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Muscle mass and muscle strength relationships to balance: The role of age and physical activity

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Abstract

Objective: To investigate the relations of balance to muscle mass (MM) and muscle strength (MS), depending on age and physical activity, which is of particular importance to functional independence in older people. Methods: This cross-sectional study included 802 volunteers (69.82 ± 5.60 years). The Fullerton Advanced Balance scale was used to assess balance and a composite score, including arm curl and chair stand tests for assessing MS. MM was estimated by dual-energy X-ray absorptiometry and physical activity by questionnaire. Results: Greater MM ($r = .26$, $p < .001$) and MS ($r = .53$, $p < .001$) were positively correlated to balance. The old-old adults and less active individuals attained lower balance. Notably, moderation and subsequent simple slope analyses revealed that the relations of balance, MM, and MS were larger in less active and the old-old adults. Conclusions: The old-old and less active adults were more prone to muscle weakness and balance impairments. Tailored interventions shouldparticularly consider these vulnerable groups.

Introduction

Balance, the ability to control postural sway during quiet standing or to react and anticipate changes as the body moves, is of particular importance in older adults because it is strongly associated with avoiding falls (Gouveia, Jardim, et al., 2016). Given that falls often lead to injury, loss of independence, and finally illness and early death in older adults, targeting determinants of balance to reduce fall risk in old age is of high importance (Howe, Rochester, Neil, Skelton, & Ballinger, 2011).

There is evidence showing that muscle strength (MS) is associated with the ability to maintain standing balance, particularly in older people. This relationship has been extensively studied across different MS body sites. For instance, Bijlsma, Pasma, Lambersm, and Maier (2013) showed in a cross-sectional study of 197 community-dwelling older adults (78 men, 119 women; mean age 82 years) that MS (assessed by handgrip and knee extension strength) is a key predictor of balance (assessed by center of pressure parameters). More recently, Alonso et al. (2018) confirmed that lower handgrip strength was correlated with worse dynamic balance and mobility performance (Time Up and Go test) in older women (mean age of 67.4 ± 5.9 years). A significant positive correlation between trunk MS and static steady-state balance has been reported by Granacher, Lacroix, Roettger, Gollhofer, and Muehlbauer (2014), whereas Melzer, Benjuya, Kaplanski, and Alexander (2009) described the association between ankle MS and limits of stability.

In spite of the ample evidence about the relationship between MS and balance, there is a paucity and inconsistency of evidence concerning the relationship between muscle mass (MM) and balance (Bijlsma et al., 2013; Muehlbauer, Gollhofer, & Granacher, 2015), possibly attributed to methodological limitations, the use of different assessment instruments and protocols, and sample characteristics. Apart from this, muscle characteristics are of special interest, as recent evidence suggests that resistance training can improve strength, power, muscle cross-sectional area, and balance, even in older adults (Lee & Park, 2013; Orr, 2010). This is explained by the fact that there are several muscle fiber adaptation responses induced by strength training. The increases in MS appear to be the result of a growth in muscle size (hypertrophy) or an increase in the number of fibers within the muscle (hyperplasia; Mayer et al., 2011; Peterson, Sen, & Gordon, 2011).

The age-related reduction of MM is well documented in the literature (Harbo, Brincks, & Andersen, 2012; Keller & Engelhardt, 2013; Morley, Baumgartner, Roubenoff, Mayer, & Nair, 2001). This decline is directly connected with loss of strength, as result of the atrophy of muscle fibers, with a preferential incidence in type II fibers (Rice & Keogh, 2009; Surakka, Aunola, Nordblad, Karppi, & Alanen, 2003). The loss of MM and MS is considered as major risk factors affecting multiple dimensions of balance (Cadore, Rodríguez-Manas, Sinclair, & Izquierdo, 2013˜ ; Howe et al., 2011; Lee & Park, 2013; Orr, 2010), and it has been directly associated to losses of independence, increased health care costs, and overall reduced quality of life.

The positive relationship between physical activity (PA) and functional fitness parameters among older people has been widely explored. Research has shown that active older people score better in functional-fitness tests (MS, balance, and endurance) than their less active peers (Gouveia et al., 2013; Ferreira et al., 2012; 1

Milanovic´ et al., 2013). In addition, there is evidence that older adults with higher PA level show MM above the sarcopenia threshold or have higher lean body mass (Gouveia et al., 2016; Park, Park, Shephard, & Aoyagi, 2010). All these results support the hypothesis that maintaining high levels of daily PA may have a direct impact on the prevention or even reversibility of the agerelated declines in functional fitness. Therefore, the study on the previously mentioned relationships can provide an important information to be considered in the development and implementation of multicomponent interventions at the community level, focused in improving MS, MM, and balance.

Most importantly, to our knowledge, no study so far has investigated whether the relationships of balance to MS and MM differed between young-old and old-old adults groups or between individuals with low compared with those with high PA level. Notably, differences between these groups seem reasonable as old-old adults and less active individuals are much more prone to losses in MM and MS (Harbo et al., 2012; Keller & Engelhardt, 2013; Mertz, Lee, Sui, & Blair, 2016; Morley et al., 2001), which may more strongly affect their ability to maintain balance, compared with young-old adults and with more active individuals.

Although previous studies have established the importance of MM and MS as key components of balance in general (Howe et al., 2011; Orr, 2010), it remains a critical open issue whether they have a universal pattern of relation or whether and how this

differs by age and PA in older adults. Thus, to extend the literature, the present study set out to investigate the relations of balance to MM and MS, depending on age and PA level in healthy older adults in detail.

Methods

Participants

This cross-sectional study included 802 participants (401 men, 401 women; mean age 69.82 years, SD = 5.60), distributed over two age cohorts (60–69 years, young-old group and 70– 79 years, old-old group). This age cohort classification was based on life expectancy in the autonomous region of Madeira, which was between 72.67 years for men and 79.74 years for women (76.54 years for both; Statistics Portugal, 2014). Proportional regional (geographic) representation was determined by stratified sampling based on Census 2001 data from the Portugal Statistics National Institute (2002) with age cohort and sex serving as stratification variables. Participants were volunteers recruited through direct contacts carried out in day care and social centers, cultural and sport clubs and associations, and residential and public places.

The study was also advertised in the daily newspaper and on local radio and television. Inclusion criteria were being community-dwelling, aged between 60 and 79 years, and able to walk independently. Exclusion criteria were any medical contraindications to submaximum exercise (assessed by a medical health history questionnaire) according to the guidelines of the American College of Sports Medicine (2006), inability to understand and follow the assessment protocol. The study was approved by the Department of Physical Education and Sport of the University of Madeira, the Regional Secretary of Education, and the Regional Secretary of Social Affairs. Informed consent was provided by all participants before the assessments and the present study included adherence to the Declaration of Helsinki.

Materials

Balance. The Fullerton Advanced Balance (FAB) scale (Rose, Lucchese, & Wiersma, 2006) was used to measure the multiple dimensions of balance (for validations see e.g., Hernandez & Rose, 2008). The FAB scale includes the following 10 items: (a) standing with feet together and eyes closed, (b) reaching forward to retrieve an object (pencil) held at shoulder height with outstretched arm, (c) turning 360° in a right and left

direction, (d) stepping up and over a 15-cm bench, (e) tandem walking, (f) standing on one leg, (g) standing on foam with eyes closed, (h) jumping for distance, (i) walking with head turns, and (j) recovering from an unexpected loss of balance. Each test item is scored using a 4-point ordinal scale (0–4), resulting in a maximum score of 40 possible points, representing an optimal balance performance. Lower scores mean lower balance performance and higher risk for falling (Hernandez & Rose, 2008). The cutoff score of 25 out of 40 on the FAB scale produced the highest sensitivity and specificity in predicting the recurrent faller status (Hernandez & Rose, 2008), allowing to draw the conclusion that an older adult who scores 25 or lower on the FAB scale is considered to be at heightened risk for falling. With one exception, item 10, all items require that the instructor demonstrates the task to perform. According to the protocol, no warming-up was performed before testing.

Body Skeletal Muscle

Total body lean soft tissue mass and appendicular lean soft tissue (ALST; considered equivalent to the sum of lean soft tissue in both the right and left arms and legs; Kim, Heymsfield, Baumgartner, & Gallagher, 2002) were measured by dual-energy X-ray absorptiometry (Lunar Prodigy Primo, with technologic fan beam—GE Healthcare, Encore 2007 software version 11.40.004; Boston, MA). Skeletal MM was calculated from $(1.13 \times \text{ALST}) - (0.02 \times \text{age}) + (0.61 \times \text{sex}) + 0.97$, where sex ($0 = \text{female}$; $1 = \text{male}$), and ALST is the sum of lean soft tissue in both the right and left arms and legs (Kim et al., 2002; see Gouveia et al., 2014 for a more detailed description).

Muscle Strength

In terms of upper body strength, MS was assessed using the arm curl testandlower body strength using the chairstand test (Rikli & Jones, 1999). The arm curl test requires people to repeatedly lift a 5 lb (2.27 kg) weight (for women) or an 8 lb (3.63 kg) weight (for men) for 30 s. The chair stand test requires people to repeatedly stand up from and sit down on a chair for 30 s. The number of lifts and stands were recorded. A detailed description of the evaluation procedures, namely, equipment, procedure, scoring, and safety precautions are detailed in the senior fitness test manual (Rikli & Jones, 2013). For analyses, we computed a composite score including upper and lower body strength (with both test scores being z standardized before), as an indicator of overall body strength.

Physical Activity

Physical activity with a reference time period of last year was assessed during face-to-face interviews using the Baecke questionnaire (Baecke, Burema, & Frijters, 1982; for validations see e.g., Gouveia et al., 2014). This questionnaire includes a total of 16 questions classified into three specific domains: PA at work/ housework, sport and leisure time, and the latter excluding sports. If the subjects were not employed or if they were retired, their occupation was coded as homemaker. The questionnaire also provides a measure of total PA, which is the sum of these three specific domains. Numerical coding for most response categories varied from 1 to 5 (Likert scale) ranging from never to always or very often.

Statistical Analyses

First, for descriptive purposes only, we reported means and SDs in age, total PA, balance, body MS (upper and lower), and body MM for the overall sample as well as separately for young-old (60–69 years) versus old-old adults (70–79 years). In addition, similar analyses were done separately for individuals with high versus those with low PA level (based on a median split on total PA score). The mean differences were tested between young-old versus oldold adults and individuals with a high PA level compared with those with a low PA level using a t test for independent groups. All moderation analyses addressing our main study goal were conducted based on the continuous variables chronological age and total PA score. Second, for descriptive purposes, we inspected bivariate relations of body MS and body MM to balance scores (by calculating Pearson correlation coefficients r).

Third, addressing our main study goal, we investigated whether the relation of body MS/body MM to balance scores varied as a function of chronological age and PA level. Specifically, we regressed balance scores on body MS/body MM as respective predictor plus chronological age/PA level as respective moderator plus the respective interaction term. Note that for these moderation analyses, we did not artificially dichotomize chronological age and PA level and instead analyzed these variables as a continuous score. In a subsequent set of simple slope analyses, we investigated moderation patterns in more detail. Specifically, to evaluate the direction of moderation effects, we estimated the relation of body MS/MM to balance scores at low and high values of the continuous variable chronological age (i.e., −1 SD [for clarity in the following referred to young-old age] and +1 SD [in the following referred to old-old age], respectively) in

the respective moderation model. Moreover, we estimated the relation of body MS/MM to balance scores at high and low values of the continuous variable PA level (i.e., +1 SD [for clarity in the following referred to high PA level] and −1 SD [in the following referred to low PA level], respectively) in the respective moderation model (Preacher, Curran, & Bauer, 2006).

Results

Descriptive Statistics

Means and SDs of measures are displayed in Table 1. Conducting t tests for independent groups showed that balance ($p < .001$), body MS (upper and lower; $p < .001$), and body MM ($p < .001$) were significantly higher in young-old compared with old-old adults. Individuals with a high PA level compared with those with a low PA level had a greater balance and MS ($ps < .001$; Table 1). With respect to bivariate relations, greater body MS ($r = .53$, $p < .001$) and greater amount of body MM ($r = .26$, $p < .001$) were significantly related to higher balance scores.

Moderation Analyses

With respect to our main study goal, there was a significant moderation of the relations of body MS and body MM to balance scores by chronological age (left panel of Table 2). Together with these significant moderation effects, subsequent analyses indicated that the relations of body MS and body MM to balance scores were significantly larger in old-old compared with young-old age (right panel of Table 2).

In addition, there was a significant moderation of the relations of body MS and body MM to balance scores by PA level (left panel of Table 3). Together with these significant moderation effects, subsequent analyses indicated that the relations of body MS and body MM to balance scores were significantly larger in individuals with a low compared with those with a high PA level (right panel of Table 3).

Discussion

To extend the literature, the present study set out to investigate the relations of balance to MM and MS, depending on age and PA level, in healthy older adults in detail. This topic is of particular importance, as it may support tailored interventions focused on balance and MM and MS improvements in a specific age and PA group. The present study emphasizes a strong positive relationship between MS (measured by a composite score including upper and lower body strength), body MM (measured by dual energy X-ray absorptiometry), and balance (measured by static and dynamic balance activities). Although the relationship between different body sites' MS and balance has already been extensively reported in the existing literature (handgrip, Alonso et al., 2018; lower limbs, Bijlsma et al., 2013; Lee & Park, 2013; ankle, Melzer et al., 2009; trunk, Granacher et al., 2014), the association between body MM and balance in older people is far from being fully understood (Bijlsma et al., 2013; Muehlbauer et al., 2015). Some disparities in results might be associated with the differences in age, gender, race, as well as to the variety of methods used to estimate body MM. However, our findings clearly support the hypotheses that keeping higher strength scores is highly recommended in older adults, to slow down body MM losses, as well as to prevent and even reverse balance impairments. Furthermore, our results support that these upper and lower body strength tests (Rikli & Jones, 2013) can be easily integrated in the clinical practice as good indicator of MM in older people. Elucidating the large variety of results across prior studies, our data confirm that the old-old adults showed lower balance, MM, and MS. This is justified by a well-known net of ageassociated physiological declines that occurs in neuromuscular and musculoskeletal functions, reduced body MM and MS, and decreased coordination and motor control (Gouveia et al., 2013, 2016; Keller & Engelhardt, 2013; Lukaski, 2005). In regard to neuromuscular and musculoskeletal systems, major quantitative age-related changes are characterized by loss of fibers, decrease in size, and fiber-type grouping. These result in atrophy of the muscles, affecting primarily the type II muscle fibers (Brunner et al., 2007; Rice & Keogh, 2009; Surakka et al., 2003). In respect to age-related changes in coordination and motor control, those are mainly associated to declines in sensorimotor functioning. Such declines include impairments in the peripheral sensorimotor system, including motor unit reorganization, changes in the brain (including neurochemistry and gray

matter atrophy), and in the functional organization of large-scale brain networks (Cassady et al., 2019).

Corroborating the well-known age-associated physiological declines on the literature, our results showed a significant moderation effect of age on the relations of balance to MM and MS. A deeper analysis showed that these relationships were significantly larger in old-old compared with young-old adults. This means that MM and MS seem to have a more important contribution to balance in later life, namely after the age of 70 years. This finding is of importance because life expectancy in the autonomous region of Madeira, is 76.54 years (INE, 2014), that means a critical age that requires more attention. Furthermore, the majority of prior studies limited their focus on middle-aged persons (40 to 60–65 years; e.g., Keller & Engelhardt, 2013 and Ferreira et al., 2012). In addition to the results of those studies in younger age groups, our study suggests that the larger MM and MS decline in advanced age (Harbo et al., 2012; Morley et al., 2001) may have disproportionately higher aftereffects on balance problems. This is highly relevant in clinical practice because more attention is then particularly needed in this more vulnerable group of very old-aged adults.

In our study, considering the last year as the reference time period, habitual PA was accessed using the Baecke questionnaire (Baecke et al., 1982). It means that we considered a meaningful index of habitual PA from this sample (i.e., PA at work/household activities, sport during leisure time, and PA during leisure time excluding sport). Hopefully, we confirmed that the most active older people (taking into consideration all three components mentioned together) showed better balance and strength scores as well as greater amount of MM in comparison with the less active older people. This confirms the well-known positive relationship between PA and functional fitness parameters in older people (Gouveia et al., 2013; Ferreira et al., 2012; Lee & Park, 2013). Together, this highlights the negative spiral of deterioration associated to the reduced PA seen in older people, leading to loss of autonomy and reduction in their quality of life. Notably, we found a significant moderation effect of PA level on the relations of balance to MM and MS. Subsequent analyses showed stronger relationships in individuals with a low compared with those with a high PA level. This emphasizes the positive association between PA and functional fitness, also consistently described in other studies (Gouveia et al., 2013; Milanovi´c et al., 2013). The present results reinforce the idea that balance, assessed in a multiple dimension

perspective (e.g., sensory, motor, musculoskeletal, cognitive), depends on a network of interrelationships, in which habitual PA is an important contributor for maintaining functional capacities such as balance. This means that the assessment of PA as well as the adequate recommendation about frequency, intensity, time, and type of PA should be addressed in clinical practice toward old-old adults, especially when approaching those who are less active. Furthermore, tailored interventions focused on the promotion of safe PA at the community level, stimulating the maintenance of regular physical activities (household, sports, and leisure-time contexts) may have a vast impact on the prevention or even reversibility of agerelated declines in functional fitness (American College of Sports Medicine, 2006; Ferreira et al., 2012). This could have an important contribution for the (re)integration of the old-old adults and the less active people in societies, contributing to keeping their ability to do the things they want in an independent and safe way as long as possible.

Some limitations and strengths of this study should be acknowledged. First , the cross-sectional design of this study limits conclusions regarding the direction of the relationships observed. Second, although the Baecke questionnaire has been shown to have acceptable reproducibility (Gouveia et al., 2014) and is appropriated for large population studies, the limited ability of some participants to accurately recall past sport and leisure activities could introduce bias and lead to misclassification. More objective data, like those collected with accelerometers, could better characterize the total PA level. Finally, the instruments used to assess MS do not allow a direct measure of strength. However, such fieldbased tests allow excellent feasibility in applied environments and have been shown to capture interindividual differences comparable with using gold-standard laboratory fitness tests (Rikli & Jones, 2013). With respect to strengths of the present study, it is important to mention that skeletal MM was estimated from the ALST using dual energy X-ray absorptiometry, which is the current goldstandard assessment for the investigating MM (Kim et al., 2002).

Moreover, to our knowledge, only few studies so far have focused on the association between balance, MM, and strength using highly reliable instruments in a large sample of community-dwelling older men and women (60–80 years), with low prevalence of sarcopenia (see Gouveia et al., 2016, for a discussion). We assessed balance using the FAB scale, a performancebased measure that comprehensively addresses the multiple dimensions of balance through static and dynamic balance activities (Hernandez &

Rose, 2008). Thus, an important strength of the study concerns the feasibility, accuracy, and reproducibility of the applied measures in clinical practice as tools to monitor important age-related changes on balance performance and MS, proven to have a direct impact on the older adults' performance in their activities of daily living. In addition, this study adds important information about the relations of balance to MM and MS as well as the moderation effects of age and PA level in a large sample of community-dwelling older men and women, including a significant cohort of healthy older adults aged 70 years and older, on which information in the literature is still limited. This data were obtained from a general homogeneous sample in terms of cultural background, living and occupation conditions, and environmental influences that reduce some variability, which helps to accentuate the relationships between the targeted variables. The present research concludes that old-old adults and individuals with a low level of PA are more prone to muscle weakness and balance impairments. Extending the literature, our findings support both the application of prehabilitation strategies focused on balance in younger ages and the implementation of tailored interventions focused on improvement of MM and MS to maintain balance even after the age of 70 years or in individuals with low PA level. However, additional longitudinal research is needed to evaluate the effect on health status and the cost-effectiveness of these interventions in the context of the health care systems.

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Legends

Table 1 *Descriptive statistics of measures*

Table 2 *Moderation analyses with body strength / body skeletal muscle as predictor of balance scores and chronological age as moderator*

Table 3 *Moderation analyses with body strength / body skeletal muscle as predictor of balance scores and PA level as moderator*

Table 1

Descriptive statistics of measures

Variables	Overall *M (SD)*	Age group YO *M (SD)*	OO *M (SD)*	PA level High PA *M (SD)*	Low PA *M (SD)*
	n = 801	*n = 411*	*n = 390*	*n = 393*	*n = 408*
Age (years)	69.8 (5.6)	65.1 (2.9)	74.8 (2.8) ***	69.2 (5.6)	70.4 (5.5) **
PA (total score)	7.3 (1.2)	7.5 (1.2)	7.1 (1.2) ***	8.3 (.72)	6.3 (.73) ***
Balance	30.5 (7.5)	32.9 (6.7)	28.0 (7.5) ***	32.5 (6.1)	28.6 (8.1) ***
30-second arm curl test	16.3 (4.1)	17.1 (4.2)	15.4 (3.8) ***	17.2 (4.1)	15.4 (3.9) ***
30-second chair stand test	13.6 (4.1)	14.6 (4.3)	12.6 (3.6) ***	14.7 (3.9)	12.7 (4.1) ***
Body skeletal muscle	22.0 (5.2)	22.6 (5.3)	21.4 (5.0) ***	22.3 (5.0)	21.8 (5.3)

Note. Descriptive statistics for the overall sample as well as separately for young-old versus old-old adults as well as separately for individuals with high versus those with low PA level, using a *t* test for independent groups. PA, physical activity; YO, young-old adults (60-69 years); OO, old-old adults (70-79 years).

*** $p < .001$; ** p $< .05$

Table 2

Moderation analyses with body strength / body skeletal muscle as predictor of balance scores and chronological age as moderator

Variable	*Moderation analysis*			*Subsequent analysis*	
	β_P	β_M	β_I	β_{YO}	β_{OO}
Body strength	.47***	-.23***	.09**	.43***	.54***
Body skeletal muscle	.21***	-.33***	.08*	.14**	.30***

Note. Left panel: Moderation analyses with body strength / body skeletal muscle as respective predictor of balance scores and chronological age as moderator. β_P = standardized coefficient of body strength / body skeletal muscle as respective predictor of balance scores. β_M = standardized coefficient of chronological age as moderator. β_I = standardized coefficient of the respective interaction term.

Right panel: Subsequent simple slope analyses to estimate the relation of body strength / body skeletal muscle to balance scores at young-old and old-old age (i.e., -1 *SD* and +1 *SD* of chronological age, respectively) in the respective moderation model. β_{YO} standardized coefficient of body strength / body skeletal muscle as respective predictor of balance scores, estimated at young-old age (-1 *SD* of chronological age). β_{OO} standardized coefficient of body strength / body skeletal muscle as respective predictor of balance scores, estimated at old-old age (+1 *SD* of chronological age).

*** $p < .001$; ** $p < .01$; * $p < .05$.

Table 3

Moderation analyses with body strength / body skeletal muscle as predictor of balance scores and PA level as moderator

Variable	*Moderation analysis*			*Subsequent analysis*	
	β_P	β_M	β_I	β_H	β_L
Body strength	.48***	.16***	-.16***	.37***	.59***
Body skeletal muscle	.23***	.34***	-.10**	.13**	.35***

Note. Left panel: Moderation analyses with body strength / body skeletal muscle as respective predictor of balance scores and PA level as moderator. β_P = standardized coefficient of body strength / body skeletal muscle as respective predictor of balance scores. β_M = standardized coefficient of PA level as moderator. β_I = standardized coefficient of the respective interaction term.

Right panel: Subsequent simple slope analyses to estimate the relation of body strength / body skeletal muscle to balance scores at high and low PA level (i.e., +1 *SD* and -1 *SD* of PA scores, respectively) in the respective moderation model. β_H standardized coefficient of body strength / body skeletal muscle as respective predictor of balance scores, estimated at high PA level (+1 *SD* of PA scores). β_L standardized coefficient of body strength / body skeletal muscle as respective predictor of balance scores, estimated at low PA level (-1 *SD* of PA scores).

*** $p < .001$; ** $p < .01$.