Original Article

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

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Abstract

Objectives: To explore associations between measures of lower limb muscle force, velocity and power from jumping mechanography (JM) and simple physical capability (PC) testing, and falls in community dwelling older adults. **Methods**: Participants performed a two-leg countermovement jump on a ground reaction force platform. Jump force, power and velocity were calculated. PC tests were 6m timed-up-and-go (TUG)(sec), grip strength (kg), gait speed (m/s) and chair rise time (secs). Two-three years after JM and PC testing, self-reported falls in the previous year were recorded, and logistic regression analysis used to determine whether JM and PC measures were associated with falls. **Results**: Fall and PC data were available for 258 (169 JM) participants. Mean (SD) age at baseline was 75(2.5) years, 50% (n=129) were women and 27% (n=70) had fallen. As power and velocity increased, the odds of being a faller decreased [(odds ratio (OR)=0.91, 95% confidence interval (CI) 0.85,0.98] and (OR=0.20, 95% CI 0.05 0.72) respectively). Whilst grip strength and TUG were associated with falling; relationships were attenuated after adjustment. **Conclusions**: Jumping mechanography-measured muscle power and velocity were associated with lower risk of falls. In this relatively healthy cohort of older adults JM appears to be more sensitive measure of muscle deficits and falls risk than standard PC measures.

Keywords: Ageing, Epidemiology, Falls, Jump, Muscle, Physical Capability

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 year[1]. 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 disability[2]. 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 falls[3,4]. These factors tend to be associated with reduced physical capability and include, but are not limited to, reduced muscle force and power[5], 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 falling[3,6]. 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[7-9]. 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[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[8]. 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[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[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[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[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
	n	**%**	**n**	**%**	**n**	**%**	
Women	129	50.0	88	46.8	41	58.6	0.09
Number of falls in 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[a]	16	6.2	15	8.0	1	1.4	0.08
[a] 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) Mean (SD)	Unable to jump (n = 89) Mean (SD)	p-value
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
	Median (Inter-quartile range)	**Median (Inter-quartile range)**	
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
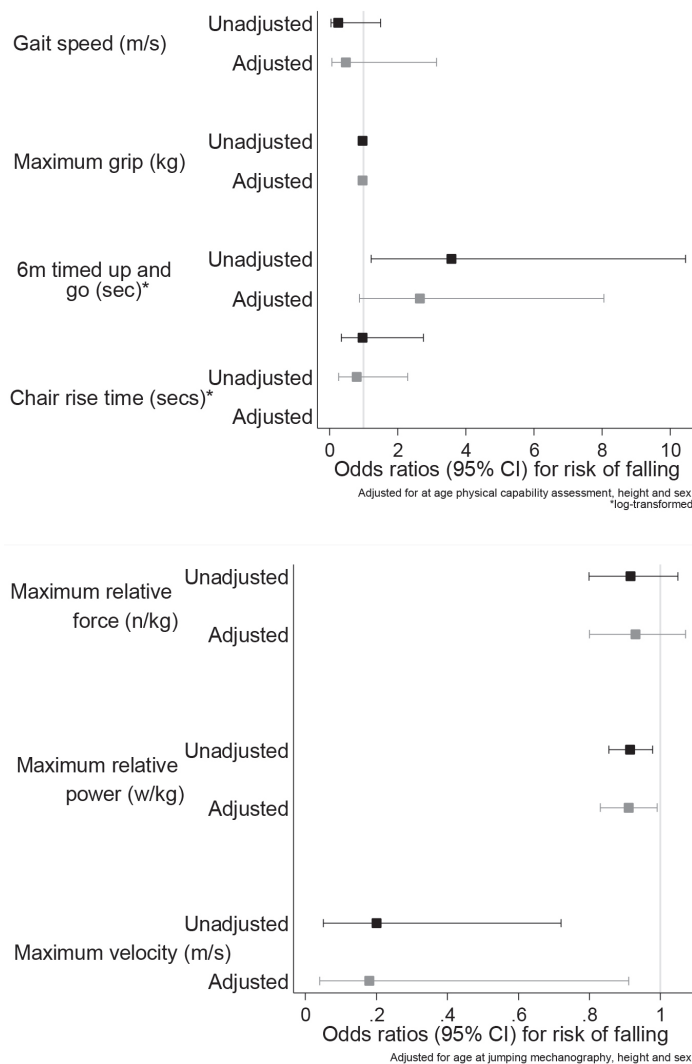
Figure 1. Risk of falling by physical capability measured using jumping mechanography and physical capability.

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

Table 3. Jumping mechanography and physical capability descriptives by falling status.

		No falls			Faller	
Jumping mechanography	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Maximum relative force (N/kg)	129	20.4	2.8	40	19.8	2.5
Maximum relative power (W/kg)	129	24.0	5.8	40	21.4	4.3
Maximum velocity (m/s)	129	1.6	0.3	40	1.4	0.2
Physical capability	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Gait speed (m/s)	180	0.8	0.2	68	0.8	0.2
Maximum grip (kg)	187	30.3	9.9	70	27.1	9.4
	N	**Median**	**Inter-quartile range**	**N**	**Median**	**Inter-quartile range**
6m timed up and go (secs)	180	11.1	9.5-12.4	68	11.9	9.9-14.2
Chair rise time (secs)	179	15.9	13.7-19.0	61	17.0	14.0-18.9

Table 4. Correlations between physical capability measure and jumping mechanography testing.

		Physical capability measures			
		Gait speed (m/s)	**Maximum grip (kg)**	**6m TUG (secs)***	**Chair rise time (secs)***
Jumping mechanography measurements	**Maximum relative force (N/kg)**	0.04 (0.62)	**0.35 (<0.01)**	-0.09 (0.26)	-0.13 (0.09)
	Maximum relative power (W/kg)	**0.40 (<0.01)**	**0.57 (<0.01)**	**-0.44 (<0.01)**	**-0.39 (<0.01)**
	Maximum velocity (m/s)	**0.46 (<0.01)**	**0.57 (<0.01)**	**-0.50 (<0.01)**	**-0.43 (<0.01)**
*Log-transformed					

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, 0.98No 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.

Fallers 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 previously[13,14].

The findings of this study are consistent with a previous studies. In the cross-sectional study by Dietzel community-dwelling older adults, women who reported falling in the previous year were found to have significantly lower average maximum two-leg jump velocity power and Esslinger Fitness Index compared to those participants who have not reported a fall. In the same study associations between mechanography measures and sarcopenia and impairment in the activities of daily living were reported[8]. In addition, in the recent Cohort of Skeletal Health in Bristol and Avon (COSHIBA) study lower limb peak muscle force, assessed using jumping mechanography was found to be associated with fracture risk in postmenopausal women[22]. Together with the current work, these studies indicate the utility of jumping to predict falls and fractures in older adults.

In this cohort of older, community-dwelling men and women we have shown the feasibility of applying jumping mechanography as a test to assess the odds of falling. The advantages of the method are that a number of different distinct components of muscle strength can be obtained from the simple quick countermovement jump test, whereas physical performance tests either physical

capability (chair-rise, timed up-and-go, gait speed) or proprioception through tandem balance[9,18,20]. In this study, gait speed and chair rise were not significantly related to falls risk whereas 6m TUG was found to be significantly associated with greater falls risk. The surprising association between poorer grip strength and a lower risk of falling we suggest, is likely a reflection of poor physical fitness and not being as active, as noted by Skelton in the ProFANE study less active individuals tend to fall less[24]. The lack of sensitivity of the standard physical capability measures on determining a person's likelihood to fall, perhaps reflects the healthy nature of the cohort; by its nature this older adult cohort is formed of the fittest individuals who were able to attend a clinic in their mid-late eighth decade. However this 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 men[15]. 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 living[8]. 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 measures[14]. 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 strength[23].

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.

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.

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