (Table 3).

For 5TSST, the higher the PT for the trunk flexors and extensors, hip flexors, knee flexors and extensors, and ankle plantar flexors and dorsiflexors, the faster the women were able to complete the test. Also, when the ability of the trunk flexors and ankle dorsiflexors to generate torque (i.e., RTD 30 ms and RTD 200 ms) was better, the women completed the test faster, indicating that this task may require rapid activation of these muscle groups. The 5TSST was also associated with TS10 % and TS50 % of the hip extensors and TS10 % of the hip abductors, which means that the better the ability to maintain a submaximal muscle contraction, the better the physical performance (Table 3).

For the forward step test, the higher the PT of the trunk flexors and extensors, hip flexors and adductors, knee flexors and extensors, ankle plantar flexors and dorsiflexors, the higher the step that the woman climbed. Forward step was also associated with the capacity of the hip adductors and knee flexors to generate torque rapidly in the later stage of contraction (i.e., RTD 30 ms and RTD 200 ms). Additionally, forward step was associated with TS10 % of trunk flexors; TS10 % of hip extensors, abductors, and adductors, as well as TS50 % of ankle plantar flexors, which means that the better the ability to maintain a

Table 1
Women's characterization.

Variables	Older women ($n = 118$)
Age (years)	68.8 (5.4)
Height (m)	1.5 (0.1)
Weight (kg)	67 (12)
Years of education	8.3 (4.7)
Body mass index (kg/m^2)	28 (4.6)
Number of medications	3.6 (2.7)
Fear of falling n (%)	64 (54 %)
Number of falls	0.4 (0.7)
Habitual gait speed (m/s)	1.1 (0.2)
Timed Up and Go (s)	9.3 (2.1)
5-times Stand-to-Sit (s)	13.0 (3.2)
Forward step (cm)	40.7 (9.1)
Lateral step (cm)	36.6 (5.6)
Tandem gait (s)	11.8 (7.5)
Level of physical activity n (%)	
Low	34 (29 %)
Moderate	78 (66 %)
High	6 (5 %)

Note: Values are described in mean (standard deviation or percentage).

Table 2
Lower limb muscle variables.

Muscle groups	Variables	Total sample ($n = 118$)
Trunk flexors	PT (Nm. kg^{-1})	0.8 (0.3)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	0.9 (0.9)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	1.0 (0.9)
	TS 10 % (standard deviation)	1.1 (1.0)
	TS 50 % (standard deviation)	2.4 (1.8)
Trunk extensors	PT (Nm. kg^{-1})	2.3 (0.7)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	2.3 (1.7)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	1.9 (1.1)
	TS 10 % (standard deviation)	2.7 (3.1)
	TS 50 % (standard deviation)	3.6 (3.9)
Hip flexors	PT (Nm. kg^{-1})	0.5 (0.27)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	0.8 (0.8)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	0.8 (0.6)
	TS 10 % (standard deviation)	1.5 (1.6)
	TS 50 % (standard deviation)	2.4 (1.2)
Hip extensors	PT (Nm. kg^{-1})	1.0 (0.4)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	0.9 (0.7)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	0.7 (0.5)
	TS 10 % (standard deviation)	1.9 (1.7)
	TS 50 % (standard deviation)	1.2 (1.3)
Hip abductors	PT (Nm. kg^{-1})	0.7 (0.2)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	0.7 (0.5)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	0.9 (0.7)
	TS 10 % (standard deviation)	1.8 (1.3)
	TS 50 % (standard deviation)	2.5 (1.3)
Hip adductors	PT (Nm. kg^{-1})	0.7 (0.2)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	0.7 (0.5)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	0.5 (0.4)
	TS 10 % (standard deviation)	1.9 (1.5)
	TS 50 % (standard deviation)	1.7 (1.5)
Knee flexors	PT (Nm. kg^{-1})	0.7 (0.2)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	0.7 (0.5)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	0.8 (0.5)
	TS 10 % (standard deviation)	1.0 (0.9)
	TS 50 % (standard deviation)	1.9 (1.3)
Knee extensors	PT (Nm. kg^{-1})	1.4 (0.4)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	1.7 (1.3)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	1.5 (0.9)
	TS 10 % (standard deviation)	1.1 (1.3)
	TS 50 % (standard deviation)	2.5 (2.0)
Ankle plantar flexors	PT (Nm. kg^{-1})	0.8 (0.4)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	0.6 (0.4)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	0.6 (0.4)
	TS 10 % (standard deviation)	0.7 (0.6)
	TS 50 % (standard deviation)	1.2 (0.9)
Ankle dorsiflexors	PT (Nm. kg^{-1})	0.3 (0.1)
	RTD 30 ms (Nm.s^{-1}.kg^{-1})	0.5 (0.3)
	RTD 200 ms (Nm.s^{-1}.kg^{-1})	0.4 (0.2)
	TS 10 % (standard deviation)	0.8 (0.5)
	TS 50 % (standard deviation)	1.2 (0.8)

PT, peak torque; RTD, rate of torque development; TS, torque steadiness. Values are described in mean (standard deviation).

Table 3
Significant associations observed between physical performance (dependent variables) and muscle parameters (independent variables).

	Muscle group	Predictors	Standardized coefficients Beta	95 % CI	*p*-value
Habitual gait speed (m/s)	Trunk flexors	TS10 %	−0.24	−0.11, -0.01	**0.02**
	Hip flexors	PT	0.27	0.07, 0.69	**0.02**
	Hip adductors	RTD 200 ms	0.23	0.00, 0.31	**0.05**
	Knee flexors	RTD 30 ms	0.46	0.06, 0.36	**0.006**
Timed Up and Go (s)	Trunk flexors	PT	−0.41	−4.24, −1.20	**0.001**
	Trunk extensors	PT	−0.32	−1.59, −0.31	**0.004**
	Hip flexors	PT	−0.30	−6.16, −0.97	**0.007**
	Hip extensors	PT	−0.27	−2.74, −0.23	**0.02**
		RTD 30 ms	−0.28	−1.43, −0.13	**0.02**
		TS10 %	0.17	0.01, 0.40	**0.04**
	Hip adductors	RTD 200 ms	−0.25	−2.72, −0.10	**0.04**
	Knee flexors	RTD 30 ms	−0.62	−3.65, −1.20	**<0.001**
	Ankle plantar flexors	PT	−0.24	−2.93, −0.01	**0.05**
5-times Stand-to-Sit (s)	Trunk flexors	PT	−0.60	−8.17, −3.72	**<0.001**
		RTD 200 ms	0.21	0.04, 1.34	**0.04**
	Trunk extensors	PT	−0.41	−2.85, −0.91	**<0.001**
	Hip flexors	PT	−0.38	−10.97, −2.96	**0.001**
	Hip extensors	TS10 %	0.18	0.02, 0.63	**0.04**
		TS50 %	0.21	0.07, 1.00	**0.02**
	Hip abductors	TS10 %	0.31	0.31, 1.42	**0.002**
	Knee flexors	PT	−0.32	−7.39, −1.17	**0.007**
	Knee extensors	PT	−0.43	−4.87, −1.58	**<0.001**
	Ankle plantar flexors	PT	−0.30	−5.03, −0.35	**0.02**
	Ankle dorsiflexors	PT	−0.26	−13.06, −1.33	**0.02**
		RTD 30 ms	−0.26	−4.46, −0.37	**0.02**
Forward step (cm)[#]	Trunk flexors	PT	0.40	5.45, 14.24	**<0.001**
		TS10 %	−0.18	−2.78, −0.14	**0.03**
	Trunk extensors	PT	0.30	1.26, 5.86	**0.005**
	Hip flexors	PT	0.49	13.58, 31.54	**<0.001**
	Hip extensors	TS10 %	−0.16	−1.48, −0.02	**0.04**
	Hip abductors	TS10 %	−0.29	−3.31, −0.87	**0.001**
	Hip adductors	PT	0.19	0.48, 11.69	**0.03**
		RTD 200 ms	0.26	0.52, 10.39	**0.03**
		TS10 %	−0.21	−2.25, −0.15	**0.02**
	Knee flexors	PT	0.26	0.47, 16.09	**0.04**
		RTD 30 ms	0.34	0.83, 9.26	**0.02**
	Knee extensors	PT	0.48	5.47, 12.55	**<0.001**
	Ankle plantar flexors	PT	0.39	4.24, 13.59	**<0.001**
		TS50 %	−0.21	−3.62, −0.18	**0.04**
	Ankle dorsiflexors	PT	0.41	15.96, 40.87	**<0.001**
Lateral step (cm)[#]	Trunk flexors	PT	0.36	2.04, 7.85	**0.002**
	Trunk extensors	PT	0.21	0.24, 2.26	**0.01**
	Hip flexors	PT	0.38	4.60, 14.49	**<0.001**
	Hip extensors	TS10 %	−0.18	−0.83, −0.03	**0.03**
	Hip abductors	PT	0.30	2.00, 10.74	**0.003**
		TS10 %	−0.21	−1.36, −0.004	**0.05**
	Hip adductors	TS10 %	−0.22	−1.27, −0.05	**0.03**
	Knee extensors	PT	0.40	1.86, 6.20	**0.001**
	Ankle plantar flexors	PT	0.36	1.40, 7.51	**0.006**
	Ankle dorsiflexors	PT	0.39	7.43, 22.00	**<0.001**
		TS50 %	−0.19	−1.85, −0.04	**0.03**
Tandem gait (s)	Trunk extensors	PT	−0.39	−6.46, −1.73	**0.001**
	Hip extensors	PT	−0.32	−11.11, −1.26	**0.02**
	Hip abductors	PT	−0.29	−18.22, −1.30	**0.02**

PT, peak torque; RTD, rate of torque development; TS, torque steadiness; Significant associations at $p < .05$ in bold according to multiple linear regression analysis. Adjusted for age, height, and physical activity level.
[#] Bootstrapping based on 5000 replicates (95 % IC BCa).

submaximal muscle contraction was, the better the physical performance (Table 3).

For the lateral step, the higher the PT of the trunk flexors and extensors, the hip flexors and abductors, knee extensors, and ankle plantar flexors and dorsiflexors, the higher the step that the woman climbed. Also, lateral step was associated with TS10 % of the hip extensors, abductors, and adductors, as well as TS50 % of the ankle dorsiflexors, which means that the better the ability to maintain a submaximal muscle contraction, the better the physical performance (Table 3).

For the tandem gait, the higher the PT of trunk extensors and hip extensors and abductors, the faster the woman completed the test. Fig. 1

Discussion

Our study presents a conceptual framework regarding the association of physical performance and muscle variables in community-dwelling older women. The result overview shows that different physical performances are associated with different muscle variables, and although PT is an important muscle parameter, TS rather than RTD is a parameter involved in physical performance, which means that besides the maximum muscle strength, the ability to maintain a submaximal contraction at a given torque level (TS) must also be considered for

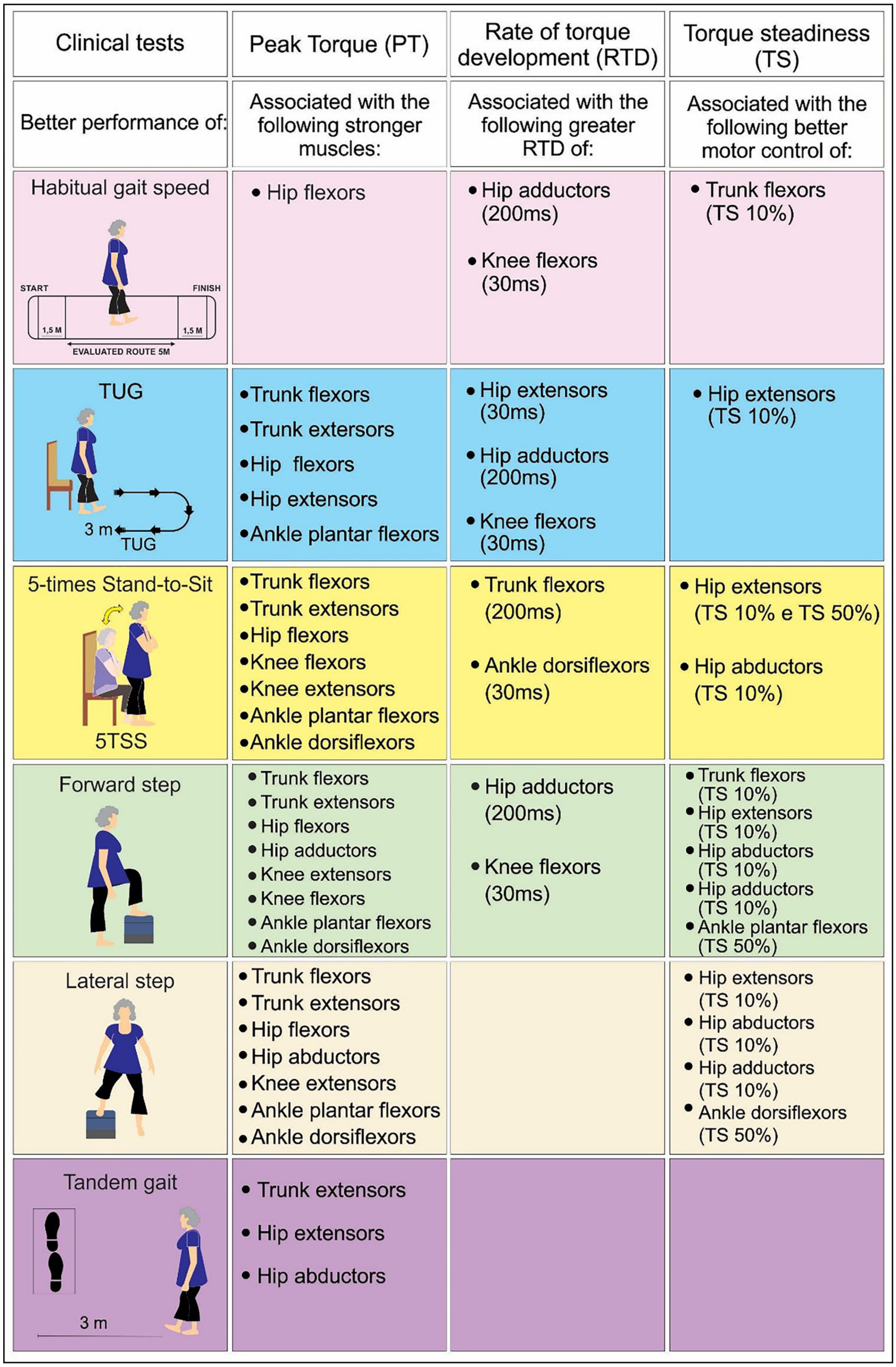

Fig. 1. Framework for the association between physical performances and muscle variables.

future longitudinal research that aims at verifying the role of muscle groups and muscle variables to predict changes in physical performance over time.

Gait speed has been used as an important health status indicator. When it is slow, the older adult has a higher risk of functional decline, social restriction, depression, falls, institutionalization, and mortality.[29,30] Therefore, the improvement of gait speed usually is a target in a physical rehabilitation program. Our results are in agreement with previous studies that have shown that walking does not require a maximum muscle strength generation,[31,32] because we identified that habitual gait speed was only associated with PT of the hip flexors, and higher RTD of the hip adductors and knee flexors, which represents the ability to generate torque at the beginning of muscle contraction. Also, gait speed was associated with torque steadiness at 10 % of PT of the trunk flexors. Our results point out to the direction that gait does not require stronger muscle, which is probably the reason that older adults, even with some degree of dysfunction, are able to walk short distances in unchallenged situations, such as flat surface, even though adopting a reduced gait speed.[33]

On the other hand, in clinical practice, there are many other physical tests that demand more from trunk and lower limb muscles. Mobility performance has been widely evaluated using the TUG test, which requires different motor tasks, as standing up from a chair, walking at a usual pace, turning, and returning to sit down on the chair.[34] For this task, stronger trunk flexors and extensors, hip flexors and extensors, and ankle plantar flexors were associated with a better performance, probably because these muscle groups are involved in the movement of standing up from and sitting down on the chair. Similarly to gait speed, in TUG performance, the RTD 200 ms of the hip adductors and RTD 30 ms of the knee flexors are involved, probably associated with the gait domain. Also, the rapid hip extensors and adductors strength generation may be required to achieve the fast upright posture after standing from the chair, and the rapid action of the hip adductors is required to maintain hip alignment. The ability of the adductor muscles to rapidly generate torque may be related to the fact that in complex movements, where transfer and rotation components are required, it is likely that the hip adductor muscles are bilaterally and simultaneously active to control both femoral-on-pelvic and pelvic-on-femoral hip movements.[35]

The 5TSST has been used to evaluate muscle strength and power of lower limb muscles,[36] and a poor test performance may predict future falls and disability in the older population.[37] For this test, stronger trunk extensors and flexors, hip flexors, knee flexors and extensors, ankle plantar flexors and dorsiflexors were associated with a better test performance. Our results are aligned with those by Porto et al.,[38] who showed that 5TSST is able to discriminate older women with reduced global muscle strength. The submaximal control (TS) of the hip extensors and abductors contraction seems to influence the test, as the ability to rapidly generate strength (RTD) of the trunk flexors and ankle dorsiflexors were associated with the test performance, probably because it is required to sit down again quickly.

Step tests have been proposed as a challenging test that can evaluate the physical performance of older adults during a motor activity that requires single lower limb support.[4,12,22] For the forward step test, stronger PT of the trunk flexors and extensors, hip flexors and adductors, knee flexors and extensors, and ankle plantar flexors and dorsiflexors were associated with a higher step that a woman could climb. Our findings are in line with the concept that step climbing requires a higher demand for muscle strength.[4,39] Our results also demonstrate that the ability to control the muscle contraction of the trunk flexors, hip extensors, abductors, adductors and ankle plantar flexors, as the ability to generate rapid strength (RTD) of the hip adductors and knee flexors are important components for achieving a higher step.

For the lateral step test, stronger trunk flexors and extensors, hip flexors and abductors, knee extensors, and ankle plantar flexors and dorsiflexors were associated with a higher step that women could climb. After a fatigue protocol of hip abductor muscles, Martins and collaborators[40] observed a worse performance of lateral step, which is in line with our findings. The ability to control the muscle contraction at 10 % of PT for the hip extensors, abductors, and adductors and 50 % of PT for ankle dorsiflexors was associated with a higher step, probably because it allows better control of the movement, allowing better trunk-pelvic alignment and lifting the foot during step climbing.

Tandem gait has been used to challenge mediolateral stability because it is a dynamic task performed on a narrow support base. Aligned with our results, many previous studies[12,41] have suggested that this task demands lumbopelvic stability. Porto et al.,[12] have proposed the combination of lateral step and tandem gait to identify older women with reduced abductor muscle strength and in agreement with our results, for a better performance of lateral step and tandem gait, greater hip abductor muscle strength is required. Additionally, the greater the strength of the trunk extensors and hip extensors, the faster the women completed the test, probably due to the need of keeping the trunk-pelvic alignment during the task.

Van Cutsem et al.[42] showed that neural adaptations caused by explosive strength training are the main factors for an increase in RTD. However, heavy-resistance strength training can also lead to improvements in the capacity of torque generation during muscle contraction, in addition to increasing PT.[43] So far, it is not possible to define an optimal mode of training to improve TS. However, studies show that Tai Chi[44] and resistance training with heavy load[45] can improve TS in older adults. Therefore, because muscle performance adaptations are highly specific depending on the training program, understanding different muscle parameters in relation to functional performance allows the elaboration of a more specific physical therapy program. Then, our results may guide the study design of future longitudinal research to confirm causality and assist physical therapists in their decision-making.

The community-dwelling older women population was chosen to establish a referential base for the understanding of muscle variable role on physical performance. One of the limitations of the study was the fact that we only included older women, because we did not have a representative male sample size, and the inclusion of men in our results could be a bias because we have previously shown that the performance is different between older men and women, probably because men are stronger and taller than women.[13] Another limitation is that this was a cross-sectional study; therefore, to confirm causality, a longitudinal cohort study is needed. Furthermore, studies are needed to confirm whether the training of specific muscles, suggested in the conceptual framework, will improve physical performance.

Conclusion

The results show that different physical performances are associated with different muscle variables. Gait speed was the test the least associated with muscle strength performance. The 5TSST and the forward and lateral step tests seem to be the physical tests most associated with muscle strength. Also, performance on the lateral step and tandem gait were associated with stronger hip abductor muscles. The forward step, lateral step, and 5TSST were the tasks most associated with the ability to control a submaximal torque. The ability to rapidly generate torque seems to have an important role mainly for the TUG and gait speed, although it also showed association with the 5TTST. Trunk muscles, mainly PT, must also be considered for the performance of physical function.

Declaration of competing interest

The authors declare no competing interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjpt.2024.101143.

References

1. Sherrington C, Fairhall NJ, Wallbank GK, et al. Exercise for preventing falls in older people living in the community. *Cochrane Database Syst Rev.* 2019;1, CD012424.
2. Hunter SK, Thompson MW, Adams RD. Relationships among age-associated strength changes and physical activity level, limb dominance, and muscle group in women. *J Gerontol A Biol Sci Med Sci.* 2000;55(6):B264–B273.
3. Porto JM, Freire Júnior RC, Bocarde L, et al. Contribution of hip abductor-adductor muscles on static and dynamic balance of community-dwelling older adults. *Aging Clin Exp Res.* 2019;31(5):621–627.

4. Porto JM, Freire Júnior RC, Cangussu-Oliveira LM, et al. Accuracy of the step test to evaluate lower limb muscle strength in community-dwelling older women. *J Bodyw Mov Ther*. 2021;25:133–139.
5. Porto JM, Freire Júnior RC, Capato LL, et al. Rate of torque development and torque steadiness of the lower limb and future falls among community-dwelling older adults without previous falls: a longitudinal 1-year study. *J Aging Phys Act*. 2021: 1–9.
6. Porto JM, Spilla SB, Cangussu-Oliveira LM, Freire Júnior RC, Nakaishi APM, de Abreu DCC. Effect of aging on trunk muscle function and its influence on falls among older adults. *J Aging Phys Act*. 2020:1–8.
7. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, Duchateau J. Rate of force development: physiological and methodological considerations. *Eur J Appl Physiol*. 2016;116(6):1091–1116.
8. Oomen NM, van Dieën JH. Effects of age on force steadiness: a literature review and meta-analysis. *Ageing Res Rev*. 2017;35:312–321.
9. Montero-Odasso M, van der Velde N, Martin FC, et al. World guidelines for falls prevention and management for older adults: a global initiative. *Age Ageing*. 2022;51 (9).
10. Eckstrom E, Vincenzo JL, Casey CM, et al. American geriatrics society response to the world falls guidelines. *J Am Geriatr Soc*. 2024;72(6):1669–1686.
11. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing*. 2019;48(4):601.
12. Porto JM, Cangussu-Oliveira LM, Freire Junior RC, et al. Diagnostic accuracy of clinical tests for the indirect assessment of hip abductor muscle strength in community-dwelling older women. *Phys Ther*. 2020;100(11):1967–1976.
13. Carvalho de Abreu DC, Freire Junior RC, Mello Porto J, Errera Magnani P, Silva Tofani P, Rodrigues Iosimuta NC. Functional performance of older adults: a comparison between men and women. *Women Health*. 2021;61(4):372–380.
14. Stotz A, Hamacher D, Zech A. Relationship between muscle strength and gait parameters in healthy older women and men. *Int J Environ Res Public Health*. 2023;20 (7).
15. Sebastiani C, Wong JYX, Litt A, et al. Mapping sex and gender differences in falls among older adults: a scoping review. *J Am Geriatr Soc*. 2024;72(3):903–915.
16. Anderson C, Seff LR, Batra A, Bhatt C, Palmer RC. Recruiting and engaging older men in evidence-based health promotion programs: perspectives on barriers and strategies. *J Aging Res*. 2016;2016, 8981435.
17. Borg DJ, Haritopoulou-Sinanidou M, Gabrovska P, et al. Barriers and facilitators for recruiting and retaining male participants into longitudinal health research: a systematic review. *BMC Med Res Methodol*. 2024;24(1):46.
18. Apolinario D, Lichtenthaler DG, Magaldi RM, et al. Using temporal orientation, category fluency, and word recall for detecting cognitive impairment: the 10-point cognitive screener (10-CS). *Int J Geriatr Psychiatry*. 2016;31(1):4–12.
19. Machado Á, da Silva CB, da Rocha ES, Carpes FP. Effects of plantar foot sensitivity manipulation on postural control of young adult and elderly. *Rev Bras Reumatol Engl Ed*. 2017;57(1):30–36.
20. Santos AD, Prado-Rico JM, Cirino NTO, Perracini MR. Are foot deformity and plantar sensitivity impairment associated with physical function of community-dwelling older adults? *Braz J Phys Ther*. 2021;25(6):846–853.
21. Matsudo S, Araújo T, Matsudo V, Andrade D. Questionário Internacional de Atividade Física (IPAQ): estudo de validade e reprodutibilidade no Brasil. 6. *Revista Bras Ativ Fis Saúde*. 2001:5–18.
22. Porto JM, Iosimuta NCR, RC Freire Júnior, et al. Risk factors for future falls among community-dwelling older adults without a fall in the previous year: a prospective one-year longitudinal study. *Arch Gerontol Geriatr*. 2020;91, 104161.
23. LaRoche DP, Cremin KA, Greenleaf B, Croce RV. Rapid torque development in older female fallers and nonfallers: a comparison across lower-extremity muscles. *J Electromyogr Kinesiol*. 2010;20(3):482–488.
24. Arnold CM, Warkentin KD, Chilibeck PD, Magnus CR. The reliability and validity of handheld dynamometry for the measurement of lower-extremity muscle strength in older adults. *J Strength Cond Res*. 2010;24(3):815–824.
25. Krishnan C, Allen EJ, Williams GN. Effect of knee position on quadriceps muscle force steadiness and activation strategies. *Muscle Nerve*. 2011;43(4):563–573.
26. Cangussu-Oliveira LM, Porto JM, Freire Junior RC, et al. Association between the trunk muscle function performance and the presence of vertebral fracture in older women with low bone mass. *Aging Clin Exp Res*. 2020;32(6):1067–1076.
27. Porto JM, Nakaishi APM, Cangussu-Oliveira LM, Freire Júnior RC, Spilla SB, Abreu DCC. Relationship between grip strength and global muscle strength in community-dwelling older people. *Arch Gerontol Geriatr*. 2019;82:273–278.
28. Templeton FGA. Two-step approach for transforming continuous variables to normal: implications and recommendations for IS research. *Commun Assoc Infor Syst*. 2011;28:pp–pp.
29. Montero-Odasso M, Schapira M, Soriano ER, et al. Gait velocity as a single predictor of adverse events in healthy seniors aged 75 years and older. *J Gerontol A Biol Sci Med Sci*. 2005;60(10):1304–1309.
30. Studenski S, Perera S, Patel K, et al. Connor EB and others. Gait speed and survival in older adults. *JAMA*. 2011;305(1):50–58.
31. Samuel D, Rowe P, Nicol A. The functional demand (FD) placed on the knee and hip of older adults during everyday activities. *Arch Gerontol Geriatr*. 2013;57(2): 192–197.
32. Magee D.J. Avaliação Musculoesquelética. 4 ed, editor: Manole 2005.
33. Grimmer M, Riener R, Walsh CJ, Seyfarth A. Mobility related physical and functional losses due to aging and disease - a motivation for lower limb exoskeletons. *J Neuroeng Rehabil*. 2019;16(1):2.
34. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc*. 1991;39(2):142–148.
35. Neumann DA. Kinesiology of the hip: a focus on muscular actions. *J Orthop Sports Phys Ther*. 2010;40(2):82–94.
36. Buatois S, Miljkovic D, Manckoundia P, et al. Five times sit to stand test is a predictor of recurrent falls in healthy community-living subjects aged 65 and older. *J Am Geriatr Soc*. 2008;56(8):1575–1577.
37. Zhang F, Ferrucci L, Culham E, Metter EJ, Guralnik J, Deshpande N. Performance on five times sit-to-stand task as a predictor of subsequent falls and disability in older persons. *J Aging Health*. 2013;25(3):478–492.
38. Porto JM, Peres-Ueno MJ, de Matos, Brunelli Braghin R, Scudilio GM, de Abreu DCC. Diagnostic accuracy of the five times stand-to-sit test for the screening of global muscle weakness in community-dwelling older women. *Exp Gerontol*. 2023;171, 112027.
39. Nightingale EJ, Pourkazemi F, Hiller CE. Systematic review of timed stair tests. *J Rehabil Res Dev*. 2014;51(3):335–350.
40. Martins PP, Porto JM, Vieira FT, Trimer IR, Capato LL, de Abreu DCC. The effect of unilateral muscle fatigue of hip abductor muscles on balance and functional capacity in community-dwelling older women. *Arch Gerontol Geriatr*. 2020;91, 104222.
41. Vieira FT, Porto JM, Martins PP, Capato LL, Suetake FS, de Abreu DCC. Hip muscle strength, dynamic balance and functional capacity of community-dwelling older adults aged 60 and older: a cross-sectional study. *J Biomech*. 2021;129, 110753.
42. Van Cutsem M, Duchateau J, Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J Physiol*. 1998;513(Pt 1):295–305.
43. Häkkinen K, Komi PV. Training-induced changes in neuromuscular performance under voluntary and reflex conditions. *Eur J Appl Physiol Occup Physiol*. 1986;55(2): 147–155.
44. Christou EA, Yang Y, Rosengren KS. Taiji training improves knee extensor strength and force control in older adults. *J Gerontol A Biol Sci Med Sci*. 2003;58(8):763–766.
45. Tracy BL, Byrnes WC, Enoka RM. Strength training reduces force fluctuations during anisometric contractions of the quadriceps femoris muscles in old adults. *J Appl Physiol (1985)*. 2004;96(4):1530–1540.