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ORIGINAL ARTICLE

Maximal isokinetic and isometric muscle strength of major muscle groups related to age, body mass, height, and sex in 178 healthy subjects

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Abstract The main objective of this study was to establish normative values for maximal concentric isokinetic strength and maximal isometric strength of all major muscle groups in healthy subjects applying sex, age, height, and body mass-adjusted statistical models. One hundred and seventy-eight (178) (93 male and 85 female) healthy non-athletic Danish volunteers aged 15–83 years were recruited. Eighteen test protocols for each sex were applied to determine isokinetic and isometric muscle strength at knee, ankle, hip, shoulder, elbow, and wrist using a dynamometer (Biodex System 3 PRO). Multiple linear regressions were performed with maximal muscle strength (peak torque) as dependent variable and age, height, and body mass as independent variables. Muscle strength significantly related to age in 24, to height in 13 and to body mass in 27 out of the 36 models. In gender-specific analyses, the variables age, height and body mass accounted for 25% (20–29) (95% confidence interval) of the variation (r^2) in strength for men and 31% (25–38) for women. The r^2 was similar for the isokinetic models and the isometric models [31% (22–40) vs. 28% (23–34)]. Age, height, and body mass related to strength in most muscle groups and gender-specific models with estimated prediction intervals were established for maximal strength of major muscle groups.

Keywords Muscle strength · Dynamometer · Normative values · Outcome assessment · Rehabilitation

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Introduction

In rehabilitation following surgical interventions and medical diseases, it is desirable to improve physical function and muscle strength. To assess such changes in muscle performance, accurate, reliable, and applicable methods to evaluate muscle performance should be applied. Furthermore, to define objective goals for and evaluate a rehabilitation program normative data which include information about the influence of variables such as sex, age, height, body mass, and daily physical activity on muscle performance are required.

The manual muscle test (MMT) developed by the Medical Research Council (MRC) is used in daily clinical practice to estimate weakness and is easily performed without use of expensive instruments. However, studies have shown that MRC test is insensitive for the detection of mild to moderate weakness of larger muscle groups such as ankle plantarflexors, knee extensors, and hip flexors, in particular, when symmetrical weakness is present (Andersen and Jakobsen 1997). Furthermore, the inter-rater reliability can be low because MMT is highly dependent on the skills and experience of the examiners. In comparison, dynamometry provides an unbiased estimation of strength performances using a linear scale enabling accuracy and sensitivity for the whole range of values and the applicability of more powerful parametric statistical tests.

Maximal strength can be assessed during an isokinetic and an isometric contraction. Isokinetic dynamometry has been most widely applied because the technique evaluates the function as well the strength of a joint. However, in neurological disorders with spasticity or ataxia isometric contractions are more appropriate as patients often are unable to comply with the isokinetic procedures.

Although dynamometric muscle testing has been performed in many studies, evaluation of maximal isokinetic and isometric strength of all major muscle groups in the same study population has never been reported. No consensus exists concerning the applied procedures. Equipment, alignment of the dynamometer axis to the axis of the joint, the position of the test person (e.g. standing or supine), range of movement, and angular velocity are all factors that have an influence on the muscle strength. Consequently, results obtained at different laboratories with variable test procedures cannot be directly compared.

The objective of this study is to define normative data with prediction intervals for maximal concentric isokinetic strength as well as isometric strength of all major muscle groups in healthy subjects using standardized and reliable test procedures and statistical regression models in relation to the explanatory variables sex, age, height, body mass, and daily physical activity level.

Methods

Subjects

One hundred and seventy-eight (178) healthy non-athletic Caucasian subjects (93 male and 85 female) aged 15–83 years were recruited from a large and a small Danish town by advertising in local newspapers. Denmark is a small country with a homogenous population and the demographics of a large and a small town are considered to be representative of the Danish population. Exclusion criteria were any neurological, endocrine, psychiatric, malignant or cardio-pulmonary disorder, recent muscle injury or surgery, or a history of drug or alcohol abuse. Self-reported information about age, height, and hand and leg dominance was collected whereas body mass was determined just prior to the muscle testing.

Approval for the study was obtained by the Danish Data Protection Agency and the Ethics Committee of Aarhus County and all participants gave informed signed consent.

Physical activity scale

A questionnaire to estimate 24-h daily physical activity of sports, work, and leisure time on an average weekday was applied (Aadahl and Jorgensen 2003). The intensity of each specific activity was expressed as a metabolic equivalent (MET) ranging from sleep/rest (0.9 MET) to high-intensity physical activities ($\geq$6 MET). The MET was multiplied with the time spent on each activity resulting in an estimate of daily energy expenditure (MET time). Persons with an extensive physical activity or elite athletes were excluded.

Test protocol

Isokinetic and isometric strength was determined at one session in the mentioned order using the Biodex System 3 PRO dynamometer® (Biodex Medical Systems, NY, http://www.biodex.com and the computer software program version 3.29 and 3.30). Maximal muscle strength defined as the highest peak torque (Newton-meters, Nm) obtained in each series was used for further data analyses.

Based on the Biodex System 3 Pro manual, recommendations from other labs (Keating and Matyas 1996), and a previous study from our lab (Andersen 1996) the 18 test protocols were established. Two examiners performed the tests using two identical dynamometers at the Department of Neurology, Aarhus University Hospital and at Hammel Neurorehabilitation and Research Centre, Aarhus University Hospital. The dominant arm and non-dominant leg were tested. Prior to each test participants became familiar with the procedures by performing 5–10 submaximal contractions and 1 or 2 maximal contractions as warm-up. During the test they were guided with standardized instructions recorded and played as an audio file to encourage maximal muscle performance. Participants were stabilized in the chair with shoulder and abdominal straps. The anatomical axis of rotation was aligned to the dynamometer axis using visual inspection and manual palpation. The isokinetic tests included eight maximal concentric reciprocal contractions, each contraction separated by a 15 s rest whereas isometric tests included three maximal muscle contractions each lasting 5 s separated by 40 s rest intervals. At least 3 min rest separated each test. The range of motion (ROM) was set wide enough to obtain maximal speed at the isokinetic tests. Isokinetic strength was measured for extension and flexion at knee [ROM = 80°, 90°/s (movement velocity)], ankle (ROM = 48°, 60°/s), hip (ROM = 60°, 60°/s), elbow (ROM = 110°, 60°/s), wrist (ROM = 45°, 90°/s), and abduction and adduction at shoulder (ROM = 70°, 60°/s), whereas isometric strength was evaluated at knee and ankle extension, hip, elbow and wrist flexion, and shoulder abduction at neutral joint positions. For each test including all the contractions performed, the coefficient of variation was calculated. To avoid sub-maximal performance or outliers, the test was redone or data discarded if the coefficient of variation exceeded 10% for ankle and knee, and 15% for hip, shoulder, elbow, and wrist. Gravity correction was used but the dynamometer was not adjusted to preload as it is not considered to affect the peak torque at the ROMs and angular speeds used in our protocols (Kannus 1994; Keating and Matyas 1996), however, the dynamometer software was set to estimate peak torque for the preset test speed only, which excluded data from the acceleration and deceleration phases (Sapega et al. 1982).

Data analysis

Multiple linear regression analyses were performed with isokinetic and isometric peak torque recorded at each muscle group as dependent variables, and age, height, body mass, and MET time as independent variables. With the results of the regression analyses estimation of the squared product moment correlation coefficient (r^2) was presented as well as predictive models for peak torque (mean ± SD) and standard deviation of the residuals (RSD). Assumptions were tested by plots of residuals versus explanatory variables, residual versus expected values and probability plots of residuals. Descriptive data including median and range are provided for the explanatory variables. Statistical comparisons between the explanatory variables as well as the subgroups of sex, upper and lower limbs, isokinetic, and isometric strength were performed using a t test. All analyses were performed using the Intercooled STATA 9.2 software. Two-tailed p values below 0.05 were considered statistically significant.

Results

Explanatory variables

Men were taller than women [1.78 m (1.67–1.89) vs. 1.67 m (1.53–1.83)], had a larger body mass [80 kg (52–115) vs. 62 kg (46–105)], and were more physically active [49.8 MET time (32.6–77.8) vs. 44.3 MET time (33.1–61.8)] whereas no difference was identified concerning age for the two sexes [53 years (15–83) vs. 52 years (21–75)]. For all muscle groups including isokinetic and isometric tests men were stronger than women ($P < 0.001$).

Physical activity level

In only 4 out of the 36 multivariate linear regression analyses we found a statistically significant relationship between physical activity level (MET time) and strength. Therefore, level of physical activity was not included in the further data analysis or any of the regression models. All four models with significant relationships were for leg muscles in women (isokinetic knee extension, knee flexion, and hip flexion as well as isometric knee extension).

Gender-specific models

Gender-specific difference was seen in the variation of strength that could be explained by the regression models. For all muscle groups, the SD of the means and the SD of the residuals (RSD) were smaller and the predictive intervals narrower for women than for men. For example, the RSD of maximal isokinetic knee extension strength was 30.2 Nm for men and 15.2 Nm for women whereas the RSD in a combined model including data from men and women would have been 23.8 Nm. Therefore, gender-specific analyses and equation models are presented for all strength tests (Tables 1, 2, 3, 4, 5).

Maximal muscle strength, prediction models, and associations

As an example, univariate correlations are presented for maximal isokinetic muscle strength of knee extension for women including the dependent variables age, height, and body mass (Fig. 1a–c).

Muscle strength was significantly related to age in 24, to height in 13 and to body mass in 27 out of the 36 models. Prediction models with prediction intervals for maximal isokinetic and isometric strength of all muscle groups for men and women can be generated from the data in Tables 1, 2, 3, 4. For example, the predicted peak torque of isokinetic knee extension for a 40-year-old man with a height of 1.80 m and body mass of 80 kg is 81.8–1.44 Nm/year × 40 year + 41 Nm/m × 1.80 m + 1.25 Nm/kg × 80 kg = 198 Nm with a prediction interval of 198 Nm ± 30.1 (168–228 Nm).

The percentage variation in muscle strength that could be explained by the variables was higher for leg muscles (knee, ankle and hip) compared to arm muscles (shoulder, elbow and wrist). Thus, the r^2 (leg) was 34% (28–39) when compared with r^2 (arm) 22% (18–26) [mean (95% CI)], $P < 0.005$. Also, women had smaller RSD and larger r^2 when compared with men [31% (25–38) vs. 25% (20–29), $p < 0.005$ (Tables 3, 4)].

Isokinetic compared to isometric testing

Although the mean isometric strength was higher than isokinetic strength for all muscle groups except shoulder abduction (women) and elbow flexion (both gender) ($p < 0.05$) (Tables 3, 4) there were close relations between the isokinetic and the isometric strength for all muscle groups ($r^2 = 95\%$, $p < 0.00001$). Also, including all explanatory variables for the individual muscle groups no

Table 1 Predictive models for maximal strength (peak torque) of upper limb muscle groups with inclusion of the explanatory variables age, height and body mass for each sex

Variable	Sex (*n*)	Intercept	β (95% CI)		
			Age (years)	Height (m)	Body mass (kg)
Shoulder abduction	M (89)	−47.7	−0.16 (−0.30; −0.03)	42 (−4; 8.8)	0.51 (0.29; 0.73)
Isokinetic	F (81)	−9.3	−0.20 (−0.32; −0.09)	24 (−3; 50)	0.28 (0.09; 0.46)
Shoulder adduction	M (88)	−72.9	−0.06 (−0.29; 0.17)	72 (−7; 151)	0.38 (0.01; 0.76)
Isokinetic	F (84)	−24.5	−0.15 (−0.30; −0.01)	40 (7; 73)	0.18 (−0.04; 0.40)
Shoulder abduction	M (78)	−30.8	−0.24 (−0.42; −0.07)	36 (−25; 96)	0.49 (0.21; 0.78)
Isometric	F (69)	−28.2	−0.21 (−0.34; −0.08)	35 (3; 66)	0.29 (0.08; 0.51)
Elbow extension	M (91)	−4.4	−0.07 (−0.18; 0.04)	12 (29; 52)	0.42 (0.22; 0.61)
Isokinetic	F (84)	6.4	−0.10 (−0.19; −0.02)	5 (−14; 24)	0.27 (0.14; 0.40)
Elbow flexion	M (92)	−37.2	−0.18 (−0.32; −0.04)	36 (−13; 84)	0.41 (0.18; 0.64)
Isokinetic	F (84)	−16.5	−0.12 (−0.21; −0.03)	27 (6; 47)	0.09 (−0.05; 0.23)
Elbow flexion	M (82)	−23.8	−0.13 (−0.30; 0.03)	22 (−35; 80)	0.51 (0.23; 0.78)
Isometric	F (75)	6.9	−0.13 (−0.22; −0.04)	9 (−12; 30)	0.18 (0.04; 0.32)
Wrist extension	M (91)	−11.1	−0.02 (−0.05; 0.02)	12 (−2; 26)	0.03 (−0.03; 0.10)
Isokinetic	F (73)	−9.0	−0.01 (−0.04; 0.02)	9 (3; 16)	0.01 (−0.03; 0.06)
Wrist flexion	M (91)	1.7	−0.07 (−0.13; 0.00)	4 (−19; 27)	0.21 (0.10; 0.32)
Isokinetic	F (79)	−2.3	−0.02 (−0.07; 0.03)	8 (−3; 19)	0.04 (−0.04; 0.12)
Wrist flexion	M (82)	−6.9	−0.07 (−0.17; 0.02)	10 (−23; 43)	0.21 (0.06; 0.37)
Isometric	F (73)	−22.2	−0.04 (−0.10; 0.03)	23 (8; 38)	0.00 (−0.10; 0.11)

Values are given with 95% confidence intervals (CI). Predicted peak torque [Nm] = intercept + $\beta 1 \times$ age + $\beta 2 \times$ height + $\beta 3 \times$ body mass. Prediction interval = Predicted peak torque ± 1.96*RSD (SD of the residuals, Table 4)

β unstandardized regression coefficient, *Nm* Newton meter

difference in r^2 was found comparing the isokinetic models with the isometric models [31% (22–40) vs. 28% (23–34)].

Standard deviation of the residuals (RSD)

By subtracting the RSD from the SD of the means, the predicting effect of our explanatory variables could be quantified in absolute values. In the various muscle groups, the absolute value varied from 0.01 to 9.70 Nm for men and from 0.06 to 10.15 Nm for women. The prediction models for muscle strength at the wrist (extension and flexion) and ankle (extension) did not contribute to a clinically relevant narrowing of the prediction intervals (SD − RSD < 1).

Discussion

Gender-specific prediction models were established for maximal isokinetic and isometric strength of major muscle groups in upper and lower extremities in healthy subjects including estimated prediction intervals. The variation in muscle strength that could be explained by the variables age, height, and body mass varied considerably between muscle groups (9–63% for women and 8–43% for men).

The prediction models for women explained more of the variation in muscle strength than for men. Thus, including sex in the prediction models would unnecessarily result in broader prediction intervals for women and more narrow intervals for men underscoring the importance of sex-specific models. As sex is a very strong predictor for maximal muscle strength the r^2 values found in our study seems low compared to the values found in studies where sex has been included in the model. For instance, r^2 for isokinetic knee extension would be 74% if our data were analyzed with a prediction model including sex as an explanatory variable compared to 43% for men and 63% for women in the sex-specific models that we present.

Subtracting the RSD from the SD of the means enable us to quantify the predicting effect of our explanatory variables in absolute values supplementing the r^2 values of the regression analyses. It is noteworthy that gender-specific prediction models for muscle strength at the wrist (extension and flexion) and ankle extension did not contribute to a clinically relevant narrowing of the prediction intervals. Thus expressing the prediction intervals in absolute numbers enables identification of statistically significant r^2 values that are without clinical relevance.

We found that age, height, and body mass explained 9–63% of the variation in maximal strength for women and

Table 2 Predictive models for maximal strength (peak torque) of lower limb muscle groups with inclusion of the explanatory variables age, height and body mass for each sex

Variable	Sex (*n*)	Intercept	β (95% CI)		
			Age (years)	Height (m)	Body mass (kg)
Knee extension	M (77)	81.8	−1.44 (−1.88; −1.01)	41 (−112; 195)	1.25 (0.53; 1.98)
Isokinetic	F (80)	−96.7	−1.00 (−1.27; −0.73)	137 (75; 200)	0.62 (0.21; 1.04)
Knee flexion	M (83)	−90.8	−0.49 (−0.81; −0.17)	80 (−28; 190)	0.82 (0.30; 1.33)
Isokinetic	F (74)	−40.2	−0.48 (−0.67; −0.28)	57 (14; 100)	0.46 (0.12; 0.80)
Knee extension	M (79)	−107.9	−1.40 (−2.04; −0.77)	158 (−67; 384)	1.75 (0.68; 2.83)
Isometric	F (74)	−201.0	−0.96 (−1.50; −0.41)	216 (90; 342)	0.88 (0.05; 1.71)
Ankle extension	M (82)	−13.4	−0.07 (−0.16; 0.01)	23 (−7; 54)	0.10 (−0.05; 0.26)
Isokinetic	F (78)	−11.4	−0.10 (−0.17; −0.03)	16 (1; 32)	0.17 (0.06; 0.27)
Ankle flexion	M (76)	97.7	−0.72 (−1.04; −0.39)	4 (−111; 119)	0.52 (−0.03; 1.08)
Isokinetic	F (77)	33.2	−0.68 (−1.00; −0.36)	24 (−48; 096)	0.59 (0.11; 1.06)
Ankle extension	M (79)	−88.9	−0.04 (−0.17; 0.08)	68 (23; 113)	0.16 (−0.05; 0.37)
Isometric	F (73)	−37.8	−0.04 (−0.14; 0.05)	35 (13; 56)	0.16 (0.01; 0.30)
Hip extension	M (87)	−49.8	−0.97 (−1.50; −0.43)	103 (−91; 298)	1.14 (0.22; 2.06)
Isokinetic	F (83)	−108.7	−0.87 (−1.26; −0.35)	147 (44; 251)	0.50 (−0.20; 1.20)
Hip flexion	M (90)	−79.9	−0.75 (−1.07; −0.44)	107 (−5; 220)	0.79 (0.23; 1.34)
Isokinetic	F (84)	−72.3	−0.42 (−0.64; −0.20)	96 (47; 146)	0.38 (0.05; 0.72)
Hip flexion	M (81)	37.6	−0.72 (−1.11; −0.34)	36 (−99; 171)	1.12 (0.46; 1.78)
Isometric	F (75)	−72.4	−0.20 (−0.47; 0.08)	78 (16; 140)	0.89 (0.47; 1.31)

Values are given with 95% confidence intervals (CI). Predicted peak torque [Nm] = Intercept + β1 × age + β2 × height + β3 × body mass. Prediction interval = Predicted peak torque ± 1.96 × RSD (SD of the residuals, Table 4)

β unstandardized regression coefficient, *Nm* Newton meter

Table 3 Mean and standard deviation (SD) of maximal strength (peak torque) of upper limb muscle groups presented together with the SD of the residuals (RSD), and the correlation coefficient (r^2) from the regression analyses following inclusion of age, height, and body mass for each sex

Variable	Sex (*n*)	Mean peak torque (Nm)	SD of mean (Nm)	RSD (Nm)	r^2
Shoulder abduction	M (88)	59.5	12.0	9.94	0.35
Isokinetic	F (80)	37.4	7.88	6.65	0.32
Shoulder adduction	M (87)	83.1	17.7	16.6	0.14
Isokinetic	F (83)	45.7	9.1	8.23	0.21
Shoulder abduction	M (79)	61.1	14.1	12.3	0.28
Isometric	F (69)	38.0	8.66	6.95	0.38
Elbow extension	M (90)	46.7	9.99	8.92	0.24
Isokinetic	F (83)	27.2	5.53	4.78	0.28
Elbow flexion	M (91)	51.0	12.20	10.7	0.26
Isokinetic	F (83)	27.8	5.79	5.15	0.24
Elbow flexion	M (83)	50.9	13.6	12.3	0.23
Isometric	F (75)	26.5	5.58	4.99	0.23
Wrist extension	M (90)	11.4	3.12	3.05	0.08
Isokinetic	F (72)	6.01	1.68	1.56	0.17
Wrist flexion	M (90)	22.1	5.51	5.00	0.21
Isokinetic	F (78)	13.1	2.81	2.73	0.09
Wrist flexion	M (83)	24.7	7.45	7.05	0.14
Isometric	F (73)	14.4	3.90	3.60	0.18

* r^2 values are estimates of how much of the variation in muscle strength the predictive models explain (interval 0–1). The 95% prediction interval can be estimated as the predicted strength (see Tables 1 or 2) ±1.96 × RSD

Table 4 Mean and standard deviation (SD) of maximal strength (peak torque) of lower limb muscle groups presented together with the SD of the residuals (RSD), and the correlation coefficient (r^2) from the regression analyses following inclusion of age, height, and body mass for each sex

Variable	Sex (*n*)	Mean peak torque (Nm)	SD (Nm)	RSD (Nm)	r^{2*}
Knee extension	M (78)	185.4	39.2	30.1	0.43
Isokinetic	F (80)	121.5	24.5	15.2	0.63
Knee flexion	M (84)	95.1	26.0	22.9	0.26
Isokinetic	F (74)	59.3	13.9	10.3	0.47
Knee extension	M (80)	246.6	56.3	46.7	0.35
Isometric	F (74)	166.6	38.2	30.1	0.41
Ankle extension	M (83)	33.0	6.56	6.29	0.12
Isokinetic	F (78)	21.3	4.62	3.81	0.35
Ankle flexion	M (77)	111.8	25.0	22.3	0.25
Isokinetic	F (77)	76.4	20.0	17.2	0.29
Ankle extension	M (80)	43.5	10.3	9.30	0.22
Isometric	F (73)	27.5	6.11	5.20	0.31
Hip extension	M (88)	178.1	45.6	41.0	0.23
Isokinetic	F (83)	128.7	30.3	25.9	0.30
Hip flexion	M (89)	137.6	29.6	24.6	0.35
Isokinetic	F (83)	91.2	15.8	12.5	0.40
Hip flexion	M (82)	156.2	32.8	28.6	0.27
Isometric	F (75)	104.4	19.2	15.1	0.40

* r^2 values are estimates of how much of the variation in muscle strength the predictive models explain (interval 0–1). The 95% prediction interval can be estimated as the predicted strength (see Tables 1 or 2) ±1.96 × RSD

8–43% for men (range of r^2 values in Tables 3, 4). There are other studies in which assessment of strength in one or two muscle groups has been related to anthropometric variables. Isokinetic strength of knee extensor muscles was closely related to the explanatory variables of our model with correlation coefficients of 63% for women, 43% for men, and 74% if we include gender in the model. This is in line with a previous study of 280 healthy subjects where correlation coefficients of 53 and 64% were found for women and men (Borges 1989) as well as the correlation coefficient of 74% found in a gender-mixed regression model of isokinetic strength including 134 subjects (Gross et al. 1989). Adding physical activity to gender, age, height, and body mass as an explanatory variable increased the correlation coefficient to 85% in a study of isokinetic knee strength in 96 subjects (Neder et al. 1999). For isokinetic ankle plantar flexion, the variables age, circumference of the lower leg, and sex could explain 79% of the variation in a study of 40–64 years aged subjects (Gerdle and Fugl-Meyer 1986) compared to 53% in our study (gender-mixed r^2 value). Inclusion of the lower leg circumference and the narrow age distribution may explain the higher r^2 value compared with our study.

An inverse relation between age and muscle strength was found. This is in line with earlier studies, including isokinetic and isometric strength at the knee (Baron 1995; Borges 1989; Lindle et al. 1997; Lynch et al. 1999; Neder et al. 1999), hip (Cahalan et al. 1989), ankle (Gerdle and Fugl-Meyer 1986), and elbow (Lynch et al. 1999) including populations with different age spans (17–93 years). Expanding the age span to include children from the age of 6 years has indicated that strength increases until an age of 30 years (Falkel 1978; Larsson et al. 1979). Post-hoc regression analysis of our data, however, did not indicate age dependent increases in muscle strength from 15 to 30 years of age and no difference was found between the age group below 30 years and the group from 30 to 39 years (Table 5).

We found that models for the lower extremity muscle groups explained more of the variation in muscle strength compared to the upper extremity muscle groups. Also, at the upper extremity, models for the proximal weight bearing muscles of shoulder abduction explained more of the variation in muscle strength than the more distal joints (elbow and wrist). In particular, body mass is an important predictor in those models probably because of these larger muscle groups' weight-bearing work during standing and walking.

Assessment of physical activity is difficult. Ideally all physical activities during 24-h should be included and day-to-day variation has to be accounted for. The physical activity scale used in the present study is based on a questionnaire of self-reported daily activity on an average week-day. The questionnaire is easily applied, has been validated in Danish population and correlates closely to data recorded in 4 days activity diary (Aadahl and Jorgensen 2003). The level of self-reported daily physical activity expressed in metabolic equivalents only related to maximal strength performance in a few lower extremity muscle groups in women. Leg muscles are particularly

Table 5 Mean ± standard deviation (SD) of maximal strength (peak torque, Nm) of all muscle groups presented in age intervals for each sex

Variable	Sex	Age groups (years)					
		<30	30–39	40–49	50–59	60–69	>70
Knee extension	M	215 ± 41	212 ± 22	192 ± 29	179 ± 40	166 ± 32	146 ± 18
Isokinetic	F	138 ± 17	145 ± 23	127 ± 17	118 ± 18	101 ± 22	92 ± 12
Knee flexion	M	106 ± 30	96 ± 18	94 ± 17	106 ± 37	91 ± 21	72 ± 16
Isokinetic	F	76 ± 9	67 ± 12	58 ± 12	60 ± 13	49 ± 12	48 ± 9
Knee extension	M	265 ± 73	294 ± 39	245 ± 43	259 ± 56	230 ± 41	190 ± 30
Isometric	F	185 ± 47	190 ± 54	172 ± 33	165 ± 24	141 ± 28	142 ± 24
Ankle flexion	M	128 ± 24	118 ± 22	112 ± 23	120 ± 19	105 ± 22	83 ± 24
Isokinetic	F	89 ± 28	89 ± 21	74 ± 13	77 ± 19	67 ± 17	52 ± 10
Ankle extension	M	35 ± 6	33 ± 5	35 ± 9	35 ± 7	31 ± 5	27 ± 4
Isokinetic	F	22 ± 2	25 ± 4	20 ± 3	22 ± 5	18 ± 5	17 ± 3
Ankle extension	M	44 ± 11	44 ± 9	42 ± 9	51 ± 12	42 ± 9	37 ± 7
Isometric	F	29 ± 5	30 ± 6	25 ± 5	28 ± 6	27 ± 8	25 ± 5
Hip flexion	M	154 ± 39	151 ± 17	139 ± 29	148 ± 25	131 ± 21	103 ± 14
Isokinetic	F	96 ± 10	105 ± 15	90 ± 18	90 ± 15	82 ± 9	79 ± 7
Hip extension	M	197 ± 58	202 ± 35	175 ± 39	192 ± 32	172 ± 47	128 ± 26
Isokinetic	F	151 ± 41	149 ± 37	125 ± 28	121 ± 23	126 ± 17	101 ± 26
Hip flexion	M	167 ± 37	170 ± 18	166 ± 31	161 ± 32	147 ± 34	126 ± 14
Isometric	F	101 ± 11	113 ± 21	104 ± 19	105 ± 20	100 ± 21	98 ± 9
Shoulder abduction	M	57 ± 12	67 ± 10	63 ± 10	62 ± 12	57 ± 11	49 ± 9
Isokinetic	F	42 ± 8	40 ± 9	37 ± 8	39 ± 7	32 ± 5	31 ± 6
Shoulder adduction	M	77 ± 14	92 ± 16	88 ± 23	84 ± 14	83 ± 18	71 ± 10
Isokinetic	F	46 ± 14	50 ± 9	46 ± 10	45 ± 9	41 ± 7	42 ± 6
Shoulder abduction	M	60 ± 14	70 ± 9	67 ± 11	64 ± 14	58 ± 16	46 ± 8
Isometric	F	43 ± 13	41 ± 9	38 ± 7	39 ± 7	31 ± 8	32 ± 8
Elbow extension	M	43 ± 11	52 ± 9	49 ± 9	49 ± 11	46 ± 9	40 ± 6
Isokietic	F	28 ± 5	30 ± 6	27 ± 6	26 ± 4	26 ± 6	27 ± 6
Elbow flexion	M	52 ± 14	55 ± 10	54 ± 12	56 ± 12	50 ± 11	39 ± 6
Isokinetic	F	30 ± 6	30 ± 5	28 ± 7	28 ± 5	24 ± 5	23 ± 4
Elow flexion	M	50 ± 18	51 ± 11	59 ± 15	51 ± 11	48 ± 13	44 ± 9
Isometric	F	30 ± 7	28 ± 8	27 ± 6	26 ± 3	24 ± 5	24 ± 4
Wrist extension	M	11 ± 3	11 ± 2	13 ± 3	13 ± 5	11 ± 2	9 ± 2
Isokinetic	F	7 ± 2	7 ± 2	7 ± 2	7 ± 1	6 ± 2	7 ± 1
Wrist flexion	M	21 ± 5	24 ± 3	24 ± 6	24 ± 6	22 ± 6	17 ± 3
Isokinetic	F	13 ± 4	14 ± 3	14 ± 3	13 ± 3	12 ± 2	14 ± 2
Wrist flexion	M	25 ± 6	24 ± 3	24 ± 7	29 ± 9	25 ± 9	19 ± 5
Isometric	F	15 ± 4	16 ± 5	15 ± 3	15 ± 4	12 ± 3	14 ± 2

Mean ± SD of (age; height; body mass) in each age group of males (24 ± 5; 179 ± 6; 74 ± 8) (34 ± 4; 180 ± 5; 82 ± 12) (45 ± 3; 179 ± 4; 82 ± 9) (55 ± 3; 181 ± 5; 82 ± 13) (64 ± 2;179 ± 5; 81 ± 11) (74 ± 4; 174 ± 4; 78 ± 8) and females (25 ± 4; 168 ± 9; 59 ± 10) (35 ± 3; 169 ± 7; 64 ± 6) (44 ± 3; 167 ± 6; 61 ± 7) (56 ± 2; 167 ± 7; 64 ± 11) (63 ± 3; 163 ± 5; 63 ± 12) (73 ± 2; 164 ± 4; 62 ± 7)

involved in most strenuous physical activities and exercises, which probably account for the preference of positive relationship between level of physical activity and maximal strength in leg muscles. A clear association between maximal muscle performance and level of physical activity has not been established for healthy inactive to moderately active subject (Borges 1989; Gerdle and Fugl-Meyer 1986; Neder et al. 1999). This association would probably become evident in a more inhomogeneous population including highly physical active as well as disabled subjects.

Identification of other contributing factors to predict muscle performance and to narrow the estimated prediction intervals is warranted. Muscle fibre characterization in

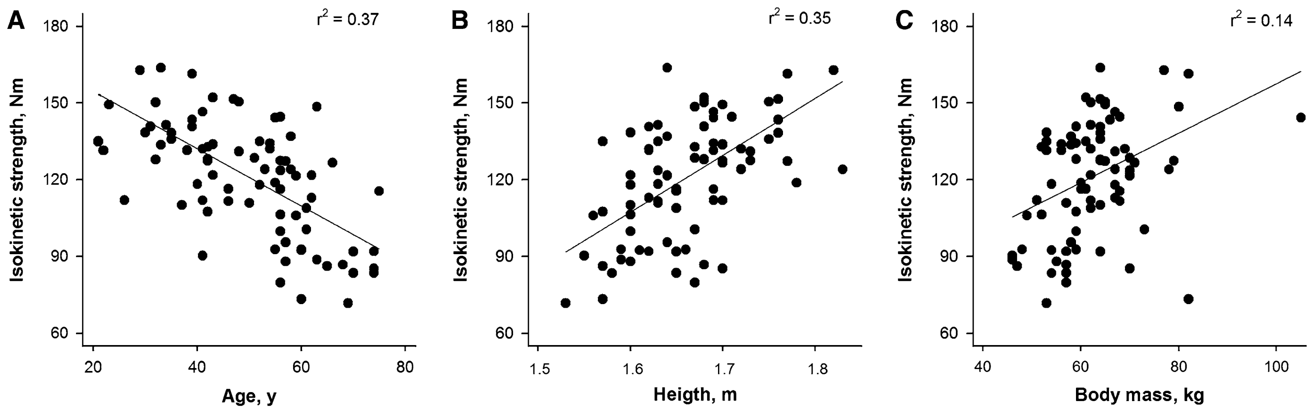

Fig. 1 Maximal isokinetic knee extension strength for women in relation to **a** age, **b** height, and **c** body mass; $n = 80$, *line* = best fit, r^2 = squared product moment correlation coefficient

muscle biopsy (Stalberg et al. 1989), estimation of total muscle mass with stereological MRI techniques (Gadeberg et al. 1999) as well as cross-sectional area of muscles measured with computer tomography (Overend et al. 1992) or ultrasound scanning (Hakkinen et al. 1996) are advanced methods that can increase the explanatory fraction for muscle strength. However, simple available variables such as sex, age, height, and body mass can be expected to predict muscle strength just partly as shown in the present study.

Hereditary variation in gene loci coding for proteins that modulate muscle function and structure can cause severe muscle disease like muscle dystrophy or it can result in a genetic polymorphism without any visible manifestations. Although not being associated with any disease, genetic polymorphisms can have quantitative effects on muscle function and be responsible for variation in muscle performance in normal healthy persons. Alpha actinin 3 is one protein in a family of proteins that bind to actin at the Z-line of type 2 muscle fibres (Beggs et al. 1992). To date, 18% of the world's population are homozygous for a nonsense mutation (R577X) of the gene that codes for alpha actinin 3 leading to complete depletion of the protein (Mills et al. 2001). The alpha actinin 3 phenotype has been associated with elite athletic performance in several studies with a positive impact on power and sprinting abilities, whereas, homozygosity of the R577X mutation has been associated with reduced maximal voluntary isometric contraction strength of elbow flexor muscles in women (Lek et al. 2010). Further insight into genetic polymorphisms having an impact on muscle function and body composition will help us to understand more of the variation in muscle performance.

During the last decades isokinetic dynamometry has been commonly used for the evaluation of muscle strength in sports and medicine. In some situations, however, it is preferable to apply isometric testing. Patients with ataxia, rigidity, or spasticity are often unable to comply with the preset velocity during the whole ROM at isokinetic test protocols. Therefore it is noteworthy that we found very close relations between maximal isokinetic and isometric strength (r^2, 95%). Furthermore, the percentage that our prediction-models could explain was similar for isokinetic and isometric strength.

Normal values in a non-athletic healthy population should be clearly defined before dynamometry is considered a suitable method to quantify strength among patients with motor dysfunction. This study provides clinically useful reference materials for interpretation of maximal isokinetic and isometric voluntary strength obtained at standardized conditions. Presentation of prediction intervals along with the estimated mean value for normal strength is important as the wide ranges for normal strength should be considered. The models are based on the prediction variables sex, body mass, height and age, only. In the future, addition of other variables such as genetic factors or muscle mass estimation may further narrow these intervals. Nevertheless, this quantitative measure is a valid evaluation tool that together with other functional measures enables assessment of weakness and planning of a rehabilitation process based on objective measures.

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Conflict of interest The authors report no conflicts of interests.

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