

Relationships between physical performance measures, age, height and body weight in healthy adults

MONIQUE M. SAMSON, INGRID B. A. E. MEEUWSEN, ALAN CROWE, JOS A. G. DESSENS¹,
SIJMEN A. DUURSMA, HARALD J. J. VERHAAR

Mobility Laboratory, Department of Geriatrics, Utrecht University Hospital, PO Box 85500, 3508 GA, Utrecht, The Netherlands

¹Utrecht University Faculty of Social Science, Department of Methodology and Statistics, Utrecht, The Netherlands

Address corresponding to: M. M. Samson. Fax: (+31) 302544397. Email: samson@gaz.azu.nl

Abstract

Objective: we measured muscle strength and functional mobility in healthy men and women over the adult age range to investigate the changes with age and sex, and to establish the effects of the anthropometric indices height and weight.

Design: cross-sectional study.

Subjects and methods: we recruited 74 healthy women (mean age 49.0, range 20–90) and 81 healthy men (mean age 51.6, range 20–90). We measured maximum isometric knee extension strength, handgrip strength and explosive leg extensor power. We assessed functional mobility quantitatively with the timed 'get up and go' test and the modified Cooper test.

Results: older subjects had lower values for muscle strength and muscle power than young subjects. Times for the timed 'get up and go' test were longer and distances in the modified Cooper test shorter. At about the age of 55, women showed an acceleration in the decline of isometric knee extension strength and handgrip strength (between 20 and 55 years, knee strength decreased by 10.3% and handgrip strength decreased by 8.2%, between 55 and 80 years the decreases were 40.2% and 28% respectively). Men showed a more gradual declines over the adult age range, with decreases in knee and handgrip strength of 24% and 19.6% between 20 and 55 years, and 23% and 17.4% between 55 and 80 years. The age-related decline is partly associated with differences in height and body weight. Women had higher correlations between muscle strength and functional mobility tests than men.

Conclusions: muscle strength and functional mobility decline with age in healthy people; in women we observed an accelerated decrement in muscle strength above the age of 55. Lower values in healthy old subjects are partly associated with differences in height and body weight.

Keywords: age, height, physical performance, weight

Introduction

As people get older, the sensorimotor system tends to deteriorate [1]. The diminished functioning in sensorimotor systems in old people can be a limiting factor in the maintenance of an independent lifestyle and can increase the risk of falls and fractures [2–6]. Understanding the changes in muscle strength and functional mobility with age is becoming more important because of a longer life expectancy and an increasing elderly population.

Normal values for muscle strength and functional mobility might be useful for the assessment of pathology

and the evaluation of interventions [7–13]. Muscle strength has been measured in healthy young subjects, in older subjects and in different age groups [14–23]. Since younger generations tend to be taller, the differences found between young and old subjects could be partially associated with differences in height and weight. Besides anthropometric factors, hormonal status may also influence muscle function. Philips *et al.* found that low postmenopausal oestrogen levels were associated with lower strength of the abductor pollicis muscle [24].

In this cross-sectional study we measured muscle strength and functional mobility over a wide age range

to establish the changes with age in these variables. We also determined to what extent sex, height and weight contribute to differences in muscle strength and functional mobility. In particular, we were interested in whether the menopause had any influence on muscle strength.

Materials and methods

Subjects

Adults of either sex, distributed over the age range 19–90 years, were recruited by press advertisements. We screened subjects on the basis of the health questionnaire developed by Greig *et al.* [13]. They had no signs of cardiological, neurological or orthopaedic abnormalities and had no history of cognitive disorders (Mini-Mental State Examination score > 24 out of a maximum of 30). They had to be able to walk unaided. All participants gave written informed consent. The programme was approved by the hospital ethical committee.

Measurements

We performed measurements in a room free from external distractions in which only the investigator and the subject were present.

We measured weight to the nearest 0.1 kg and height to the nearest mm using a wall-mounted stadiometer [25].

To measure maximum isometric knee extension strength (IKES), subjects were seated in an adjustable straight-back chair with the pelvis fixed by an adjustable strap and the strain gauge attached by a strap to the distal leg just above the ankle [26]. The subject extended their legs isometrically left and right to a maximum with the knee flexed to 90. The highest score of five attempts was recorded in Newtons.

We measured explosive leg extensor power (LEP) with the Nottingham power rig [27]. The subject, in a seated position with arms folded, gave a maximal push to a large foot pedal setting a flywheel in motion. The initial flywheel speed reflected the LEP of the subject. The measurement was repeated until no further improvements were seen, up to a maximum of 10 pushes. We used the best recorded power output for each leg for the analysis in Watts.

Handgrip strength (HGS) was measured with a mechanical Takei Kiki Kogyo Handgrip mechanical dynamometer [28]. The size of the grip was set so that the subject felt comfortable. Subjects stood upright and held the dynamometer close to their body with the arm vertical. The subject squeezed the grip with maximal force, alternating the left and right hand. We measured at least four trials until no further improvements were seen. We recorded the best measure in kg.

We assessed functional mobility quantitatively with the timed 'get up and go' test [29, 30]: the time in

which an individual needs to rise from a standard arm chair (46 cm high), walk 3 m, turn around and sit down again as fast as possible. The subject is requested to sit with their back against the chair and arms resting on the chair and performs the test three times. The fastest time was recorded in s.

Finally, subjects were asked to perform the modified Cooper test: a 2-min walking test, which appears to be highly correlated with the 12-min Cooper test [31] and is a reproducible measure of endurance. The subject is asked to walk as fast as possible for 2 min and the distance is recorded in m.

Stability of physical performance measures

We evaluated the stability of all measurements by measuring 10 randomly chosen subjects for a second time after an interval of 1 week.

Relationships between physical performance measures

We calculated the correlation coefficients (r) between the five tests of muscular strength and functional mobility in women and men.

For simple linear regression, individual scores for each variable were regressed on age. We calculated regression coefficients, multiple correlation coefficients (R) and levels of significance.

We used the bent linear regression to determine whether the changes might tend to be more rapid at the onset of a particular boundary age [32]. We tested boundary ages of 30, 40, 50, 60 and 70 years for all the variables. A bent linear regression with a bend for the age of 55 years is simply fitted by forming the product of the individual scores on (age–55) and the individual scores on an indicator variable (I) that specifies if a woman is under 55 ($I=0$) or above that age ($I=1$), and including this product term together with age in the regression model. In this way two regression coefficients are obtained, one for age and one for the product term. The regression slope for women under 55 corresponds to the regression coefficient of age, that for women above the age of 55 is obtained by adding the coefficients of age and the product term. A statistically significant regression coefficient for the product term indicates that the regression line bends at the age of 55 years. Furthermore, it is possible to test for what boundary age bent linear regression is optimal by varying the age at which the bend is expected. The bent linear regression with a bend on the age of 55 years seems to be the optimal model.

Multiple regression analysis made it possible to evaluate the age effect net of the effects of anthropometric measures like height and weight. These net effects can be evaluated by comparing the predicted reduction in the measures of muscle strength and functional mobility between the ages of 20 and 80 years based on the (bent) linear regression model with

Table 1. Correlation coefficient (*r*) between IKES, HGS, LEP, COOP and GUG in 81 men and 74 women

	IKES	HGS	LEP	COOP	GUG
Men					
IKES	–				
HGS	0.70	–			
LEP	0.80	0.68	–		
COOP	0.46	0.37	0.50	–	
GUG	–0.60	–0.56	–0.59	–0.55	–
Women					
IKES	–				
HGS	0.82	–			
LEP	0.81	0.72	–		
COOP	0.70	0.62	0.75	–	
GUG	–0.71	–0.65	–0.74	–0.68	–

IKES, isometric knee extensor strength; HGS, handgrip strength; LEP, explosive knee extensor power; COOP, modified Cooper test; GUG, timed 'get up and go' test.

the predicted reduction based on the multiple regression model extended with the anthropometric measures. We performed calculations separately for men (with an average height of 1.80 m and an average body weight of 80 kg) and women (with an average height of 1.65 m and an average body weight of 70 kg).

Results

Seventy-four women (mean age 49, range 20–90) and 81 men (mean age 51, range 20–90) satisfied the selection criteria.

Stability of physical performance measures

The correlations between repeated measurements of IKES, LEP and HGS and results of the 'get up and go' test and the modified Cooper test in 10 randomly

chosen subjects, with a 1-week interval between tests, were 0.99, 0.98, 0.98, 0.98 and 0.99 respectively.

Relations between the tests

Higher correlations between muscle strength and muscle power with the functional mobility tests were found in women than in men. This was especially strong for the correlations between muscle strength and the modified Cooper test (Table 1, range: women 0.62–0.82, men 0.37–0.80).

Simple linear regression

In Table 2 the slopes of the lines of best fit indicate that IKES, LEP and HGS decrease with age ($P < 0.001$). Legs lost their strength at a faster rate than arms. The time taken to complete the 'get up and go' test tended to be

Table 2. Equations of lines of best fit for muscle strength, muscle power and functional mobility for 74 healthy women and 81 healthy men, Pearson correlation coefficients (*r*) and level of significance (*P*)

	Line of best fit	<i>r</i>	<i>P</i> -value
Women			
IKES (N)	– 3.81 (age) + 611.29	0.69	< 0.001
HGS (kg)	– 0.19 (age) + 390.42	0.61	< 0.001
LEP (W)	– 3.39 (age) + 416.56	0.78	< 0.001
COOP (m)	– 1.34 (age) + 315.68	0.64	< 0.001
GUG (s)	0.04 (age) + 1.82	0.77	< 0.001
Men			
IKES (N)	– 5.43 (age) + 887.80	0.69	< 0.001
HGS (kg)	– 0.31 (age) + 61.50	0.63	< 0.001
LEP (W)	– 4.18 (age) + 590.76	0.65	< 0.001
COOP (m)	– 1.10 (age) + 338.16	0.41	< 0.001
GUG (s)	0.03 (age) + 1.91	0.64	< 0.001

IKES, isometric knee extensor strength; HGS, handgrip strength; LEP, explosive knee extensor power; COOP, modified Cooper test; GUG, timed 'get up and go' test.

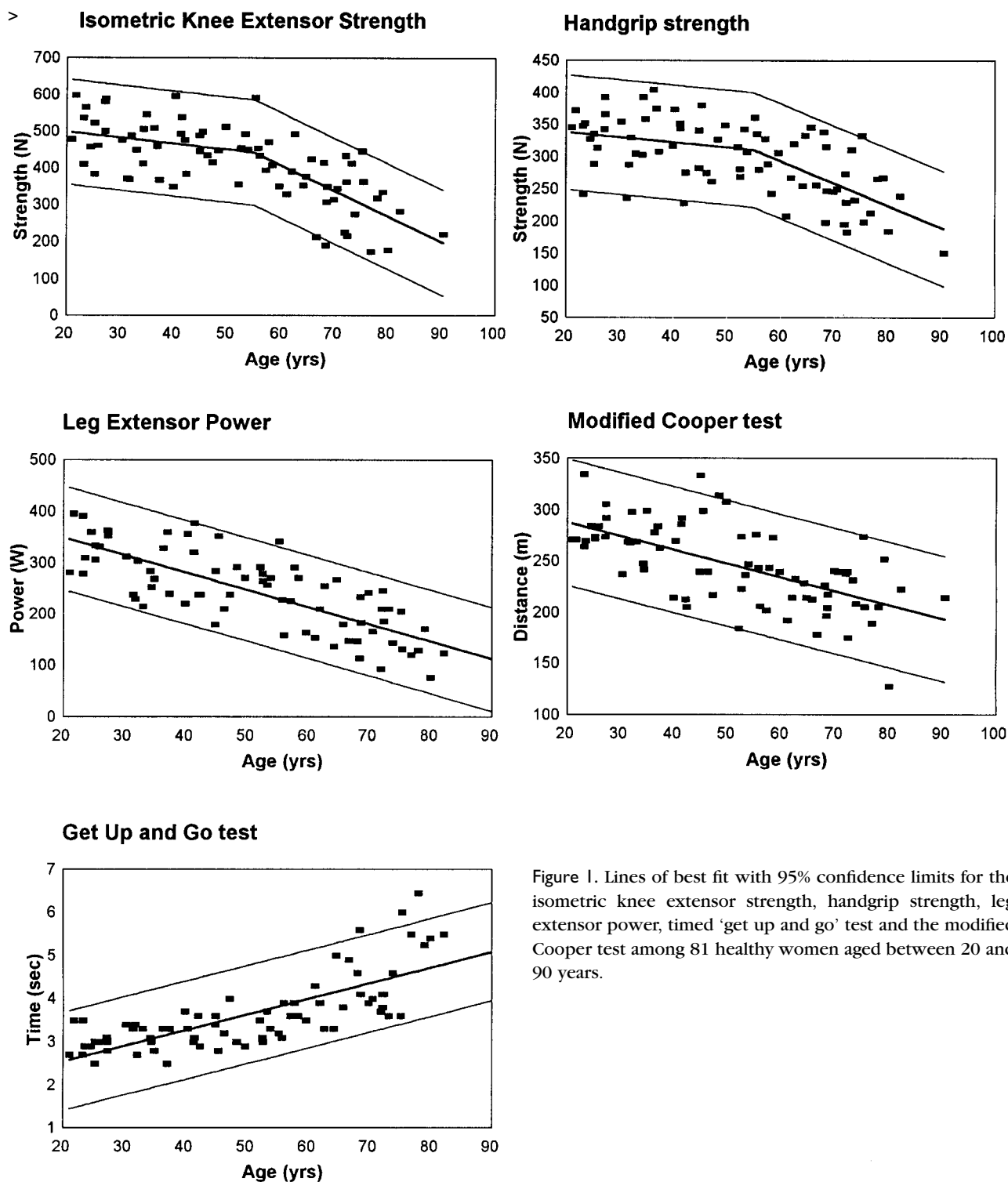


Figure 1. Lines of best fit with 95% confidence limits for the isometric knee extensor strength, handgrip strength, leg extensor power, timed 'get up and go' test and the modified Cooper test among 81 healthy women aged between 20 and 90 years.

longer and the distance of the modified Cooper test shorter with increasing age ($P < 0.001$).

Comparison between subjects aged 20 and 80 years showed declines in IKES of 46% (women) and 42% (men), declines in HGS of 34% (women) and 34% (men), and declines in LEP of 61% (women) and 49% (men). The time for the 'get up and go' test increased

by 47% in women and 42% in men. The walking distance over 2 min decreased by 28% in women and 21% in men.

Bent linear regression

Figure 1 and Table 3 show the acceleration in the decline in IKES and HGS at the age of 55 years for

Table 3. Bent linear regression for 74 healthy women with boundary age at 55 years

	b1	b2	Multiple R
Isometric knee extensor strength	− 1.47 <i>P</i> = 0.102	− 5.70 <i>P</i> = 0.003	0.73
Handgrip strength	− 0.08 <i>P</i> = 0.137	− 0.27 <i>P</i> = 0.026	0.65

$$y = b_0 + b_1 (\text{age}) + b_2 (\text{age} - 55) I; \text{ where } I = 0 \text{ if age} < 55, \text{ otherwise } I = 1.$$

women: for IKES, the decrease between 20 and 55 years was 10.3%, while the decrease between 55 and 80 years was 40.2%; for HGS, the decrease between 20 and 55 was 8.2%, and the decrease between 55 and 80 was 28%. No acceleration was observed in decline in LEP.

For men (Figure 2), the use of bent regression lines did not improve the fit of the regression model for muscle strength and power: for IKES, the declines were 24% between 20 and 55, and 23% between 55 and 80; for HGS, the declines were 19.6% and 17.4%.

Multiple regression analysis

For both sexes, weight and height had a significant influence on the differences between old and young healthy subjects in IKES, LEP and HGS (Table 4). In women 11% of the decline in performance between 20 and 80 years in IKES, 21% of the decline in HGS, 16% of the decline in LEP and 21% of the decline in modified Cooper test performance is associated with height and weight. None of the decline in 'get up and go' test performance in women over this period is associated

with height and weight. In men, 5% of the decline in IKES, 24% of the decline in HGS, 22% of the decline in LEP, 52% of the decline in modified Cooper test performance and 14% of the decline in 'get up and go' test performance is associated with height and weight.

Anthropometric parameters over the age range

In women the correlation between age and height is -0.368 ($P < 0.01$), and that between age and weight is 0.228 ($P < 0.05$). For men, the correlation between age and height is -0.514 ($P < 0.01$) and the correlation between age and weight is 0.023 (not significant). These results are shown in Figure 3.

Discussion

This study shows that muscle strength, muscle power and functional mobility values decline with age. While there is little difference in the percentage reduction between men and women over the adult age range (Table 2), the absolute values for muscle strength and

Table 4. Effects of age on muscle strength (IKES, HGS, LEP) and functional mobility (COOP, GUG) controlling for height and weight

	Age	Age >55	Height	Weight	<i>R</i> ²	Net reduction, 20–80 years ^a	% associated with height and weight
Women^b							
IKES	− 1.63 ^c	− 4.12 ^d	132.85	2.04 ^d	0.58	0.41	11
HGS	− 0.04	− 0.24 ^d	25.21 ^c	− 0.02	0.47	0.27	21
LEP	− 2.27 ^d	− 1.12	242.88 ^d	0.84	0.67	0.51	16
COOP	− 0.88 ^d	− 0.30	154.14 ^d	− 0.64	0.45	0.22	21
GUG	0.01	0.07 ^d	− 1.89	0.01 ^c	0.70	1.76	− 3
Men							
IKES	− 5.15 ^d	−	− 120.91	4.72 ^d	0.57	0.40	5
HGS	− 0.23 ^d	−	25.66 ^c	0.21 ^d	0.50	0.26	24
LEP	− 3.14 ^d	−	228.12	4.46 ^d	0.59	0.40	22
COOP	− 0.49	−	310.95 ^d	− 1.00 ^d	0.30	0.10	52
GUG	0.02 ^d	−	− 3.33 ^d	0.02 ^d	0.48	1.47	14

IKES, isometric knee extensor strength; HGS, handgrip strength; LEP, explosive knee extensor power; COOP, modified Cooper test; GUG, timed 'get up and go' test.

^a(Gross-net reduction)/gross reduction 100%.

^bUsing the equation for the bent linear regression: $y = b_0 + b_1 (\text{age}) + b_2 (\text{age} - 55) I$; where $I = 0$ if age < 55, otherwise $I = 1$.

^c $0.05 < P < 0.10$; ^d $P < 0.05$.

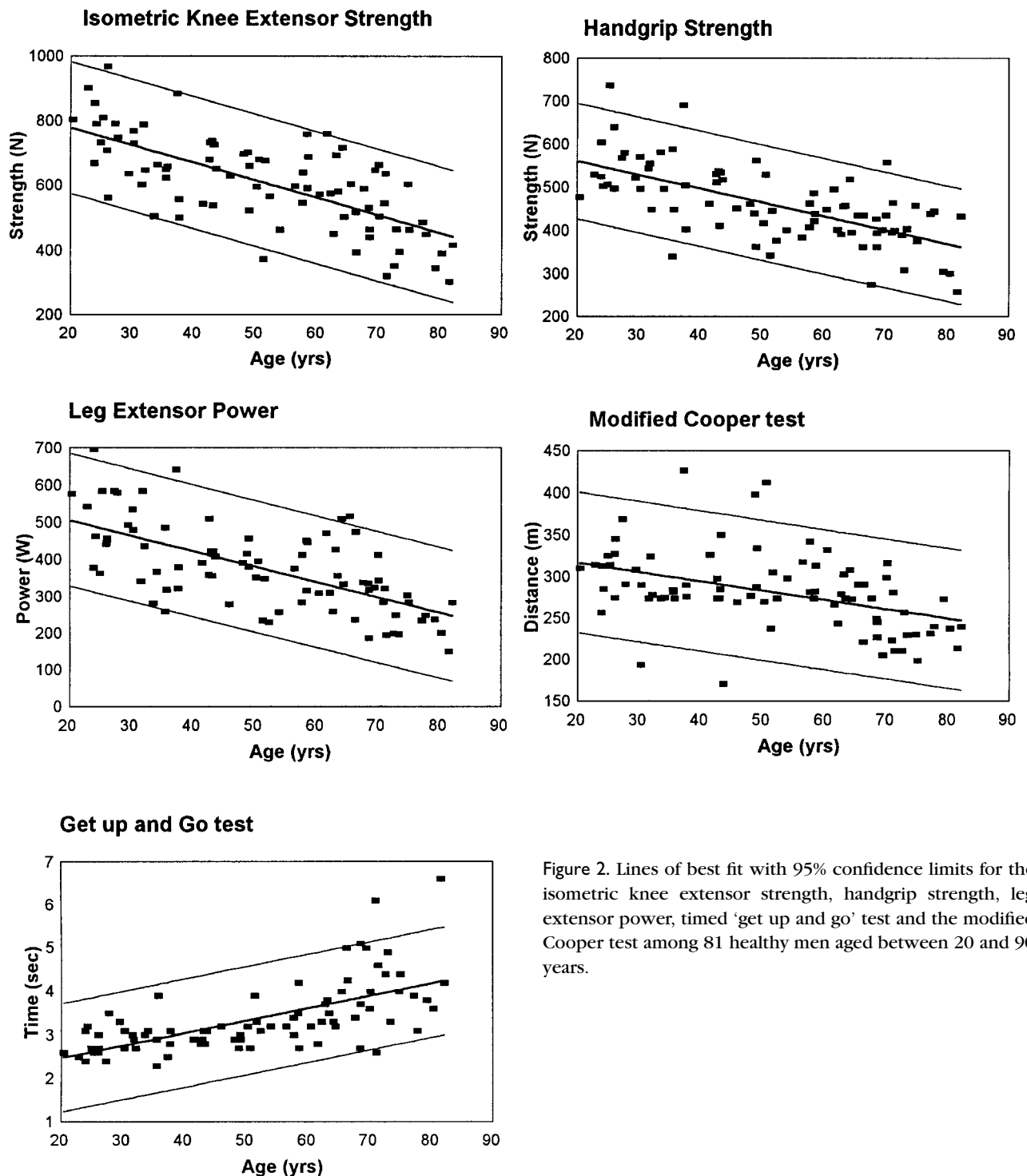


Figure 2. Lines of best fit with 95% confidence limits for the isometric knee extensor strength, handgrip strength, leg extensor power, timed 'get up and go' test and the modified Cooper test among 81 healthy men aged between 20 and 90 years.

power are lower, functional mobility test times were longer and walking distance shorter in women than men at all ages. For instance, the mean IKES of a 70-year-old man is the same as that of a 35-year-old women. We found that legs lost strength at a faster rate than arms [33].

The change of the slope for IKES and HGS in

women around the age of 55 years [34] is of interest. Philips *et al.* [24] showed that the menopause was associated with a negative effect on muscle strength. The menopause may partly explain our findings. No change of the slope was found for IKES or HGS in men.

It has been demonstrated that differences in height

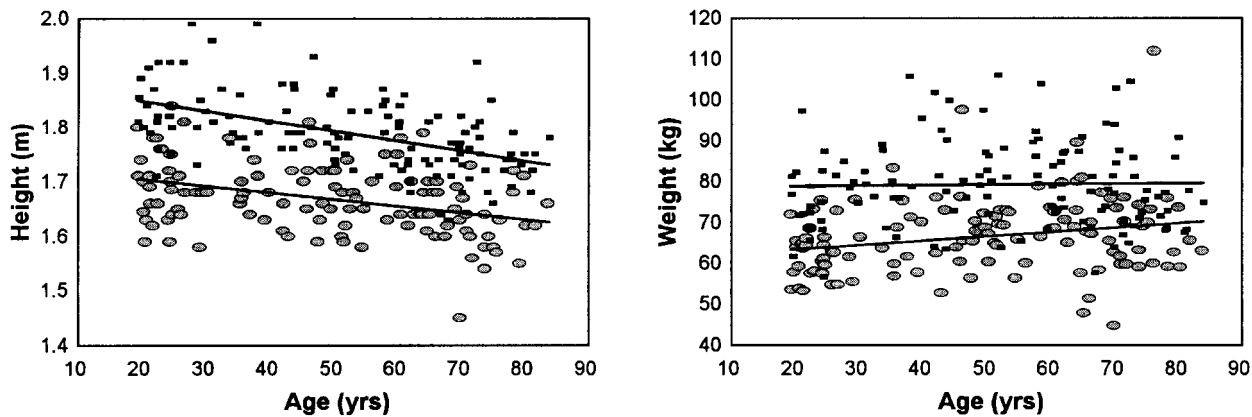


Figure 3. Height and body weight against age for 74 women (●) and 81 men (■).

and weight between healthy young and old subjects contribute to the differences in walking speed and stride length [35–37]. Using multiple regression analysis we have demonstrated that height and weight affected the differences in muscle strength and functional mobility between the young and old healthy subjects (Table 4). The differences found in the five physical performance measures between healthy young and old groups might therefore be partly associated with age and partly with differences in height and weight.

Avlund *et al.* [3], Bassey *et al.* [17] and Hyatt *et al.* [18] found that a reduction in muscle strength and power might be associated with a reduced function in various activities of daily living. In our study, we found higher correlations between muscle strength and functional mobility values in women than men (Table 1). These findings are in accordance with the observation of Young *et al.* [37, 38], who found that healthy elderly women are closer to their strength-related functional limits than men. The high correlations between IKES, HGS and LEP, and the results of the 'get up and go' test and modified Cooper test make it justifiable to reduce the number of tests for clinical assessment to one muscle strength and one functional mobility test to evaluate physical performance.

In conclusion, muscle strength and functional mobility decline with age in healthy people over the adult age range; in women an acceleration was observed after the age of 55 years for knee extension and handgrip strength. Lower values in healthy older subjects are partly the consequence of changes in height and weight.

Key points

- The decline in muscle strength accelerates at about the age of 55 in women; men have a more gradual decrease of muscle strength over the adult age range.
- The age-related decline in muscle strength and

functional mobility is partly associated with differences in height and weight.

- The correlations between muscle strength and functional mobility are higher in women than men.

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