Hand grip strength is strongly associated with lower limb strength but only weakly with postural control in community-dwelling older adults

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ABSTRACT

Background: Hand grip strength is frequently used as a measurement of muscle strength, especially among older adults. Muscle strength is only one of the many components in postural control and it is currently unclear to what extent hand grip strength is associated with postural control. The aim was to analyze the association between hand grip strength and lower limb muscle strength, and postural control among older adults.

Methods: Forty-five community-dwelling individuals over 70 years of age provided isometric hand grip strength and lower limb strength (including hip extension and abduction, knee flexion and extension, and ankle dorsiflexion and plantarflexion), as well as postural control measurements. In the latter, center of pressure excursions were recorded for quiet stance and limits of stability tests on a force plate. Orthogonal projection of latent structures regression models were used to analyze associations between hand grip strength and lower limb strength as well as postural control, respectively.

Results: Lower limb strength explained 74.4% of the variance in hand grip strength. All lower limb muscle groups were significantly associated with hand grip strength. In a corresponding model, postural control measured with center of pressure excursions explained 20.7% of the variance in a statistically significant, albeit weak, model.

Conclusions: These results support that hand grip strength is a valid method to estimate lower limb strength among older adults on a group level. However, strength measurements seem insufficient as a substitute for measuring postural control, and therefore specific balance tests are necessary.

1. Introduction

Hand grip strength (HGS) is one of the most frequently used measurements of muscle strength in older adults. The measurement is quick and simple and has been associated with overall strength, commonly measured with knee extensor strength (Bohannon, 2012; Samson et al., 2000). Besides being related to a number of health-related outcomes such as frailty (Fried et al., 2001), sarcopenia (Cruz-Jentoft et al., 2019), and several chronic diseases (Cheung, Nguyen, Au, Tan, & Kung, 2013), lower HGS is also associated with slow gait speed (Alley et al., 2014; Phaswana-Mafuya, 2014; Rantanen et al., 1999), and an increased risk of falls (Pijnappels, van der Burg, Reeves, & van Dieën, 2008; Pluim et al., 2006; Stel, Smit, Pluim, & Lips, 2003). Falls are common among older adults, and also related to posturographic measures of postural control (Merlo et al., 2012).

Postural control involves multiple sensory and motor operations. The two main goals of postural control are orientation and balance (Horak, 2006). The central nervous system (CNS) combines information from visual, auditory, vestibular, and somatosensory receptors, as well as motor actions and reactions, in order to maintain balance. Besides using dynamic or functional performance-based tests, postural control can...
also be measured with posturography. This is often performed by the use of a force plate, measuring center of pressure (CoP) excursions during quiet stance, i.e., postural sway (Qiu & Xiong, 2015; Sheldon, 1963) or maximal amplitude of CoP in the limits of stability (LoS) test (Clark & Rose, 2001; Sheldon, 1963).

The relation between muscle strength and postural control is not straightforward. There is a significant association between them, and muscle weakness is a contributor to balance limitations (Orr, 2010). However, the complexity of postural control and the involvement of sensory and motor control systems introduces several additional unknown factors that complicate causal assumptions. One problem is the variation of the postural control tests, commonly categorized as static, dynamic, functional, and computerized posturographic measures (Orr, 2010). Moreover, the tests can be performed with or without sensory perturbations, e.g., with eyes open or closed and on a stable or unstable surface.

Forte, Boreham, De Vito, Ditroilo, and Pesce (2014) reported an association between muscle strength - assessed as knee extension strength - and dynamic postural control, among healthy 65–75 year old individuals. Further, there was an association between muscle strength and CoP excursions in quiet stance with posturography during trials with eyes closed but not with eyes open. In another study of community-dwelling 60–82 year olds (Singh, Pillai, Tan, Tai, & Shabah, 2015), there was a significant association between postural control measured by posturography during trials with eyes open and HGS, but no association between any dynamic or functional postural control tests and HGS. In contrast, Alonso et al. (2018) demonstrated an association between HGS and dynamic postural control, but not with CoP excursions during trials with eyes open or eyes closed, in 60–85 year old women. In a floura population, a study of 65–85 year olds living in long-term care facilities found associations between HGS with both dynamic postural control and CoP excursions measured with posturography. However, there was no association between HGS and CoP excursions when adjusting for confounders (Wisniowska-Szurlej, Cwirlej-Szozatska, Wołoszyn, Sozański, & Wilmowska-Pietruszyńska, 2019). Further investigations, including more detailed information from trials with other sensory perturbations and more dynamic aspects of postural control, are needed to understand this complex relationship.

There is a clear relationship between HGS and knee extensor strength, and this association is said to reflect a common construct – overall muscle strength (Bohannon, 2009, 2012). HGS has also been associated with knee flexor strength (Alonso et al., 2018). However, the association between HGS with muscles from all three main lower limb joints has been less investigated; it is necessary to study this further to reinforce the assumption that HGS could be used as a measurement for overall muscle strength. Even though the relationship between HGS and physical functional limitations is known, only a few studies have investigated the relationship between HGS and postural control, measured objectively with posturographic CoP excursions. There is a lack of studies investigating this association that use more than one sensory perturbation and more dynamic postural control tests, and an increased knowledge would further clarify the strengths and the limitations of using HGS as an assessment of physical function among older adults.

The aim of this study was to analyze the association between hand grip strength with 1) the muscles acting over the lower limb joints, and 2) postural control using CoP excursions, among community-dwelling older adults in a population-based sample.

2. Methods

In this cross-sectional study hand grip strength, lower limb strength, and postural control variables were measured in the Human Health and Performance Lab for Movement Science at Luleå University of Technology.

The participants were recruited from a population-based study of 153 randomly selected older (≥70 years of age) community-dwelling residents of Luleå Municipality previously described in detail (Pauelsen, Nyberg, Roijezon, & Vikman, 2018). Individuals fulfilling additional inclusion criteria (n = 126), including adequate vision to read 100 pt font size, ability to stand unassisted for at least 30 s, and ability to understand and process simple instructions, were invited to a follow up study, in which 45 (36%) accepted to participate. Other results are previously published elsewhere (Pauelsen, Vikman, Strandkvist, & Roijezon, 2018).

2.1. Measurements

A hand-grip dynamometer (E-LINK, Biometrics, UK) was used to measure isometric hand grip strength (in force, N). The participants were instructed to sit on a chair with their elbows flexed at a 90° angle and to hold the dynamometer in a neutral position of the lower arm and hand (i.e., 0° supination-pronation and slight extension of hand) (Bohannon, Peolsion, Massy-Westropp, Desrosiers, & Bear-Lehman, 2006). Three attempts were performed with each hand and the highest value for both left and right hands was used for analysis.

The Biodex system 3 (Biodex, USA) was used to measure isometric lower limb strength (in torque, Nm), generated by muscles around the hip joint, knee joint, and ankle joint in a fixed position. Extension of the hip was measured laying down in a prone position on a treatment bench with the knee joint at a 90° angle and the padded attachment placed just proximal of the femur epicondyles. Abduction of the hip was measured laying down on the side on a treatment bench with the uppermost lower limb in a neutral position (0° hip and knee) and the padded attachment placed just proximal of the epicondyles. Flexion and extension of the knee joint was measured in a seated position with the seatback tilted at 85°, with the knee joint at a 30° flexion and the padded attachment placed just proximal of the malleolus. Plantar flexion dorsi flexion of the ankle joint was measured in a seated position with the seatback tilted at 55°, with a limb-support pad placed under the distal femur, the tibia/fibula parallel to the floor, and the foot strapped to the attachment in a neutral position (0° ankle). Three attempts were performed with each muscle group, and the highest value of both left and right lower limbs was used for analysis. All measurements of muscle strength were performed with standardized encouragement from the test leader.

CoP was measured with a Kistler 9286BA force plate (Kistler, Switzerland) in quiet stance during four different trials of 30 s each: stable firm surface with eyes open (SEO), stable firm surface with eyes closed (SEC), unstable soft surface with eyes open (UOE), and unstable soft surface with eyes closed (UEC). The trial started when the participant stood quiet on the force plate and the following 30 s was used for data calculations. The unstable soft surface was a balance pad of 6 cm thickness (AIREX, Switzerland) placed on the force plate. The feet distance (the first metatarsal heads) was 75% of the distance between the anterior superior iliac spines. The rotational angle of the foot was chosen by the participants. They were instructed to stand up straight, look at a dot on the wall (8 m away, 1.75 m height from the floor), and stand as still as possible. For the trials with closed eyes, the instruction was to first look at the dot on the wall and then close their eyes when ready. Further, CoP was measured during the more dynamic limits of stability (LoS) test by instructing participants to lean as far as they could in the anteroposterior (AP) and mediolateral (ML) directions, with open eyes on the stable firm surface without moving their feet, nor lifting toes or heels.

Data of the participants’ age and anthropometric measurements, including height and weight, were collected on the same occasion as the strength and postural control measurements. Other descriptive data was previously collected during home visits (Pauelsen et al., 2018): number of prescription medications, self-rated and age-comparative health (better, the same or worse in comparison to other people of their age), and fall history during the last six months. Finally, assessments of lower extremity function with the Short Physical Performance Battery (SPPB)
3 Data calculations

The force plate generated 16 signals at 3000 Hz from which the CoP trajectories were derived. Thereafter a low-pass 4th order Butterworth low pass filter with a 10 Hz cut-off (using 1 bidirectional pass as smoother) was used with MATLAB R2017a (MathWorks, USA) to apply and extract several postural control variables. These classical variables describe the participant’s CoP excursions during the four quiet stance trials: maximum AP and ML amplitude (max AP, max ML), mean velocity (mvel), and a 95% confidence ellipse of the total CoP signal (Area). A principal component analysis of the data points was drawn consisting of 95% of all data points of the CoP trajectory. The outcomes (Y) in the same model, and in this case, both models have left.

2.4 Statistical analysis

SPSS for Windows 26.0 (SPSS Inc., USA) was used to calculate the descriptive statistics. The relationships between HGS and lower limb strength and postural control were analyzed with an orthogonal projection to latent structures (OPLS) regression model with SIMCA 14.0 (Umetrics AB, Umeå, Sweden). Two separate models were constructed to investigate the association between: 1) lower limb strength (X) and left and right HGS (Y), and 2) posturographic measures (X) and left and right HGS (Y). This method provides the ability to analyze two or more outcomes (Y) in the same model, and in this case, both models have left HGS and right HGS as two separate outcomes in one model (Eriksson et al., 2006). Further, the model can handle many collinear explanatory variables as well as relatively small sample sizes, i.e., more variables than observations, in contrast to multiple linear regression (Wold, 2001). The OPLS removes the non-correlated systematic variation in the independent variables, improving the interpretation of the model. The model produces the percent of variation of the X-variables that are associated with the Y-variables (R²Y) and an estimation of how well the model predicts new data (Q²). Hence, it is theoretically possible for an X-variable to have a high VIP but not be related to the Y-variable. Thus, the relationship between each of the X-variables to the Y-variables were also investigated by a coefficient plot, expressing how strongly Y is correlated to the systemic part of the X-variables. The plot also shows if the correlation is positive or negative. A VIP-score >1 and a 95% confidence interval (CI) ≥ 0.5 was considered significant. The coefficient is significant when CI ≠ 0. Besides observational and variable diagnostics, the validity of the OPLS-models was evaluated by internal cross-validation (analyzing and comparing R²Y and Q²) as well as permutation tests (comparing R²Y and Q² to randomly permuted R²Y and Q²) (Eriksson et al., 2006).

3 Results

Basic characteristics and muscle strength measurements of the study participants are presented in Table 1. One participant (n = 1) was not able to perform a test of right HGS, and one participant (n = 1) was not able to perform a test of right ankle dorsiflexion. A few participants (n = 6) were not able to perform 30 s of quiet stance during one or more of the
postural control measurements, as presented in Table 2.

### 3.1. HGS and lower limb strength

In a strong and valid OPLS-regression model (n = 45), the included variables (lower limb strength and age) explained 74.4% (R²) of the variance in left and right HGS and had a predictive ability of 71.9% (Q²). All lower limb muscles, except for both left and right ankle dorsiflexion, were significantly important to the model according to the VIP-plot (Fig. 1), whereas the participants’ age was not significant. The significant muscles from the VIP-plot, as well as the left and right ankle dorsiflexion, all had significant and positive coefficients, indicating a positive correlation between lower limb and HGS (Fig. 2). Furthermore, the permutation test for left and right HGS (Fig. 3) showed that all permuted Q²-values were lower than the original Q²-value, and the regression line of the Q²-values intersects the vertical axis below zero, strongly indicating validity of the model.

### 3.2. HGS and postural control

In a statistically significant, but very weak and not valid OPLS-regression model (n = 44), the postural control variables explain 20.7% (R²) of the variance in HGS, and a predictive ability of 13.2% (Q²). When inspecting the different CoP-variables in a VIP-plot (Fig. 4), the variables AP limits of stability, as well as mvel UEO and max ML UEO, were the only significant variables of the 18 postural control variables. The AP LoS variable had a significant and positive coefficient for both left and right HGS (Fig. 5), indicating that a higher HGS was related to a larger amplitude in the anteroposterior direction, i.e., better postural control. Five out of eight variables in which the participants had open eyes (Area SEO, max AP SEO, mvel SEO, max ML UEO, and mvel UEO) had significant and negative coefficients, indicating that a higher grip strength was related to lower measures in these CoP-variables, i.e., better postural control. None of the eyes closed trials had a significant association to HGS (Fig. 5). In the permutation test for left and right HGS (Fig. 6), some permuted Q²-values and R²-values were higher than the respective value of the original model, indicating that the model is not valid.

In a separate model, substituting left and right HGS as Y-variables with left and right knee extensor strength, the model increases its explanatory R² percentage from 20.7% to 28.8%, but the VIP-plot (Additional file 1), coefficient-plots (Additional file 2), and the permutation test (Additional file 3) followed the same pattern as for HGS.

### 4. Discussion

In this study of community-dwelling older adults, we found that a multivariate regression model clearly showed a strong association (74%) between hand grip strength and the strength of lower limb muscles. All muscle groups were significantly important for the model, except for the muscles responsible for dorsiflexion of the ankle. The association between hand grip strength and postural control was weak but still...
significant (21%). However, the regression model was not valid, thus limiting generalization of the results.

4.1. HGS and lower limb strength

The clear association between hand grip- and lower limb-strength, confirmed by the permutation test and high predictive ability ($Q^2$), is in line with previous studies showing a strong association between hand grip strength and lower limb strength (Alonso et al., 2018; Alqahtani et al., 2017; Bohannon, 2009, 2012). Our study supports the previous assumption by Bohannon (Bohannon, 2012) that hand grip strength and knee extensor strength seem to reflect a common construct: limb muscle strength. All tested muscle groups had coefficients that were statistically significantly correlated with hand grip strength, and all, except left and right ankle dorsiflexion, were important to the model. This is, in turn, in line with a study of 29 older adults living in residential care communities, among which all other tested muscle groups, besides hip flexion, were associated with hand grip strength (Alqahtani et al., 2017). Even though one of the tested muscle groups was not important for the model in our study, the results strengthen the notion that a measurement of hand grip strength could be used as a substitute for other, more complicated or time-consuming measures when estimating overall muscle strength, at least on group level among community-dwelling older adults. The implications of this study are, however, not applicable in situations where muscles or muscle groups in the lower limb should be investigated in rehabilitation purposes regarding specific injuries, or for medical conditions in which different physical functions are expected between upper and lower extremities.

Fig. 2. Model 1: Lower Limb Strength Coefficients Plot for Left (above) and Right (below) Hand Grip Strength. Note. Error bars show 95% confidence interval. Abbreviations: Hip ext, hip extension; Hip abd, hip abduction; Knee ext, knee extension; Knee flx, knee flexion; Ankle pla, ankle plantar flexion; Ankle dor, ankle dorsiflexion; L, left; R, right.
In contrast to the lower limb strength model, the postural control model was not valid; thus, generalizations should be made with caution. However, a previous study of 140 community-dwelling older adults with a mean age of 66 years (Singh et al., 2015) found a similar correlation between sway degrees in static postural control with eyes open and hand grip strength (\( r = 0.26 \)). Further, Alonso et al. (2018) found no association between HGS and CoP trajectories among 110 women with a mean age of 67 years. The association was measured with Pearson correlation analysis, and was therefore not adjusted for anthropometric measures. Wiśniowska-Szurlej et al. (2019) studied a more frail population and found weak associations between HGS and several CoP variables, but these were not significant after adjusting for age, BMI, and height. In our study, only three of the 18 different postural control variables were significantly important to the model, and six had coefficients that were significantly correlated with hand grip strength. All of the quiet stance CoP-variables significant for the model or for the association with hand grip strength were tests performed with eyes open. Thus, the association between hand grip strength and static postural control was observed only when the participants had the possibility to adjust their postural control via visual orientation. Orientation is one of the main goals of postural control (Horak, 2006) involving active control of body alignment in relation to gravity, support surfaces, internal references, and the visual environment. Removing the visual information introduced higher demands on the other sensory systems. This may have affected the participants’ motor actions and reactions when attempting to stand still, and sensorimotor functions other than strength were more important. Again, both the low \( Q^2 \)-value and the permutation test revealed that the postural control model was not valid, in contrast to the lower limb strength model. A low validity in the OPLS-model implies that the model is not sufficient in predicting the association in another data set, i.e., generalizing the results to the population (Wold et al., 2001), even though the association was significant in our sample. A higher number of
participants than our study sample (n = 45) might yield a more robust model.

To investigate the association between postural control to a muscle that is primarily involved in postural control, hand grip strength was exchanged with knee extensor strength in the regression model. The association increased slightly, from 20.7 to 28.8%, but the model was still weak and not valid. Interestingly, the pattern of which CoP-variables were significant was similar in both the hand grip- and knee extensor-strength models, strengthening the value of HGS as a representative measure of overall strength. In a meta-analysis (Muehlbauer, Gollhofer, & Granacher, 2015), significant but small correlations were found between muscle strength and static-, dynamic-, and functional aspects of balance in old adults (≥67 years), concluding that strength and balance are independent and task specific. Paillard (2017) suggests that an increase in strength can increase the postural control for those with very low or low muscle strength. When a threshold of sufficient strength is reached, a further increase in strength will not improve postural performance. As presented in Table 1, the participants had a relatively high score in the SPPB-test, indicating high physical function. It is possible that the results in this study would be different if the participants had a lower physical function. However, there was no clear association between HGS and CoP trajectories in the previously mentioned study of individuals in long-term care facilities (Wiśniowska-Szurlej et al., 2019). Direct comparisons to the current study should be made with caution due to the differences in the methods used. Future studies could focus on investigating the longitudinal association between hand grip strength and postural control among elderly populations.
lower limb strength; all tested muscle groups were significantly correlated with hand grip strength, and all but ankle dorsiflexion muscles had and valid model showing an association between hand grip strength and lower limb strength, and inclusion of detailed assessments of postural control, to investigate the temporal relationship between these components during aging.

4.3. Strengths and limitations

The strengths of this study include the analyses of the association between hand grip strength to all major muscle groups in the lower limbs, not just knee extensor strength (Bohannon, 2012). Another strength is that the association between HGS and lower limb strength is analyzed with an OPLS-regression model, which is equipped to handle more than one independent variable or outcome (Y-variables), multiple X-variables, as well as collinearity between the X variables. In the regression model for hand grip strength and postural control it is possible to present how much the postural control variables associate with hand grip strength as well as which variables are important for the model. This would not have been possible with a single correlation analysis or a traditional multiple linear regression model. However, due to the cross-sectional study design it is not possible to draw any conclusion on whether reduced hand grip strength occurs before, after, or simultaneously with a decrease in lower extremity muscle strength or a postural control decline. A longitudinal study is necessary to answer that question. Another limitation of this study is that postural control was measured in fairly static tasks with no movement of the feet. We therefore chose to measure lower extremity muscle strength using isometric tests. This is also in line with the HGS test, which is performed as an isometric test. Postural control is generally a dynamic motor skill, and if the postural control tests had been more dynamic we might have found different results. In a review of postural control and strength performance in healthy older adults (Muelbauer et al., 2015) the authors conclude there is an association between isometric and dynamic muscle strength; however, static and dynamic aspects of postural control might be unrelated. Together, this justifies future research to test both strength and postural control, and to include both static and dynamic balance tasks.

5. Conclusions

In this study of community-dwelling older adults there was a strong and valid model showing an association between hand grip strength and lower limb strength; all tested muscle groups were significantly correlated with hand grip strength, and all but ankle dorsiflexion muscles had significant importance for the regression model. There was a significant but very weak model showing association between hand grip strength and postural control, measured with CoP excursions. This second regression model was not valid; thus, generalization of results should be made with caution. These results indicate that strength measurements alone are not sufficient as a substitute for measuring postural control, and therefore specific balance tests are necessary. We suggest future evaluations of the longitudinal relationship of hand grip strength and lower limb strength, and inclusion of detailed assessments of postural control, to investigate the temporal relationship between these components during aging.

Authors’ statement

VS made substantial contributions to the conception and design of the work, the acquisition, analysis, and interpretation of data; and primarily drafted the work and substantively revised it. ALa made substantial contributions to the conception and design of the work and substantively revised it. MP made substantial contributions to the conception and design of the work, the acquisition, analysis, and interpretation of data; and drafted the work and substantively revised it. LN made substantial contributions to the conception and design of the work, the acquisition and interpretation of data; and substantively revised the work. IV made substantial contributions to the conception and design of the work, the acquisition and interpretation of data; and substantively revised the work. ALi made substantial contributions to the interpretation of data and substantively revised the work. TG made substantial contributions to the analysis and interpretation of data and substantively revised the work. UR made substantial contributions to the conception and design of the work, the acquisition, analysis, and interpretation of data; and drafted the work and substantively revised it. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The study was approved by the Regional Ethical Review Board in Umeå, Sweden. 2015/182-31. All participants gave written informed consent before data collection.

Consent for publication

All participants gave written informed consent for publication, however, no details relating to an individual person were published.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available, but are available from the corresponding author.
on reasonable request.

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Declaration of Competing Interest

The authors declares that they have no conflicts of interest.

Supplementary materials


References


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