Are jumping mechanography assessed muscle force and power, and traditional physical capability measures associated with falls in older adults?

Results from the Hertfordshire Cohort Study

Camille M. Parsons¹, Mark H. Edwards¹,², Cyrus Cooper¹,³,⁴, Elaine M. Dennison¹, Kate A. Ward¹,⁵

¹MRC Lifecourse Epidemiology Unit, University of Southampton, Southampton General Hospital, Southampton, UK; ²Portsmouth Hospitals NHS Trust, Portsmouth, UK; ³National Institute for Health Research Biomedical Research Centre, University of Southampton and University Hospital Southampton NHS Foundation Trust, UK; ⁴National Institute for Health Research Musculoskeletal Biomedical Research Unit, University of Oxford, UK; ⁵MRC Nutrition and Bone Health Research Group, Cambridge, UK

Introduction

Falls and the risk of falling increase with age, and in the UK it has been estimated that one in three people aged over 65 years suffers a fall each year¹. The result of falls may not only be an injury or fragility fracture, but also a loss of confidence and independent living, increased morbidity and disability². Given the rapid rise in the ageing population across the globe, there will be a substantial effect of increased falls on health and social care costs both on an individual and population level.

Falls are a complex condition, involving multiple body systems and a number of studies have assessed physical risk factors for falls³,⁴. These factors tend to be associated with reduced physical capability and include, but are not limited to, reduced muscle force and power⁵, flexibility, balance and reaction time. Assessing an individual’s functional capacity, using the short physical performance battery, or through isokinetic assessments are important parts of understanding a risk for falling⁶. Such tests include measures of walking speed, timed up-and-go, chair rise time, and standing...
balance. It is important to note that these do not provide quantitative measures of muscle force and power which are important individual components of muscle strength giving measures of the velocity-generating capacity of the muscle, an important determinant of falls\(^{5,9}\). For example, in findings from two previous studies associations between low muscle power, assessed by leg extensor power-rigs, and increased risk of falling were reported\(^{10,11}\).

Jumping mechanography is a reproducible measurement, with little learning effect and gives a real-time recording of lower-limb muscle force and velocity in the lower limb from a single two-leg jump\(^\text{12}\). In the first studies using jumping mechanography, muscle power and velocity were shown to have stronger associations with age than standard physical capability tests and the authors suggested this demonstrated jumping mechanography had greater sensitivity to age-related declines in neuromuscular function and potential for the method to be applied more widely\(^{12,13}\). Muscle power from jumping mechanography has been used as an outcome to assess sarcopenia status and is associated with activities of daily living\(^{8,14-16}\). One previous study has examined the cross-sectional association between muscle power and force and falls, assessed by jumping mechanography, and found these measures were associated with past fall history in women, but not men, aged 60-85 years old\(^6\). The method has been applied in several, large cohorts and studies including MrOs, Vertical Impacts in Bone (VIBE), European Men Ageing Study and the Gambian Bone Ageing study; showing utility and acceptability across ages, functional capabilities and populations\(^9,14-16\).

The aim of this pragmatic study was to determine how jumping mechanography and standard physical capability measures were related to fall history, assessed up to 3 years after the muscle and physical capability measures, in community dwelling older men and women who participated in the Hertfordshire Cohort Study (HCS) in the United Kingdom.

Materials and methods

Participants

The HCS has been previously described in detail\(^\text{17}\). In brief the HCS is a large, prospective, population-based study of the lifecourse origins of adult disease among community dwelling men and women. To be eligible for inclusion, study participants were born in Hertfordshire between 1931 and 1939 and still living in the county between 1998 and 2004. In 2010-2012, 570 study participants were invited to attend a follow-up assessment, and of those 376 agreed to participate, at which time demographic information such as height, weight and comorbidities (defined as high blood pressure, diabetes, lung disease, rheumatoid arthritis, multiple sclerosis, thyroid disease, vitiligo, depression, Parkinson’s disease, heart disease, peripheral arterial disease, stroke, osteoporosis and cancer) were obtained (ethical approval REC reference: 10/H0311/59). An assessment of physical capability was performed and each participant completed jumping mechanography (ethical approval REC reference: 11/EE/0196). A further 2 years later, participants took part in the VIBE study and as part of this were contacted again and asked to complete a postal questionnaire detailing fall history in the past year.

Jumping mechanography

Jumping tests were completed using a Leonardo Mechanography Ground Reaction Force Platform (Leonardo software version 4.2; Novotec Medical GmbH), to assess lower limb muscle force and power\(^\text{18}\). Study participants were asked to stand on the ground reaction force platform and perform a countermovement jump, i.e. to bend their knees, swing arms and jump once as high as possible; the test was repeated 3 times and the jump with the highest height was used to measure force and velocity and from these calculate power. Jump power and force were normalized to study participant’s body weight as per manufacturer guidance (W/kg, N/kg respectively).

Physical capability tests

The gait speed of individuals was quantified from the time taken to complete a 3-meter course, with no obstructions, participants were instructed to “Walk to the other end of the course at your usual speed”. Maximum grip strength of study participants was obtained using a Jamar (Loughborough, UK) hand-held isokinetic dynamometer using a standardised protocol\(^\text{19}\). Grip strength was measured three times in each hand and the maximum value was used in analysis. The time to complete a 6 meter timed up and go walking test (TUG) was also recorded, and participants were asked to complete this task at a pace which was comfortable to them. Chair rise time and balance tests were assessed using the validated protocol developed by Guralnik et al\(^\text{20}\). The total time, in seconds, to complete 5 sit-stand chair rises was recorded, with participants being asked to complete the 5 chair rises as quickly as possible. The balance of participants was assessed using a tandem stand test, the timer was stopped if a participant moved their feet or grasped the interviewer for support, or after 10 seconds had elapsed.

Statistical analysis

Characteristics of study participants were described using means and standard deviations (SD) for continuous, normally distributed variables, and median and inter-quartile ranges for skewed variables. Frequencies and percentages were used to summarise binary and categorical variables. Due to the relatively small number of study participants with 1 or more falls in the previous year, study participants were categorised as either ‘no falls’ or as a ‘faller’. Differences in characteristics between fallers and non-fallers was assessed using independent samples t-tests, Chi-squared or Fisher Exact tests as appropriate. Due to the skewed nature of chair rise times and 6m TUG, a natural log transformation was performed. Logistic
Table 1. Study population descriptive statistics.

|                      | All (n=258) | No Falls (n = 188) | Fallers (n = 70) | p-value |
|----------------------|-------------|--------------------|-----------------|---------|
|                      | Mean   | SD | Mean   | SD | Mean   | SD |       |
| Age (years)          | 75.5   | 2.6 | 75.3   | 2.5 | 75.6   | 2.6 | 0.06  |
| Height (m)           | 1.66   | 0.09 | 1.66   | 0.09 | 1.64   | 0.09 | 0.24  |
| Weight (kg)          | 76.9   | 13.2 | 77.1   | 13.0 | 76.5   | 13.9 | 0.76  |
| BMI (kg/m²)          | 27.9   | 4.3 | 27.8   | 4.2 | 28.2   | 4.6 | 0.60  |
| Women                | 129    | 50.0 | 88     | 46.8 | 41     | 58.6 | 0.09  |
| Number of falls in the last year |       |       |       |       |       |       |       |
| 0                    | 188    | 72.9 |        |       |        |       |       |
| 1                    | 38     | 14.7 |        |       |        |       |       |
| 2                    | 23     | 8.9  |        |       |        |       |       |
| 3                    | 5      | 1.9  |        |       |        |       |       |
| 4 or more            | 4      | 1.6  |        |       |        |       |       |
| Number of comorbidities |     |       |       |       |       |       |       |
| 0                    | 59     | 22.9 | 40     | 21.3 | 19     | 27.1 |       |
| 1                    | 89     | 34.5 | 68     | 36.2 | 21     | 30.0 |       |
| 2                    | 63     | 24.4 | 46     | 24.5 | 17     | 24.3 |       |
| 3                    | 25     | 9.7  | 20     | 10.6 | 5      | 7.1  |       |
| 4 or more            | 22     | 8.5  | 14     | 7.5  | 8      | 11.4 | 0.57  |
| Muscle function affecting comorbidity | 16  | 6.2  | 15     | 8.0  | 1      | 1.4  | 0.08  |

* classified as having a stroke, Parkinson's or multiple Sclerosis.

Table 2. Comparison of those study participants who were able to jump and those who were unable.

|                      | Able to jump (n = 169) | Unable to jump (n = 89) | p-value |
|----------------------|------------------------|-------------------------|---------|
|                      | Mean (SD)              | Mean (SD)               |         |
| Age (years)          | 75.12 (2.50)           | 76.21 (2.49)            | <0.01   |
| Height (cms)         | 167.05 (8.87)          | 163.96 (9.03)           | 0.01    |
| Weight (kg)          | 76.51 (11.70)          | 77.75 (15.66)           | 0.47    |
| Gait speed (m/s)     | 0.80 (0.15)            | 0.74 (0.17)             | <0.01   |
| Maximum grip (kg)    | 30.79 (9.89)           | 26.88 (9.23)            | <0.01   |
| 6m timed up and go (sec) | 10.9 (9.3-12.1)       | 12.2 (10.3-14.5)        | <0.01   |
| chair rise time (secs) | 15.8 (13.5-18.0)      | 17.3 (14.7-22.5)        | <0.01   |
|                      | n (%)                  | n (%)                   |         |
| Number of falls in the last year |        |                       |         |
| 0                    | 129 (76)               | 59 (66)                 |         |
| 1                    | 20 (12)                | 18 (20)                 |         |
| 2                    | 16 (10)                | 7 (8)                   |         |
| 3                    | 2 (1)                  | 3 (3)                   |         |
| 4 or more            | 2 (1)                  | 2 (2)                   | 0.19    |
| Number of comorbidities |     |                       |         |
| 0                    | 44 (26)                | 15 (17)                 |         |
| 1                    | 62 (37)                | 27 (30)                 |         |
| 2                    | 42 (25)                | 21 (24)                 |         |
| 3                    | 16 (10)                | 9 (10)                  |         |
| 4 or more            | 5 (3)                  | 17 (19)                 | <0.01   |
| Muscle function affecting comorbidity | 4 (2) | 12 (13)             | <0.01   |
regression analysis was used to explore associations between jumping mechanography measurements and physical capability assessment with falling status. Results are presented as odd ratios (OR) with associated 95% confidence intervals (95% CI). All models were adjusted for age at physical capability assessment or jumping mechanography testing, height and sex. Associations between the physical capability measures and odds of falling were repeated in those participants who were able to jump. The correlation between physical capability measures and jumping mechanography measurements was determined by calculating the Pearson’s correlation coefficient. Statistical significance was defined at the 5% level and all analyses were undertaken using Stata 14 (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP).21

Results

Characteristics of all 258 study participants are presented in Table 1; jumping mechanography measurements were available in 169 of those participants. The mean (SD) age of study participants was 75.5 (2.6) years, and 50% (n=129) were women. Two-three years after the initial physical capability and jumping tests, just over 27% of all study participants reported having fallen at least once in the previous year. Participants categorised as fallers were similar in height, weight and BMI to non-fallers (Table 1). Just under 43% of study participants reported having 2 or more comorbidities, and the proportions were almost identical in fallers and non-fallers, 42.6% and 42.8% respectively. Interestingly in comparison to 15 non-fallers, only 1 participant in the faller group reported having comorbidities that affect muscle function or co-ordination, defined here as

---

**Figure 1.** Risk of falling by physical capability measured using jumping mechanography and physical capability.
those who reported having a stroke, being diagnosed with Parkinson's disease or multiple Sclerosis.

The main reason for non-completion of jumping mechanography testing was due to joint replacement. No adverse events occurred. Table 2 shows a comparison between those able to jump versus unable. Jumpers were younger slightly younger and taller than those unable. They performed better at all physical capability tests and, as would be expected, proportionately fewer reported a fall in the previous year during the 2-3 year follow up (not significant). Interestingly the number of comorbidities was slightly higher in the jump group; though those with muscle function/co-ordination affecting co-morbidities were far fewer in the jump versus non jumpers.

The descriptive statistics for the jumping mechanography and physical capability measures by falling status are presented in Table 3. Fallers had lower maximum relative power, velocity and jump force compared to those who had not fallen in the previous year assessed 2-3 years follow up. Mean gait speed was similar amongst fallers and non-fallers. Whereas fallers had poor physical capability than non-faller, having on average lower mean maximum grip strength, slower median 6m TUG and slower median chair rise time.

Figure 1 shows the results of the unadjusted and adjusted logistic regression analysis assessing the association between the odds of falling in the previous year assessed after 2-3 years follow-up and physical capability and jumping mechanography measures. An increase in maximum velocity was associated with a decrease in the odds of falling (OR=0.20, 95% CI 0.05, 0.72). Similarly, a greater maximum total power normalised for body weight was associated with a decrease in the odds of falling (OR=0.91, 95% CI 0.85, 0.98). No associations were found between jump force normalised to body weight and fall status. All associations remained unchanged and were robust to adjustments for age at jumping mechanography test, height and sex.

For standard physical capability measures, a greater 6m TUG test was associated with increased odds of falling, (OR=3.57, 95% CI 1.22, 10.44). On average, a 1kg lower maximum grip strength was associated with a 3% reduction in the odds of falling (OR=0.97, 95% CI 0.94, 1.00). No association was found between gait speed and chair rise time with falls risk in this study populations. After adjustment for age at physical capability test, height and sex associations between maximum 6m TUG (OR=2.65, 95% CI 0.87, 8.05), and grip strength were attenuated.

After restricting these analyses to only those study participants able to perform jumping tests, the unadjusted association between 6m TUG and odds of falling was attenuated (OR=3.81, 95% CI 0.75, 19.5).

In those study participants with both jumping mechanography measurements and physical capability
measures, positive correlations were found between maximum relative power and velocity and gait speed (Table 4). A positive association was also found between maximum relative force, power and velocity and maximum grip strength. Whilst negative correlations were found between maximum relative power, velocity and 6m TUG; and maximum relative power and velocity were negatively correlated with chair rise time.

**Discussion**

This pragmatic study explored if measures of jump force, velocity and power, and standard physical capability tests, were associated with falls 2-3 years later in a community dwelling older population. As muscle power and velocity increased, a significant reduction in the odds of falling was observed. In contrast, no significant associations were found between jump force and falls. These associations were robust to adjustment.

Fellers had significantly poorer physical capability as measured using 6m TUG, and, poorer grip strength was associated with 3% reduction in risk of falling. This is likely a reflection of the fact that those with poorer grip are potentially less active and so less likely to fall, as reflected by positive correlations between maximum grip strength and maximum relative force, power and velocity. All physical capability relationships were attenuated after adjustment, though there remained a trend for TUG to be longer in those who fell (OR=2.65, 95% CI 0.87, 8.05). When the sample was restricted to only those able to perform the jump-test, no associations were found between physical capability tests and falling; indicating that jumping may be more sensitive to functional deficits in fitter individuals. These observations are consistent with previous reports, as reported previously13,14. The findings of this study are consistent with a previous study less active individuals tend to fall less 24. The lack of associations with traditional physical capability testing is in line with other studies. For example, a previous study reported jump muscle power and force had better sensitivity and specificity than grip strength in identifying sarcopenia in both women and men15. Similarly, another study showed that in sarcopenic vs. non-sarcopenic men, differences were much greater in parameters of muscle power, than in a measure of activities of daily living6. Data from the Vertical Impacts in Bone in the Elderly (VIBE) study of community dwelling women aged 71-87 years, peak power and force explained a significant, but limited proportion of variance in the short physical performance battery (SPPB) score; only peak power was related to grip, the authors concluding that jumping tests showed greater sensitivity to muscle deficits that standard physical performance measures14. These observations were further confirmed by the findings from the PRUE study in which authors found no strong association between grip strength and the risk of injury from falls, concluding that assessing upper limb strength, using the traditional grip strength measurement, might not be a suitable surrogate for lower limb strength23.

The main limitation of this study is that the nature of the jumping mechanography testing means only those older study participants who retain a certain level of lower limb mobility are able to complete the assessment. However, when the data were restricted to a sample of people who could jump, the physical performance measures did not distinguish between fallers versus non-fallers. To fully assess associations between jumping mechanography and falls risk, it will be important to study this prospectively, for longer, in a younger, less-frail cohort and see whether such measures are also associated with falls risk in younger, fitter individuals. Another limitation is the low number of participants who completed the follow-up questionnaire to assess fall history which reduced our sample to 169 participants. This may in part be due to healthy survivor bias which is unavoidable in a cohort aged over 77 years at follow-up. There was also around 6 month time gap between physical capability and jumping mechanography testing, and so further studies obtaining these measurements are the same time point would be warranted to ensure the generalisability of these findings.
However given the consistency of the findings in this study with previous research it is unlikely this small time difference had an effect on the overall results.

In conclusion, in this relatively healthy cohort of older community dwelling adults jumping mechanography appears to be a more sensitive measure of muscle deficits and falls risk than standard physical capability measures. Therefore the results of this pragmatic pilot study could be used to help develop thresholds for identifying those at risk of falls in future studies containing large numbers of physically able participants.

Acknowledgements

We are extremely grateful to the Hertfordshire Study Cohort participants who took part in each stage of this research. Also to Versus Arthritis and the Medical Research Council of Great Britain who funded the study. KW’s research is part-supported by MRC Programme Number U105960371.

Authors’ contribution

CP and KW were responsible for the design of the study, and CP was responsible for the statistical analysis. ME aided with data collection, and all authors were responsible for the interpretation of the data and drafting of the manuscript.

References

1. age UK. News Health 2010 [cited 2017 22nd November 2017]. Available from: https://www.ageuk.org.uk/latest-press/archive/falls-over-65s-cost-nhs/
2. Tinetti ME, Williams CS. The effect of falls and fall injuries on functioning in community-dwelling older persons. J Gerontol A Biol Sci Med Sci 1998;53(2):M112-9.
3. Veronese N, Bolzetta F, Toffanello ED, Zambon S, De Rui M, Perissinotto E, et al. Association between Short Physical Performance Battery and falls in older people: the Progetto Veneto Anziani Study. Rejuvenation research 2014;17(3):276-84.
4. Ward RE, Leveille SG, Beauchamp MK, Travison T, Alexander N, Jette AM, et al. Functional Performance As a Predictor of Injurious Falls Among Older Adults. J Am Geriatr Soc 2015;63(2):315-20.
5. John EB, Liu W, Gregory RW. Biomechanics of muscular effort: age-related changes. Med Sci Sports Exerc 2009;41(2):418-25.
6. Lauretani F, Ticinesi A, Gionti L, Prati B, Nouvenne A, Tana C, et al. Short-Physical Performance Battery (SPPB) score is associated with falls in older outpatients. Aging Clin Exp Res 2018.
7. Anliker E, Toigo M. Functional assessment of the muscle-bone unit in the lower leg. J Musculoskeletal Neuronal Interact 2012;12(2):46-55.
8. Dietzel R, Felsenberg D, Armbrecht G. Mechanography performance tests and their association with sarcopenia, falls and impairment in the activities of daily living - a pilot cross-sectional study in 293 older adults. J Musculoskeletal Neuronal Interact 2015;15(3):249-56.
9. Zengin A, Pye SR, Cook MJ, Adams JE, Rawer R, Wu FCW, et al. Associations of muscle force, power, cross-sectional muscle area and bone geometry in older UK men. Journal of cachexia, sarcopenia and muscle 2017;8(4):598-606.
10. Skelton DA, Kennedy J, Rutherford OM. Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. Age Ageing 2002;31(2):119-25.
11. Bassey EJ, Fiatarone MA, O’Neill EF, Kelly M, Evans WJ, Lipsitz LA. Leg extensor power and functional performance in very old men and women. Clin Sci (Lond) 1992;82(3):321-7.
12. Rittweger J, Schiessl H, Felsenberg D. Oxygen uptake during whole-body vibration exercise: comparison with squatting as a slow voluntary movement. Eur J Appl Physiol 2001;86(2):169-73.
13. Runge M, Rittweger J, Russo CR, Schiessl H, Felsenberg D. Is muscle power output a key factor in the age-related decline in physical performance? A comparison of muscle cross section, chair-rising test and jumping power. Clin Physiol Funct Imaging 2004;24(6):335-40.
14. Hannam K, Hartley A, Clark E, Sayer AA, Tobias J, Gregson C. Feasibility and acceptability of using jumping mechanography to detect early components of sarcopenia in community-dwelling older women. J Musculoskeletal Neuronal Interact 2017;17(3):246-57.
15. Zengin A, Jarjou LM, Prentice A, Cooper C, Ebeling PR, Ward KA. The prevalence of sarcopenia and relationships between muscle and bone in ageing West-African Gambian men and women. Journal of cachexia, sarcopenia and muscle 2018;9(5):920-8.
16. Strotmeyer ES, Winger ME, Cauley JA, Boudreau RM, Cusick D, Collins RF, et al. Normative Values of Muscle Power using Force Plate Jump Tests in Men Aged 77-101 Years: The Osteoporotic Fractures in Men (MrOS) Study. J Nutr Health Aging 2018;22(10):1167-75.
17. Syddall HE, Aihie Sayer A, Dennison EM, Martin HJ, Barker DJ, Cooper C. Cohort profile: the Hertfordshire cohort study. Int J Epidemiol 2005;34.
18. Hardcastle SA, Gregson CL, Rittweger J, Crabtree N, Ward K, Tobias JH. Jump power and force have distinct associations with cortical bone parameters: findings from a population enriched by individuals with high bone mass. The Journal of clinical endocrinology and metabolism 2014;99(1):266-75.
19. Roberts HC, Denison HJ, Martin HJ, Patel HP, Syddall H, Cooper C, et al. A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. Age Ageing 2011;40(4):423-9.
20. Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol 1994;49(2):M85-94.
21. 2015 S. Stata Statistical Software. Texas2015.
22. Elhakeem A, Hartley A, Luo Y, Goertzen AL, Hannam
K. Clark EM, et al. Lean mass and lower limb muscle function in relation to hip strength, geometry and fracture risk indices in community-dwelling older women. Osteoporos Int 2019;30(1):211-20.

23. Leong DP, Teo KK, Rangarajan S, Lopez-Jaramillo P, Avezum A Jr, Orlandini A, et al. Prognostic value of grip strength: findings from the Prospective Urban Rural Epidemiology (PURE) study. Lancet 2015;386(9990):266-73.

24. Skelton DA, Becker C, Lamb SE, Close JCT, Zijlstra W, Yardley L, et al. Prevention of Falls Network Europe: a thematic network aimed at introducing good practice in effective falls prevention across Europe. Eur J Ageing 2004;1(1):89-94.