TITLE

Association between knee extensor and ankle plantarflexor muscle thickness and echo intensity with postural sway, mobility and physical function in older adults

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CONFLICT OF INTEREST STATEMENT

The Authors declare that there is no conflict of interest.

ETHICAL APPROVAL

The study received approval from Coventry University Ethical Review Board (P79002)

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ABSTRACT

The purpose of this study was to assess the association between muscle thickness and echo intensity of the knee extensors and ankle plantarflexors with postural sway, mobility and physical function in older adults. Twenty-one older men and women (age; 69.9 ± 4.3 years) were assessed for postural sway (centre of pressure movement), mobility (i.e. Timed-Up and-Go-test [TUG]), physical function (i.e. 5 times sit-to-stand [STS]), and ultrasound derived measures of muscle thickness and echo intensity of the vastus lateralis (VL) and gastrocnemius medialis (GM). Significant inverse correlations were observed between VL and GM thickness with TUG (r= –.432 to –.492) and STS (r= –.473 to –.596). Significant positive correlations were observed between VL and GM echo intensity with TUG (r=.459 to .518) and STS (r=.481 to .635). Significant positive correlations were also detected between GM echo intensity and anteroposterior sway (r=.451 to .534). Two key findings emerged from the present experiment. First, this study provides novel evidence that ankle plantarflexor echo intensity, but not thickness, was associated with anteroposterior postural sway among older adults. Second, we provide new evidence that muscle thickness and echo intensity of the knee extensors and uniquely, the ankle plantarflexors, presented with similar magnitude associations with TUG and STS performance in older adults.

KEYWORDS

Muscle quality · Echo intensity · Muscle volume · Postural control · Elderly · Ultrasound

INTRODUCTION

It is well established that human ageing is associated with a progressive decline in skeletal muscle mass (i.e. sarcopenia [Clark and Manini, 2008; Goodpaster et al. 2006]) and strength/power (i.e. dynapenia; [Manini and Clark, 2012]). Crucially, sarcopenia and dynapenia are consistently and strongly associated with poor balance and mobility performance (Benichou and Lord, 2016; Clark and Manini, 2008), which are the hallmark of increased fall risk in older adults (Horlings et al. 2008; Landi et al. 2006; Moreland et al. 2004; Scott et al. 2014). Although reductions in muscle mass are thought to drive age-related functional deterioration, the rate of decline in muscle strength with age is 2–5 times greater than declines in muscle size (Delmonico et al. 2009), indicating a reduction in muscle quality with aging. Although previous studies have highlighted the importance of muscle quality (Pinto et al. 2014), rather than muscle strength or mass separately, in assessing physical performance in older adults, few existing studies have scrutinised the interrelationships between muscle quality, balance and mobility performance among older adults. Consequently, understanding how muscle quality contributes to poor physical performance in older adults may have important public health implications.

Muscle quality is widely assessed using non-invasive and easily accessible ultrasound-derived measures of muscle echo intensity (Stock and Thompson, 2020). The physiological premise of echo intensity is that skeletal muscle is comprised not only of contractile proteins, but also non-contractile proteins such as intramuscular adipocytes and fibrous tissue (McGregor et al. 2014). When examined using ultrasound imaging, these tissues provide varying levels of pixel intensity (i.e. echogenicity), with contractile proteins appearing black and both intramuscular adipose and fibrous tissue appearing white (Stock and Thompson, 2020). Echo intensity of a defined region of interest quantifies pixel intensity, whereby a greater echo intensity is associated with increases in intramuscular infiltration of fibrous and adipose tissues (i.e. low muscle quality) (Fukumoto et al. 2012; Pillen et al. 2009). Crucially, there is emerging evidence that echo intensity of the knee extensors is inversely associated with mobility (i.e. timed up and go test) and physical function (i.e. 30 s sit-to-stand) in older adults (r= –0.49 to –0.56) (Lopez et al. 2017; Rech et al. 2014; Wilhelm et al. 2014). However, only one study has investigated the relationship between echo intensity and balance performance in older adults. Palmer et al. (2020) showed that postural sway with the eyes closed was significantly associated with echo intensity of the hamstrings (r= 0.47), but not muscle cross sectional area (r= 0.02) in older men. These findings are important because postural sway, frequently assessed using objective measures of posturography (i.e. centre of pressure movements), is a strong independent predictor of falls in older people (Johansson et al. 2017; Lord, Clark and Webster, 1991; Piirtola and Era, 2006). Therefore, elucidating the potential relationship between echo intensity of lower extremity muscles with postural sway metrics will be important for identifying potential mechanisms for balance impairments and in developing countermeasures for age-related reductions in postural stability.

It is well known that the ankle muscles play a central role in minimising postural sway during quiet standing (Billot et al. 2010; Donath et al. 2016), and the plantarflexors are key agonist muscles in minimising postural sway in the anteroposterior direction (Di Giulio et al. 2009). While a significant inverse relationship between plantarflexor muscle thickness and postural sway (r= –0.39) has been reported in older adults (Kouzaki and Masani, 2012), no data exists describing the potential relationship between plantarflexor echo intensity and postural sway in this age group. This is an important gap in the literature because the single measurement of muscle thickness may overestimate the amount of contractile tissue due to the measurement of adipose and fibrous tissue deposition in older adult's muscles (Fukumoto et al. 2012) and may not reflect the greater decline in muscle strength /power as noted above. Consequently, it is important to determine whether the additional quantification of echo intensity of the plantarflexors may be a useful musculoskeletal characteristic relevant to understanding balance control with age. Therefore, the objective of this study was to assess the association between muscle thickness and muscle quality (i.e. echo intensity) of the knee extensors (vastus lateralis; VL) and plantarflexors (gastrocnemius medialis; GM) with postural sway metrics, mobility and physical function in older adults. We hypothesised that muscle thickness and echo intensity of the VL would be associated with mobility and physical function, while muscle thickness and echo intensity of the GM would be related to postural sway metrics.

METHODS

Subjects

Twenty-one healthy community-dwelling older adults aged 60 – 78 years (women; *n* = 9, men; *n* = 12) volunteered for the study (Table 1). Subjects were moderately active (IPAQ = 2.8 ± 1.5 $h\cdot wk^{-1}$) and reported low concern about falling during physical and social activities (FES-I = 18.0 ± 2.0). Prior to any involvement, participants gave their written informed consent to participate in this study. Participants also completed a health screening questionnaire to identify any contraindications that could affect their ability to perform the testing. All participants self-reported to no history of neurological (e.g. stroke, Parkinson's), musculoskeletal (e.g. tendinitis), severe cognitive problems (e.g. dementia) and cardiovascular or pulmonary diseases (e.g. coronary heart disease, chronic obstructive pulmonary disease). Following institutional ethical approval and prior to conducting the study, all participants gave their written informed consent. All risks associated with the experimental procedures were explained before testing began with the study conducted in accordance with the guidelines outlined in the Declaration of Helsinki (1964).

Testing schedule

Examination of posturography, ultrasound measurements of muscle thickness and echo intensity and physical function involved two visits. During the first visit participants were asked to read and sign an informed consent and complete health screening, physical activity and fear of falling questionnaires. Participants were also familiarised with all study procedures prior to the main trial. The second visit involved the measurement of ultrasound-derived measures of muscle thickness and echo intensity, posturography assessment and physical function, in that order. The experimental procedures were performed between 09:00 and 13:00.

B-mode ultrasonography measurements

Ultrasound images of the vastus lateralis (VL) and gastrocnemius medialis (GM) muscles were recorded using a B-mode ultrasound imaging device (LOGIQ Book XP, General Electric, Bedford, UK) and a wide-band linear probe (8L-RS, General Electric) with a 39-mm wide field of view and coupling gel (Ultrasound gel, Dahlhausen, Cologne, Germany) between the probe and skin. Ultrasound settings (Frequency: 10 MHz, Gain: 55 dB, Dynamic Range: 72) were kept consistent across participants. To ensure consistent imaging of the right and left vastus lateralis (RVL and LVL, respectively) between trials, participants were seated in a chair with hips and knees at 90°, with the shod feet flat on the floor and heels resting against the chair leg. A tape measure (Korbond, Lincolnshire, UK) was used to enable the positioning of the probe mid-thigh, inline and equidistant from the lateral proximal border of the patella to the greater trochanter. The probe was then manipulated until the superficial and deep aponeuroses could be visualised enabling longitudinal imaging of the VL muscle. To ensure consistent imaging of the right and left gastrocnemius medialis (RGM and LGM, respectively), subjects remained seated with one knee fully extended and the foot in the anatomical position resting against a wall. The GM-Achilles muscle tendon junction was visualised using ultrasound and the probe was then positioned equidistant from the popliteal fossa and the muscle tendon junction and the probe then manipulated until the superficial and deep aponeuroses could be visualised enabling longitudinal imaging of the GM. Three images (with the probe removed and replaced) were recorded at rest on both the left and right VL and GM muscles with muscle thickness measured at the centre of the image from the superficial to deep aponeurosis, with the average of three measurements used in subsequent analysis.

To assess muscle quality, the three images were recorded with the ultrasound device set to default gain levels and then exported to photo editing software (ImageJ, LOCI, University of Wisconsin). Using the imaging software a polygon region of interest was drawn bordering the VL and GM superior and deep aponeuroses and lateral edges of the ultrasound images (Harris-Love et al. 2016). Echogenicity (i.e. pixel intensity) was used to determine muscle quality by converting the ultrasound images to a grayscale histogram. Values for each pixel ranged from 0 (black) to 255 (white) arbitrary units (AU) within the ultrasound image and were used to calculate the mean grayscale histogram within the muscle image (Reimers et al. 1993). Lower values signify greater muscle quality and function (Watanabe et al. 2013). The mean echogenicity from three images for each muscle was used in subsequent analyses. The same technician performed all scans.

Posturography

Within the two minutes following the ultrasound assessment participants performed three 30 s quiet standing trials on a force platform (AMTI, AccuGait, Watertown, MA) under alternating conditions of eyes open (EO) and eyes closed (EC). To ensure continuity between trials, subjects were unshod and instructed to stand quietly with the hands clasped together in front of the body and with the feet together (Romberg stance) (Objero et al. 2019). During all quiet standing trials, participants were asked to stand as still as possible on the force platform while focussing on a circular target 1.5 meters from the force platform, adjusted to the eye level of each individual. Participants could step off the plate and rest between trials (±10 sec). Ground reaction force data were sampled at 100 Hz (AMTI, Netforce, Watertown, MA) and filtered with a 4th-order low-pass (6 Hz) Butterworth filter (BioAnalysis, V2.2, AMTI). The total displacement of COP in the anteroposterior (AP) and mediolateral (ML) directions (both cm) and mean COP velocity ($cm \cdot s^{-1}$) were subsequently calculated (AMTI, BioAnalysis, Version 2.2, Watertown, MA). The amplitude of displacement reflects the distance between the maximum and minimum COP displacement for each direction with greater values indicating poorer postural stability. The mean COP velocity reflects the efficiency of the postural control system with the smaller the velocity the better the postural control (Hill et al. 2020). The validity and reliability of these parameters have previously been established for this sampling duration (Pinsault and Vuillerme, 2009). An average of the three trials were used in subsequent analyses.

Mobility and physical function

Following the postural control assessment, participants completed three Timed-Up and-Go (TUG) tests with a 30 s rest between each trial. Subjects were initially seated and instructed to stand up from a chair without using their hands, walk 3 m as safely as possible, walk around a marker on the floor, walk back to the chair and sit down. The time taken to complete the test was recorded using a stopwatch (nearest 0.01 s), with the fastest trial included in the subsequent analyses (Podsiadlo and Richardson, 1991). Following a 2 min recovery, participants completed the five times sit-to-stand (STS) test (Bohannon, 2006a). Subjects were initially seated on a chair (seat height 45 cm) with arms folded across the chest and feet shoulder width apart. Subjects were asked to stand up fully with complete knee and hip extension and sit down as quickly for five repetitions, with participants verbally encouraged throughout the duration of the test. Participant's arms were folded across their chests during the test. The time taken to complete five STS cycles was recorded using a stopwatch (nearest 0.01 s). Among community dwelling older adults test-retest reliability (intraclass correlation coefficient [ICC]) of the TUG (ICC = 0.99; [Bohannon, 2006b]) and 5 times STS (ICC = 0.89; [Lord et al. 2002]) are excellent.

Statistical analysis

Data were analysed using SPSS version 25.0 (IBM Inc., Chicago, IL) and are presented as mean, standard deviation (SD) and range. After normal distribution was confirmed (Shapiro-Wilk tests), associations between postural sway, mobility and physical function with echo intensity and muscle thickness were assed using Pearson product moment correlation analysis. Coefficient values were interpreted as weak (r=0.10 to 0.35) moderate (r = 0.36 to 0.67) and strong (r=0.68 to 1.0). When significant correlation coefficients were found, stepwise multiple regression analyses were performed in order to investigate which of the musculature parameters could explain the postural sway, mobility or physical performance parameters. The alpha value was a priori set at p<.05 for all analyses. The variables that did not show a statistically correlation were held back from the regression analysis.

RESULTS

Table 1 shows the physical and performance characteristics, muscle quality and thickness, physical function and mobility performance and postural sway metrics for the group.

***** TABLE 1 ABOUT HERE *****

Relationship between muscle thickness, postural sway, mobility and physical function

Significant inverse correlations were observed between VL and GM thickness with TUG (r= –.432 to –.492) and five times STS (r= –.473 to –.596) performance (Table 2 and Fig. 1). There were no statistically significant correlations between muscle thickness and any postural sway metrics (p>.05) (Table 2).

***** TABLE 2 ABOUT HERE *****

***** FIGURE 1 ABOUT HERE *****

Relationship between echo intensity, postural sway, mobility and physical function

Significant positive correlations were observed between VL and GM echo intensity with TUG (r=.459 to .518) and five times STS (r=.481 to .635) performance (Table 3 and Fig. 2). The analysis also revealed statistically significant positive correlations between GM echo intensity and anteroposterior COP movements during both EO (r=.518 to .534) and EC (r=.451 to .508) conditions (Table 2, Fig. 3).

***** TABLE 3 ABOUT HERE *****

***** FIGURE 2 ABOUT HERE *****

***** FIGURE 3 ABOUT HERE *****

DISCUSSION

In examining the association between muscle thickness and quality of the knee extensors and plantarflexors with postural sway metrics, mobility and physical function in older adults, two main findings emerged. First, this study provides novel evidence that ankle plantarflexor echo intensity, but not thickness, was associated with anteroposterior postural sway among older men and women. Second, we provide new evidence that muscle thickness and echo intensity of the knee extensors and uniquely, the ankle plantarflexors, presented with similar magnitude associations with TUG and STS performance in older adults.

Relationship between postural sway and muscle thickness and echo intensity

Few studies have described the interrelationships between echo intensity and muscle thickness with balance performance in older people. Here, we found a moderate strength relationship between echo intensity of the GM with the anteroposterior COP amplitude during quiet bipedal standing with the eyes open and eyes closed. The echo intensity of the left and right GM and VL explained between 20 – 30% of the variance in the anteroposterior COP amplitude. These findings confirm our initial hypothesis and are consistent with the existing literature. For instance, a recent study showed that the sway index (i.e. root mean squared error distance of the COP in the anteroposterior and mediolateral axis) with the eyes closed was significantly associated with echo intensity of the hamstrings (r =0.47), but not muscle cross sectional area (r= 0.02) in older men (Palmer et al. 2020). Our study extends these findings in two important ways. First, we examined muscle thickness and echo intensity of the GM, which is well established as playing play a central role in minimising postural sway during quiet standing (Billot et al. 2010; Donath et al. 2016). Second, while previous studies used a composite postural sway metric (i.e. sway index) (Palmer et al. 2020), we examined the relationship between echo intensity with directional features of postural sway (i.e., anteroposterior and mediolateral COP movements). Although composite postural sway scores are useful in that they combine a set of quiet standing postural sway features into a single composite feature, different control mechanisms and different muscle groups are used to control sagittal and frontal plane motion

(Winter et al. 1996). Whilst we similarly found an association between lower-extremity echo intensity and postural sway, we additionally identified that the relationship was specific to the GM and anteroposterior sway, regardless of the visual condition. This is not surprising given that the ankle plantarflexors are the main contributors to stabilising body sway in the sagittal plane (Masani et al. 2003), while frontal plane sway is controlled by the hip abductors/adductors (i.e. frontal plane movers of the lower extremities). Overall, these findings suggest that quantification of echo intensity of the plantarflexors may be a useful musculoskeletal characteristic relevant to balance control.

Contrary to previous literature (Kouzaki and Masani, 2012) and our initial hypothesis, we were unable to identify a relationship between muscle thickness and postural sway metrics. Instead, our finding are similar to those of Palmer et al. (2020), who found no association between hamstring muscle cross sectional area and postural sway in older adults. While the single measurement of muscle thickness may overestimate the amount of contractile tissue due to the measurement of adipose and fibrous tissue deposition in older adult's muscles (Fukumoto et al. 2012), higher echo intensity values represents a greater degree of intramuscular fat (Young et al. 2015) and fibrous tissue infiltration (Pillen et al. 2009) (i.e. low muscle quality). Additionally, since muscle quality may be more affected by age than muscle quantity (Ota et al. 2020), measurements of muscle thickness may not be as important in explaining changes in postural stability in older adults. Overall, our findings suggest that ankle plantarflexor muscle quality, rather than size, may be an important characteristic relevant to postural balance in older adults. Although this study provides clear evidence of a link between muscle quality and postural control, it is important to acknowledge that the control of balance during both standing and movements is a complex motor skill (Ivanenko and Gurfinkel, 2018) which depends on the continuous integration and (re-)weighing of information from visual, vestibular and proprioceptive sensory afferents within the central nervous system (Nashner, 1976). Consequently, in addition to reducing muscle quality and quantity, age-related changes in postural control and mobility are also likely associated with a deterioration in sensory proprioceptive and exteroceptive information and/or their integration in the central nervous system.

Relationship between physical function/mobility and thickness and quality

Consistent with the existing literature, our study revealed that both muscle thickness and echo intensity presented with similar strength associations with TUG (Rech et al. 2014) and STS performance (Wilhelm et al. 2014). Whilst muscle thickness explained 15 to 36% of the variance in TUG and STS performance, muscle quality was a stronger predictor of performance with 21% to 40% of the variance explained by echo intensity. In previous studies analysing the relationship between ultrasound derived measures of muscle thickness and echo intensity with functional performance only the quadriceps musculature were investigated (Lopez et al. 2017; Rech et al. 2014; Wilhelm et al. 2014). However, the ankle plantarflexors are also important for TUG and STS performance in older adults (Jung and Yamasaki, 2016). Accordingly, a novel aspect of the present study was the quantification of GM muscle thickness and echo intensity and the correlation with functional performance. For the first time, we show that the muscle thickness and echo intensity of both the VL and GM presented with similar magnitude associations with TUG and STS performance in older adults. Overall, VL thickness (23 – 36%) and echo intensity (24 – 40%) explained a greater amount of the variance in TUG and STS performance than GM thickness (15 – 32%) and echo intensity (21 – 35%). The benefits of improving muscle quality are widely considered to be an important target of exercise interventions given its association with functional capacity (Lopez et al. 2017; Rech et al. 2014; Wilhelm et al. 2014). Therefore, it seems appropriate for exercise interventions which target muscle quality to not only focus on the intramuscular accumulation of non-contractile elements in the quadriceps femoris, but also the ankle plantarflexors.

Limitations

Although this work offers a valuable insight into the association between muscle echo intensity and balance, mobility and physical functional performance older adults, the present findings should be interpreted with the recognition that potential limitations exist. First, the study was based on a small convenience sample number of typically healthy community-dwelling older adults. The homogeneity of our small sample precludes us from generalising our findings to frail or institutionalised older adults at greater risk of falls. However, it could also be argued that the participants' homogeneity may have limited the influences of confounding demographic variables. Secondly, we included a relatively broad age range of subjects, comprising both young old (i.e. 60 – 69 years), middle old (70 – 78 years) adults (Forman et al. 1992). Analysis of a narrow age sample may be more suitable for deriving inferences regarding the associations between muscle quality and balance among older adults. Additionally, although the range of balance, mobility and physical functional performance of older adult participants was broad, this study included very high functioning people. Inclusion of more very low functioning older adults may have further strengthened the observed relationships between echo intensity and postural sway metrics. Thirdly, the cross-sectional nature of our study does not prove causality with regard to the association between echo intensity and poor balance. Future research examining longitudinal associations between these measures would be quite valuable. Finally, despite the inclusion of both males and females, this study was not adequately powered to examine gender-specific associations. Thus, larger studies are warranted to provide a more definitive view of the relationship between echo intensity and postural balance, controlling for age, gender and functional status. Additional examination of isokinetic ankle plantar flexor and knee extensor torque would also be quite valuable.

CONCLUSION

In conclusion, higher ankle plantarflexor echo intensity, but not thickness, was associated with greater amounts of anteroposterior postural sway among older adults. Additionally, muscle thickness and echo intensity of the knee extensors and ankle plantarflexors presented with similar magnitude associations with TUG and STS performance. Overall, we suggest that GM echo intensity plays an important role in older adult's postural balance, mobility and physical function. These findings represent an original contribution to the existing literature and will assist clinical decision making with respect to identification of potential balance deficits using non-invasive ultrasound-derived measures of muscle echo intensity.

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Table 1. Means ± SD demographic and performance characteristics of the sample

Dependent Variable	**Mean (*SD*)**	**Range**
Demographics and functional status		
Age (years)	69.9 (4.3)	60 – 78
Height (m)	1.70 (0.10)	1.51 – 1.87
Mass (kg)	75.4 (12.9)	49.7 – 97.0
BMI (kg/m^2)	26.0 (2.9)	20.7 – 31.3
FES-I	18.0 (2.0)	16 – 19
IPAQ (h·wk^{-1})	2.8 (1.5)	1.0 – 6.1
Physical function and mobility		
TUG (s)	6.49 (0.72)	5.0 – 7.85
Five times STS (s)	13.2 (1.8)	9.7 – 16.7
Postural sway metrics		
AP EO (cm)	2.92 (1.30)	1.59 – 5.35
AP EC (cm)	3.66 (1.47)	1.52 – 6.36
ML EO (cm)	2.55 (0.74)	1.22 – 3.98
ML EC (cm)	2.99 (0.91)	1.37 – 4.77
VEL EO (cm·s^{-1})	2.46 (0.29)	1.98 – 2.98
VEL EC (cm·s^{-1})	2.73 (0.87)	1.67 – 5.36
Echo intensity (AU)		
RVL	89.3 (5.3)	76.6 – 98.3
LVL	86.9 (4.5)	78.2 – 93.7
RGM	82.3 (8.8)	63.0 – 99.4
LGM	81.5 (9.6)	63.5 – 100.7
Muscle thickness (cm)		
RVL	1.72 (0.37)	1.18 – 2.29
LVL	1.73 (0.39)	1.20 – 2.27
RGM	1.73 (0.31)	1.22 – 2.38
LGM	1.71 (0.32)	1.11 – 2.36

BMI; Body mass index, FES-I; Falls Efficacy Scale International, IPAQ; International Physical Activity Questionnaire, TUG; Timed up-and-go, STS; Sit-to-stand, AP; Anteroposterior, ML; Mediolateral, VEL; Mean velocity, EO; Eyes open, EC; Eyes closed, RVL; Right vastus lateralis, LVL; Left vastus lateralis, RGM; Right gastrocnemius medialis, LGM; gastrocnemius medialis, AU; arbitrary unit

Table 2. Pearson correlation coefficients between muscle thickness of the knee extensors and plantar flexors with physical function, mobility and postural sway metrics

Dependent measure	**RVL**	**LVL**	**RGM**	**LGM**
Physical function and mobility				
TUG (s)	**-.492***	**-.480***	**-.432***	-.386
Five times STS (s)	**-.596***	**-.557***	**-.563***	**-.473***
Postural sway metrics				
AP EO (cm)	.325	.303	.311	.348
AP EC (cm)	.101	.015	.071	.003
ML EO (cm)	.325	.303	.311	.348
ML EC (cm)	.200	.203	.037	.038
VEL EO ($cm\cdot s^{-1}$)	.263	.288	.329	.341
VEL EC ($cm\cdot s^{-1}$)	.002	.011	.150	.093

Abbreviations: TUG; Timed up-and-go, STS; Sit-to-stand, AP; Anteroposterior, ML; Mediolateral, VEL; Mean velocity, EO; Eyes open, EC; Eyes closed, RVL; Right vastus lateralis, LVL; Left vastus lateralis, RGM; Right gastrocnemius medialis, LGM; gastrocnemius medialis. Significant correlations are displayed in bold font. *P <0.05, **P<0.001

Table 3. Pearson correlation coefficients between echo intensity (muscle quality) of the knee extensors and plantarflexors with physical function, mobility and postural sway metrics

Dependent measure	**RVL**	**LVL**	**RGM**	**LGM**
Physical function and mobility				
TUG (s)	**.491***	**.518***	**.459***	**.516***
Five times STS (s)	**.568****	**.635****	**.481***	**.590***
Postural sway metrics				
AP EO (cm)	.256	.358	**.518***	**.534***
AP EC (cm)	.321	.204	**.508***	**.451***
ML EO (cm)	.219	.040	.149	.104
ML EC (cm)	.289	.055	.188	.107
VEL EO ($cm\cdot s^{-1}$)	.087	.299	.217	.273
VEL EC ($cm\cdot s^{-1}$)	.127	.060	.084	.017

Abbreviations: TUG; Timed up-and-go, STS; Sit-to-stand, AP; Anteroposterior, ML; Mediolateral, VEL; Mean velocity, EO; Eyes open, EC; Eyes closed, RVL; Right vastus lateralis, LVL; Left vastus lateralis, RGM; Right gastrocnemius medialis, LGM; gastrocnemius medialis. Significant correlations are displayed in bold font. *P <0.05, **P<0.001

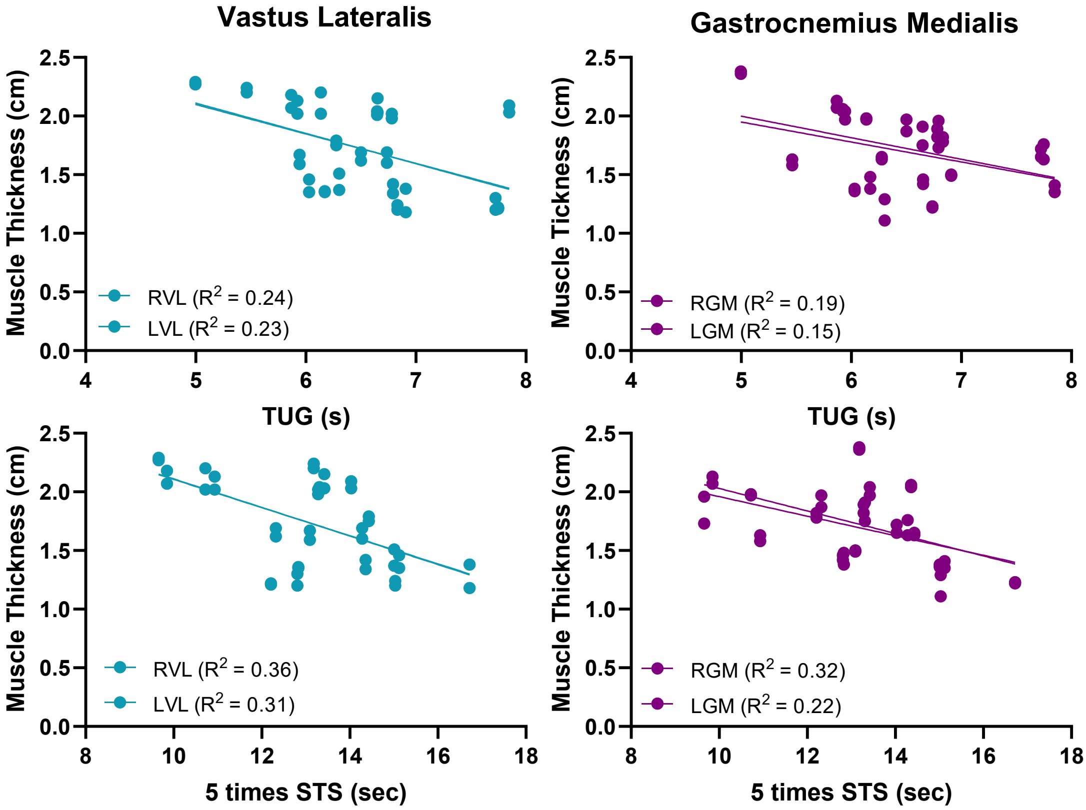

Figure 1. Relationship between vastus lateralis (left) and gastrocnemius medialis (right) muscle thickness with timed-up and go test (top) and 5 times sit-to-stand (bottom) performance. R^2 = Linear regression.

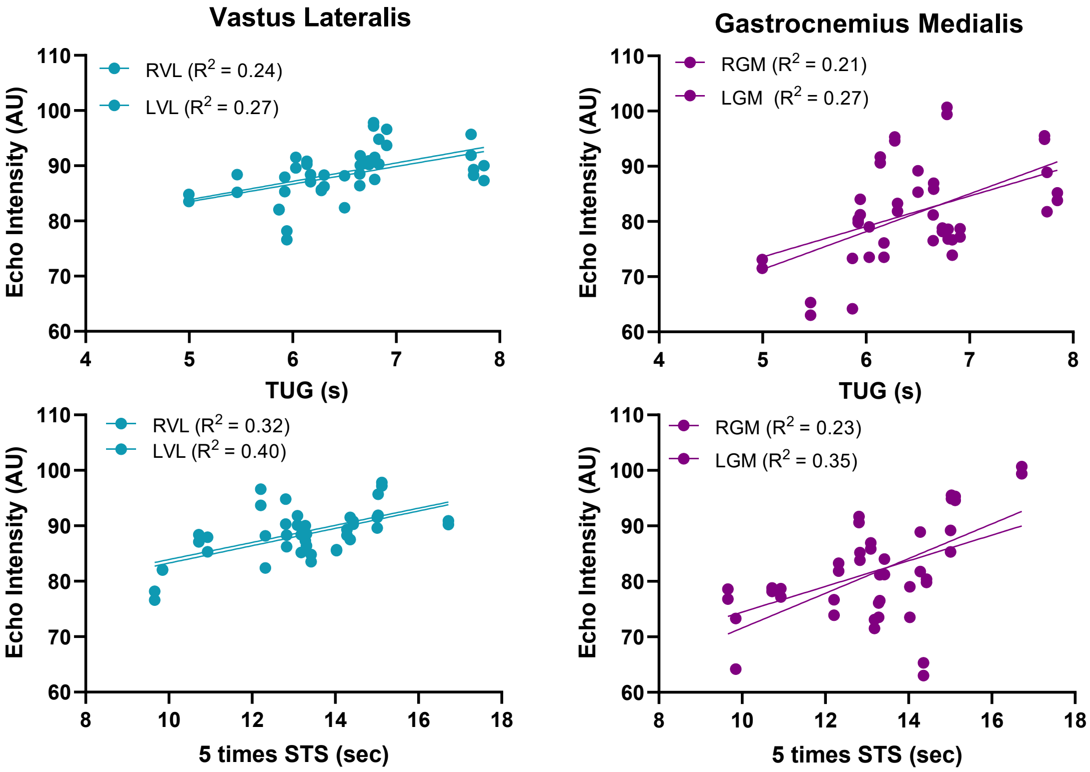

Figure 2. Relationship between vastus lateralis (left) and gastrocnemius medialis (right) muscle quality with timed-up and go test (top) and 5 times sit-to-stand (bottom) performance. R^2 = Linear regression.

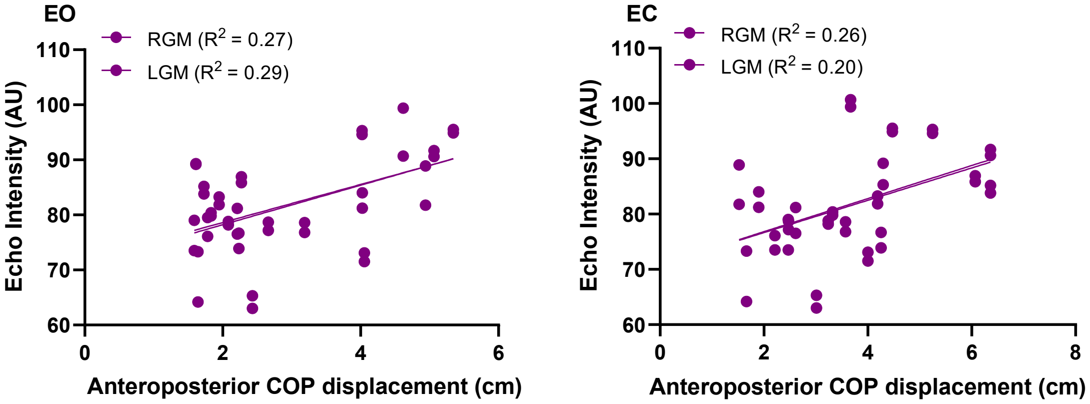

Figure 3. Relationship between gastrocnemius medialis echo intensity with the anteroposterior COP displacement during eyes open (left) and eyes closed (right) conditions. R^2 = Linear regression.