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Strength, Power and Related Functional Ability of Healthy People Aged 65–89 Years

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Summary

This cross-sectional study was designed to examine the effects of healthy ageing on muscle strength, power, and potentially related functional ability. Subjects were recruited through local and national newspapers and inclusion was based on strict health criteria, by questionnaire. Isometric knee extensor, isometric elbow flexor and handgrip strength, leg extensor power, timed rise from a low chair, lifting a weighted bag on to a surface, and stepping unaided on to boxes of different heights were measured in 50 men and 50 women, evenly distributed over the age range 65–89 years. The differences in isometric strength and leg extensor power over the age range were equivalent to 'losses' of 1–2% per annum and $\sim 3\frac{1}{2}\%$ per annum, respectively. The decline of explosive power was faster than the decline of knee extensor strength in men ($p = 0.0001$), but not significantly so in women ($p = 0.08$). Power standardized for body weight influenced chair rise time and step height. Isometric knee extensor strength standardized for body weight influenced chair rise time.

Introduction

Maximal muscle strength (the force of contraction) decreases with increasing age (reviewed by Young [1]). The loss of maximal explosive power (the product of force and velocity of contraction) may be even greater [2–5]. The increased prevalence of chronic disease in an ageing population [6] makes it difficult to know to what extent the loss of strength and power is an inevitable accompaniment of healthy ageing.

The relationship between laboratory measures of physical performance and functional ability is poorly understood. In the presence of pathology, reasonably strong associations have been demonstrated between functional ability and both strength [7] and power [8]. In healthier 80-year-old subjects, however, ability to climb up and down different step heights bore only a tenuous relationship to measurements of quadriceps strength [9]. It is important to be able to identify and measure factors limiting functional ability in old age and, if possible, to identify people most at risk of losing these abilities [1, 10]. There has been no study that has examined strength, power and functional ability in the same people.

The aims of this study were (a) to compare the strength, power and functional ability of healthy people aged 65–89, and (b) to examine the inter-relationships. Some of the results have been reported in abstract form [11, 12].

Subjects and Methods

Volunteers were recruited through articles in local and national newspapers. Potential subjects were sent a comprehensive health questionnaire to complete, and were excluded if there was any history of diagnosed or symptomatic disease likely to influence strength, power or habitual physical activity. Details of the exclusion criteria have been published [13]. One hundred independent, healthy volunteers were identified, 10 men and 10 women in each half-decade from age 65 to 89 years. Age was taken as completed years. Height (wall-mounted stadiometer) and weight (heavy clothing and shoes removed) were measured. All tests were performed on the same day and in a set order, allowing rests to avoid fatigue. The study was approved by the Hampstead Health Authority Ethical Practices Sub-committee and all subjects gave written informed consent.

Measurements: Lifestyle questionnaires were completed by discussion with the assessor. One questionnaire graded habitual physical activity on Grimby's 6-point scale [14] for each decade of adult life. The Tokyo Metropolitan Institute of Gerontology Index of social competence comprised yes/no answers to 13 questions about participation in everyday social activities [15].

Voluntary isometric knee extension strength (IKES) was measured as the force applied at the ankle, with the subject seated in an adjustable straight-back chair, the lower leg unsupported and the knee flexed to 90° [16, 17]. Isometric elbow flexor strength (IEFS) was measured as the force applied at the wrist, with the subject seated and the shoulder and elbow flexed at 90° (modified from [17]). The amplified output from the strain gauge was recorded by a rapid response oscillograph. A maximal effort was maintained until the assessor was satisfied that the force produced was no longer increasing (usually 2–4 s). Each maximal voluntary contraction was measured as the greatest force exceeded for at least one second. The best of at least three attempts, with 30 s rests between attempts, for each arm and leg were recorded. The subjects were verbally encouraged.

Handgrip strength (HGS) was measured with a Takei Kiki Kogyo Handgrip mechanical dynamometer. The size of the grip was set so that the subject felt comfortable whilst squeezing the grip. Subjects stood upright, with the wrist in the neutral position and the arm straight and close to the body and were verbally encouraged. The gauge was reset after each attempt and the best of at least three attempts for each hand recorded.

Leg extensor power (LEP) was measured with a slightly modified version [18] of the Nottingham Power Rig [19]. The seated subject pressed the footplate as hard and fast as possible. Seat position was adjusted so that the knee angle at the start of the push was 90°. The measurement was repeated for at least five efforts, until no further improvements were seen. Verbal encouragement and visual feedback were given. The best recorded power output for each leg was recorded.

Three functional ability tests were chosen for a probable relationship with strength or power. All tests were demonstrated by the assessor before being performed by the volunteer.

Chair rise: The subjects were asked to rise with their arms folded, at a comfortable speed, from a stool with a level seat 0.42 m from the floor [British Standards Institute (BSI) recommended height for a toilet pedestal plus 2 cm added for a toilet seat]. The test was performed three times and the fastest rise (timed with a 30-s stop watch) recorded.

Lifting a bag on to a surface: Subjects were asked to lift a shopping bag (46 cm handle to base) containing progressively 2, 4, and 6 kg laboratory weights, on to a 0.72 m surface (BSI recommended height for a fixed table top). The weights were chosen because 4 kg is roughly equivalent to a day's basic necessity shopping. The test was performed once at each weight, using the preferred arm.

Box stepping: The subjects were asked to step up on to five boxes (progressively 10, 20, 30, 40, and 50 cm [20]), without the use of handrails. The subject could step up with either leg. The test was performed once at each height, and the highest step was recorded.

Statistical analysis: Unless otherwise stated, results are expressed as means and standard deviations, and refer to each subject's greater strength or power value. Strength, power and anthropometry variables were normally distributed, the lifestyle and functional ability data were not. Comparisons between groups were made by parametric or non-parametric confidence interval analysis (CIA) [21] as appropriate [22]. Correlations between variables were assessed by calculating Pearson's product moment r or Spearman's ρ [23]. The slopes of the regression lines were expressed as the absolute slopes and, in order to facilitate comparisons between variables, as the relative slopes [percentage of the interpolated value at the mid-point of the age range (age 77) 'lost' per annum ($\%_{77}$ p.a.)]

Results

Men were significantly heavier and taller than women (Table I). Weight and height correlated with age in men ($r = -0.39$ and -0.38) and in women ($r = -0.47$ and -0.47). All subjects reported participation in everyday social activities [15] (men: median 13, range 10–13; women: median 13, range 6–13). Men were more active than women ($p < 0.05$), with the men reporting activity scores of median 4 (range 2–6) and women median 3 (range 1–5) on the 6-point scale [14]. Activity score was not correlated with age in men ($\rho = -0.01$) or women ($\rho = -0.29$). In men, there was no correlation between IKES or LEP and activity score, but in women there was a weak correlation between LEP and activity score ($\rho = 0.36$).

There was considerable variance in strength at similar ages (Figure 1). Men were significantly stronger than women in all three muscular strength tests ($p < 0.01$) (Table II). For IKES and IKES standardized for body weight (IKES/kg) women had on average 68% and 84% of the men's strength. For IEFS women managed 61% of men's strength, and for HGS 60%. The male/female difference was greater for IEFS than for IKES ($p < 0.01$). IKES, IKES/kg, HGS and IEFS correlated significantly with age (Table III). There was no sex difference

Table I. Physical characteristics of subjects

Age (years)	Weight (kg)	Height (m)
Men		
65–69	76.9 (7.9)	1.74(0.07)
70–74	75.4 (8.7)	1.74(0.06)
75–79	66.3 (9.6)	1.69(0.08)
80–84	72.4 (6.7)	1.72(0.06)
85–89	64.6(11.6)	1.63(0.09)
Women		
65–69	60.9 (9.1)	1.59(0.07)
70–74	63.2 (5.8)	1.59(0.04)
75–79	55.5 (8.3)	1.56(0.06)
80–84	51.4 (5.1)	1.53(0.04)
85–89	53.5 (6.9)	1.52(0.06)

Values expressed as means (SD). n = 10 per group

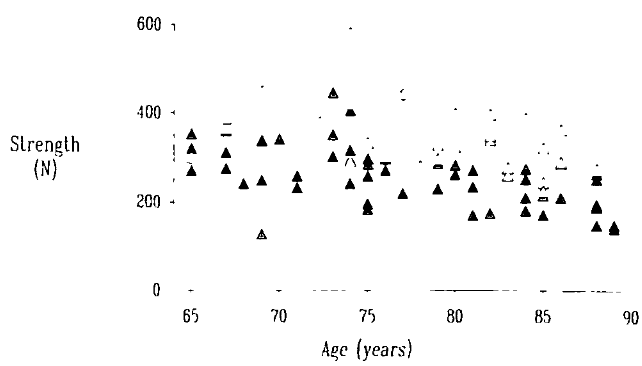

Figure. 1. Isometric knee extensor strength (stronger quadriceps), in healthy men (open triangles) and women (filled triangles).

Table II. Reference values [mean (SD)] for strength and power in healthy elderly people

Age (years)	Better leg LEP (watts)	LEP/kg (watt/kg)	IKES (Newtons)	IKES/kg (Newton/kg)	Better hand HGS (Newtons)	Better arm IEFS (Newtons)
Men						
65–69	213(51)	2.8(0.5)	432(87)	5.7(1.1)	458(78)	234(28)
70–74	191(43)	2.5(0.4)	414(80)	5.4(0.9)	394(49)	216(23)
75–79	148(37)	2.3(0.6)	363(62)	5.6(1.1)	364(49)	205(42)
80–84	130(30)	1.8(0.4)	338(61)	4.7(0.8)	379(49)	231(55)*
85–89	80(49)	1.5(0.4)	305(63)	4.8(0.7)	304(50)	171(40)
Women						
65–69	119(38)	2.0(0.6)	290(71)	4.8(1.1)	255(29)	148(17)
70–74	103(36)	1.6(0.5)	305(68)	4.8(1.0)	265(49)	137(26)
75–79	80(27)	1.5(0.6)	247(38)	4.5(1.0)	216(59)	128(36)
80–84	70(29)	1.4(0.6)	226(46)	4.4(1.0)	226(39)	131(25)†
85–89	64(26)	1.2(0.4)	194(43)	3.6(0.7)	186(42)	102(21)

For each age group n = 10 for men and n = 10 for women, except *n = 9 and † n = 7.
LEP leg extension power; IKES isometric knee extension strength; HGS handgrip strength; IEFS isometric elbow flexor strength.

in the slopes of the regression lines for any of the strength variables.

Men were significantly more powerful than women ($p < 0.01$) (Table II and Figure 2), despite considerable variability in power output at similar ages. Women, aged 65–84 years, typically had 55% of the LEP of men, 69% of the LEP/kg, but aged 85–89 years the difference was less marked (women having ~ 80% of LEP and LEP/kg of men). LEP and LEP/kg correlated with age (Table III). In men and women the rates of loss of LEP were 5.9 watts (W) p.a. (3.7%$_{77}$ p.a.) and 2.8 W p.a. (3.2%$_{77}$ p.a.), respectively, and of LEP/kg were 0.07 W/kg p.a. (3.0%$_{77}$ p.a.) and 0.03 W/kg p.a. (1.7%$_{77}$ p.a.), respectively. Men lose LEP (W) faster than women ($p = 0.002$).

The loss of LEP with age is greater than the rate of loss of IKES with age in men ($p = 0.0001$), but not significantly so in women ($p = 0.08$). There were significant correlations among strength variables and between strength and power, in both men and women. The strongest correlations were seen between IKES and LEP ($r = 0.72$ for men and 0.71 for women). HGS correlated more strongly with LEP ($r = 0.71$ in men and 0.61 in women) than with IKES ($r = 0.57$ for men and 0.50 women).

All men and 49 women were able to rise from a low stool, with their arms folded, in less than 2 s. One women (aged 88) took 3.5 s to rise. LEP/kg (sum of both legs) correlated strongly with the reciprocal of chair rise time ($\rho = 0.38$ for men and 0.56 for women).

Table III. Relationship with age

	Men r	Slope Absolute change p.a.	%$_{77}$ p.a.*	95% CI	Women r	Slope Absolute change p.a.	%$_{77}$ p.a.*	95% CI
IKES (N)	−0.53	−6.62	−1.8	−2.6 to −0.9	−0.56	−5.25	−2.0	−2.9 to −1.2
IKES/kg (N/kg)	−0.36	−0.05	−0.9	−1.7 to −0.2	−0.38	−0.05	−1.1	−2.0 to −0.3
LEP (W)	−0.73	−5.87	−3.7	−4.8 to −2.7	−0.55	−2.75	−3.2	−4.5 to −1.8
LEP/kg (W/kg)	−0.71	−0.07	−3.0	−3.8 to −2.1	−0.46	−0.03	−1.7	−3.5 to −0.9
HGS (N)	−0.61	−6.47	−1.7	−2.3 to −1.1	−0.52	−3.53	−1.5	−2.4 to −0.8
IEFS (N)†	−0.36	−2.29	−1.0	−1.9 to −0.2	−0.47	−2.52	−2.0	−3.1 to −0.9

$p < 0.05$ for $r < 0.30$. *%$_{77}$ p.a. = % change per annum calculated from the slope of the regression line and the interpolated value at age 77. 95% CI = 95% confidence interval for the standardized slope. n = 50 for men and for women, except † IEFS where n = 47 for women and n = 49 for men.
LEP leg extension power; IKES isometric knee extension strength; HGS handgrip strength; IEFS isometric elbow flexor strength.

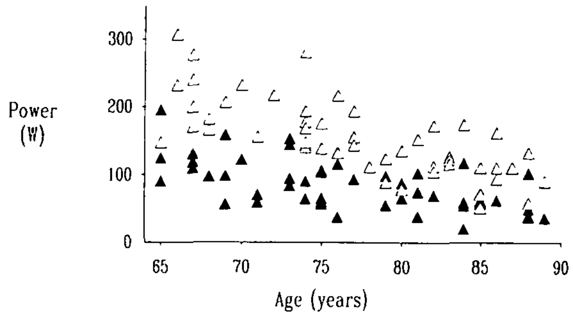

Figure 2. Leg extensor power (more powerful leg), in healthy men (open triangles) and women (filled triangles).

In the men, IKES/kg (sum of both legs) and IKES/kg (better leg) correlated with the reciprocal of chair rise time ($\rho = 0.5$ and 0.46, respectively), but in women only IKES/kg (better leg) correlated significantly ($\rho = 0.35$). All the men were able to lift the 6 kg bag on to the 0.72 m shelf. All but three women (aged 75, 84, 88) were able to lift the 6 kg bag; all three lifted the 4 kg bag successfully.

Women show a greater age effect in ability to step than men (Table IV). In men and women step height correlated with age ($\rho = -0.58$ and -0.67, respectively) and with LEP/kg ($\rho = 0.58$ and 0.47, respectively). In both men and women, age has an independent effect separate from the age-associated loss of LEP/kg (see variance of step height section). There was a wide variation in stepping ability when LEP/kg was considered, some subjects with low values of LEP/kg were able to step 50 cm and some subjects with high values of LEP/kg stepped smaller steps, so that it was not possible to identify a lower limit of LEP/kg at which stepping a certain height became impossible. A plot of step height against body height showed no suggestion of the taller subjects managing better step heights. Habitual physical activity did not influence step height.

Variance of IKES and LEP: Stepwise multiple regression analysis showed that weight and age have independent effects and accounted for good percentages of the variance in IKES and LEP. For IKES, weight accounted for 35% of the variance in women and 34% in men. Inclusion of age increased R^2 to 0.45 for both women and men. For LEP, weight accounted for 40% of the variance in women, and 35% in men. Inclusion of age increased this statistic to 48% for women and 64% for men. The inclusion of present activity level raised the R^2 statistic further, though not significantly. The following equations could be used to predict IKES and LEP output in healthy men and women:

Women:

$$\text{IKES (N)} = 323 - 3.4 \text{ age (years)} + 3.4 \text{ weight (kg)}$$

where $R^2 = 0.45$, and p values for inclusion of age and weight are 0.005, and 0.001, respectively.

$$\text{LEP(W)} = 87.4 - 1.6 \text{ age (years)} + 2.1 \text{ weight (kg)}$$

where $R^2 = 0.50$, and p values for inclusion of age and weight are 0.01, and 0.0002, respectively.

Men:

$$\text{IKES (N)} = 445 - 4.5 \text{ age (years)} + 3.9 \text{ weight (kg)}$$

where $R^2 = 0.45$, and p values for inclusion of age and weight are 0.004, and 0.0004, respectively.

$$\text{LEP (W)} = 377 - 4.8 \text{ age (years)} + 2.0 \text{ weight (kg)}$$

where $R^2 = 0.64$, and p values for inclusion of age and weight are 0.0001, and 0.0004, respectively.

Variance of step height: Age and LEP/kg showed strong correlations with step height. Their separate effects on step height were determined by stepwise linear multiple regression. In women, age accounted for 41% of the variance in step height ($p = 0.0001$), and the addition of LEP/kg accounted for only another 6%. On the other hand, LEP/kg accounted for 26% ($p = 0.03$) and the addition of age accounted for another 21%. The addition of body height to the equations, because of the effect that lower limb length might have had on stepping, did not increase the amount of variance explained ($p = 0.5$). In men, age accounted for 33% of the variance in step height ($p = 0.04$), the same as the amount of variance accounted for by LEP/kg ($p = 0.04$). When both were included in the equation

Table IV. Number of healthy men : women successfully climbing steps of various heights

	Age (years)				
cm	65–69 M : F	70–74 M : F	75–79 M : F	80–84 M : F	85–89 M : F
10	10 : 10	10 : 10	10 : 10	10 : 10	10 : 10
20	10 : 10	10 : 10	10 : 10	10 : 10	10 : 9
30	10 : 10	10 : 10	10 : 10	10 : 9	10 : 7
40	10 : 10	10 : 9	10 : 9	10 : 8	5 : 5
50	10 : 7	10 : 7	8 : 4	8 : 0	2 : 0

n = 10 for men and for women in each age group.

the amount of variance explained was increased to only 39%, indicating overlap. Body height did not increase the amount of variance explained ($p = 0.6$).

It is possible, with the use of ordered logistical regression, to use these data to predict the maximum step height for an individual. This technique takes discontinuous data into consideration. The prediction equations can be obtained from the authors.

Discussion

There has been no study that has examined strength, power and functional ability in healthy older people. Our subjects were not selected as representative of the overall elderly population but to allow us to study the effects of healthy ageing.

In this cross-sectional comparison of healthy elderly people IKES and HGS declined at $1\frac{1}{2}$–2%$_{77}$ p.a. Cross-sectional studies (for review—[1]) of subjects meeting less strictly defined health criteria have shown rates of loss of strength of ~ 1.5% p.a., similar to those seen in this study. It appears that a loss of muscle performance may be an inevitable accompaniment of healthy ageing.

Two longitudinal studies [24, 25], again of subjects meeting less strictly defined health criteria, have also shown rates of loss of strength similar to those seen in this cross-sectional study. Greig *et al.* [26] in their small longitudinal study, however, showed a non-significant loss of IKES of only 0.3% p.a. Their healthy over-80-year-old subjects had all maintained or increased their activity levels over the eight-year period. Bassey *et al.* [27, 28] and others [29, 30] have tentatively concluded that a high level of customary activity might help to protect against some of the age-associated loss of muscle mass or performance. There was little evidence from the present study to suggest that higher levels of physical activity alone helped to maintain muscle strength or power. Although men were slightly more active than women, the decline of LEP over the age range was faster in men than in women. Our subjects were generally active (though not to competitive levels). There was no decrease in activity score over the age range, yet the loss of strength with age, even in the absence of disease, was consistent with other cross-sectional studies.

It has been considered that the loss of muscle strength might accelerate after the age of 70, when there appears to be a faster muscle atrophy with a reduction in the size of fast twitch fibres [31]. This study was not designed to test this possibility, but there were some large differences between the 80–84 and 85–89 age groups (for LEP and IEFS for men and for IEFS in women). This may suggest that in strictly healthy and mobile elderly people the acceleration of muscle loss may be deferred to an older age.

It has been suggested that a reduced strength or power may be associated with reduced function in various daily activities [1, 7, 32]. In our healthy group, there were correlations between strength, power and the functional ability tasks (chair rise and stepping), but these were weaker than those reported in a group of people with multiple diseases [8]. Age explained more of the variance in step height than did LEP/kg, IKE/kg, or present activity level, so other age-associated factors, such as joint mobility, balance, or hip abductor strength, may also be influencing the ability to climb steps. With the exception of age, LEP/kg was the strongest determinant of step height, and the difference in LEP/kg between sexes may partly explain the difficulty the women had with stepping.

Women were weaker and less powerful for their weight than men. Our women in the 65–69 age group often had the same, or lower IKES/kg or LEP/kg than men in the 85–89 age group (Table II). This may contribute to the prevalence of disability amongst women [6]. Our healthy men did not have difficulty with the functional tasks, except for stepping ability in the 85–89 age group. In a separate (unpublished) study a sex difference was evident in the rather harder task of rising from the kneeling position on the floor.

Handgrip may be functionally important as it is potentially limiting in many tasks such as using tools, opening containers, lifting weights, and holding on to handrails to ascend a step. The United Kingdom *General Household Survey* [33], showed that 50% of men aged ⩾85 years and only 20% of women, in the same age group, use public transport on their own. The loss of handgrip and IEFS, coupled with a reduced stepping ability, may render public transport unacceptably difficult for elderly women. Functionally, a 50 cm step is rarely found, but Routemaster buses (found throughout England) commonly have a 42 cm step from the ground, and steps of 45 cm are encountered on some British Rail trains.

There was very little evidence of definable strength or power 'thresholds' below which functional tasks become impossible. There are three possible reasons for this. (i) Our subjects were exceptionally healthy and fairly active and it may be that the ability to perform the tasks is more affected by inactivity or disease than by strength or power *per se*. (ii) Perhaps these 'thresholds' are even lower than the strength and power values recorded for our subjects and in order to identify such thresholds in healthy elderly people we must study an even older group, with even lower strength or power. (iii) The study method used will have recruited people who are still mobile and functionally able whatever their strength or power.

It is important to identify people at risk of functional decline, and a recent study has shown that minor functional difficulties are good indicators of further and more important declines in mobility [34]. In order to detect mild disability there must be 'ideal' standards with which to compare the abilities of other elderly people. Our results may help in the identification of those most at risk of becoming dependent.

Women are functionally dependent for about four years longer than men [35], so women should be the initial target of interventions to increase strength and power and to help maintain or increase the ability to perform everyday tasks. Women were weaker than men, and the recent findings that hormone replacement therapy has a protective effect on muscle strength per unit muscle mass [36] in women may mean that this sex difference can be reduced. Strength and power of elderly muscle can also be increased by training [37–39]. It will be important, however, to resolve whether any increase in strength or power will improve functional performance.

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