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ALLOMETRICALLY ADJUSTED ISOKINETIC LEG EXTENSION TORQUE OF ADULTS IN RELATION TO BODY MASS

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Abstract. The purpose of the study was to examine the isokinetic leg extension torque of adult participants using allometric scaling to account for differences in body mass. 10 men (23.1y, 1.72m & 64.5kg) and nine women (20.7y, 1.62m & 52.1kg) participated in the study. Peak isokinetic leg extension torque at 1.02, 3.12 and 5.20 $rad \cdot s^{-1}$ were determined using a Cybex 6000 isokinetic dynamometer. Torque at 1.04 $rad \cdot s^{-1}$ was significantly higher than torque at 3.12 $rad \cdot s^{-1}$ and 5.20 $rad \cdot s^{-1}$ in men and women. Torque in newton.metre in men were 162.5, 167.3 and 151.3% but were reduced to 130.2, 126.2 and 121.8% that of women when the data were allometrically scaled to body mass$^{b=0.89,\ 1.13\ \&\ 0.97}$. Common identified b exponents between torque and body mass included b=1.0 within the 95% confidence intervals, as predicted by geometric similarity theory.

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Key words: Allometric scaling - Leg extension torque

Introduction

The literature is replete with sex differences in isokinetic leg extension torque at multiple angular velocities [5] but more commonly at a single angular velocity [1] in young people and in adults. The magnitude of the sex difference in isokinetic torque is between 40 and 60%, depending on the test protocol and the muscle segment assessed [2].

However, differences in isokinetic testing protocols exist-some of these differences are in the muscle groups being assessed (e.g. lower extremity vs. upper extremity), the posture adopted during the assessment (e.g. upright vs. supine), the angular velocity or velocities assessed and the torque of interest (extension, flexion, concentric, eccentric or composite).

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Equally important is the treatment of the data and the statistical approaches used to compare the data between groups and across different studies. Most studies use non-normalised data (i.e. absolute torque) and ratio-scaled data (torque divided by body mass$^{1.0}$, fat-free body mass$^{1.0}$ or thigh muscle volume$^{1.0}$) to compare sex differences in torque or differences in torque across different studies [13]. Yet, in most cases, the common b exponents that exactly describe the relationship between isokinetic torque and body mass not exactly equal to 1.0 [4].

Allometric scaling of performance data in relation to a body size descriptor has been advocated as statistically tenable alternative to ratio-scaling in more appropriately accounting for body size differences in generating a size independent power function ratio, which is performance variable/body size b exponent [7,13]. There is a growing acceptance that allometric scaling should be employed in the statistical treatment of torque data but the method is infrequently employed [7,12].

Therefore the purpose of the study was to examine the isokinetic leg extension torque of men and women using allometric scaling in relation to body mass.

Material and Methods

Participants and testing arrangement: Ten men and nine women with informed consent participated in the study. Testing took place over two occasions within 14 days and all assessments were made between 0900 hours and 1200 hours. Men and women were tested in two separate sessions.

On the first laboratory visit, participants' anthropometric measurements (i.e. stature, body mass and body mass index) were computed using standardised procedures and calibrated equipment. All participants were right lower limb dominant. Familarisation procedures for the isokinetic strength assessment involved two practice trials in which three repetitions of sub-maximal and maximal effort leg extension of the right lower limb at each of three test velocities (60^0, 180^0 and $360^0 \cdot s^{-1}$) were conducted.

The second laboratory visit was devoted to assessments of isokinetic strength at three velocities. The test order was randomised for each participant. All participants were instructed to refrain from strenuous exercise at least 12 hours before the tests.

Isokinetic leg extension torque assessment: Isokinetic strength tests for concentric leg extension of the right lower limb were conducted using a calibrated Cybex 6000 dynamometer. Prior to testing, each participant adhered to a standardised warm-up routine that consisted of two minutes of passive stretching for the quadriceps and hamstring group of muscles of the right lower limb, and three submaximal trials at each test velocity. Care was taken to ensure that each participant was correctly positioned in the apparatus, with the lever arm individually adjusted for body size.

The range of motion for all the tests was set from 90^0 (1.57 rad) flexion to 180^0 (3.14 rad) extension of the leg with the range stop control set at 'soft'. Restraining straps were used to minimise upper body movement. Before each test commenced, gravity correction was carried out in accordance to the recommendations described by Nelson and Duncan [14]. Right lower limb isokinetic extension torque was assessed at three velocities- 60^0 (1.04 rad), 180^0 (3.12 rad) and 300^0(5.20 rad)$\cdot s^{-1}$. The order of the velocity set was randomised.

The maximal torque assessment involved three maximal voluntary innervations of leg extension at each velocity set, with a passive rest interval of 90 s between the three test velocities [8]. All participants were verbally encouraged to give a maximal effort during testing.

Statistical analyses: All relevant data were stored and analysed using SPSS for Windows (Version 11.0). The Shapiro-Wilks and Levene tests were used to check for normality of distribution and homogeneity of variance in the torque data sets. Descriptive statistics of the participants were generated.

One-way ANOVA was used to identify differences in the sexes for physical characteristics, peak isokinetic leg extension torque. Effect size (ES= difference in mean divided by pooled standard deviation) was calculated to determine the meaningfulness of the difference between the means [11].

Allometric analyses were performed using SPSS general liner model (general factorial) with Ln of isokinetic torque at each angular velocity entered as the dependent variables, Ln of sex (sex dummy codes: 2=female, 3=male), entered as the fixed factor, and Ln of body mass and Ln of age entered as covariates.

Adjusted means [13] were subsequently computed. These represented the antilogs of the log values derived from analyses of covariance (ANCOVAs) on log-transformed data. Statistical significance was accepted at $p<0.05$.

Results

Normality of distribution and homogeneity of variance: Checks for normality of distribution and homogeneity of variance for peak isokinetic leg extension torque showed that there were normality of distribution (all Shapiro-Wilks statistics, $p>0.05$) and homogeneity of variance (all $p>0.05$).

Descriptive data of men and women: The descriptive statistics of men and women are summarized in Table 1.

Table 1
Descriptive characteristics of male and female adults

Variable	Men (n=10)	Women (n=9)
Age (y)	23.1±0.9	20.7±2.9∗
Stature (m)	1.72±0.06	1.62±0.07∗
Body mass (kg)	64.5±5.8	52.1±8.5∗

Values are mean ±SD; ∗denotes p<0.0

Men were significantly older, taller, and heavier then women.

Peak isokinetic leg extension torque: Peak isokinetic leg extension torque of men was significantly greater than women at 60^0 (1.04 rad)·s^{-1} (202.71±26.93 vs.124.78±22.16 Nm, p<0.05, ES=3.20), at 180^0 (3.12 rad)·s^{-1} (135.14±27.46 vs.80.78±19.12 Nm, p<0.05, ES=2.33) and at 300^0 (5.20 rad)·s^{-1}(104.57±18.99 vs.69.11±14.99 Nm, p<0.05, ES=2.08). Torque at 1.04 rad·s^{-1} was significantly higher than torque at 3.12 rad·s^{-1} and 5.20 rad.s^{-1} in men and women.

Results of allometric scaling revealed no significant interaction effects for sex and body mass or sex and age (both p>0.05), indicating that men and women shared common *b* exponents for body mass and similar *b* exponents for age.

Common *b* exponents for men and women that described the allometric relationships between composite leg extension and flexion torque at 60^0 (1.04 rad)·s^{-1}, 180^0 (3.12 rad)·s^{-1} and 300^0 (5.20 rad)·s^{-1} and body mass were mean (95% confidence interval): 0.89 (-0.68 to 2.62), 1.13 (-1.59 to 3.04) and 0.97 (-1.86 to 2.71), respectively.

Allometrically adjusted peak isokinetic leg extension torque for men and women are summarized in Fig. 1. In essence, the adjusted means for torque at 60^0 (1.04 rad)·s^{-1}, 180^0 (3.12 rad)·s^{-1} and 300^0 (5.20 rad)·s^{-1}, for men were significantly higher than in women.

Fig. 1 shows that isokinetic torque in men were 130.2%, 126.2% and 121.8% that of women at 60^0 (1.04 rad)·s^{-1}, 180^0 (3.12 rad)·s^{-1} and 300^0 (5.20 rad)·s^{-1}, respectively, after allometrically accounting for differences in body mass.

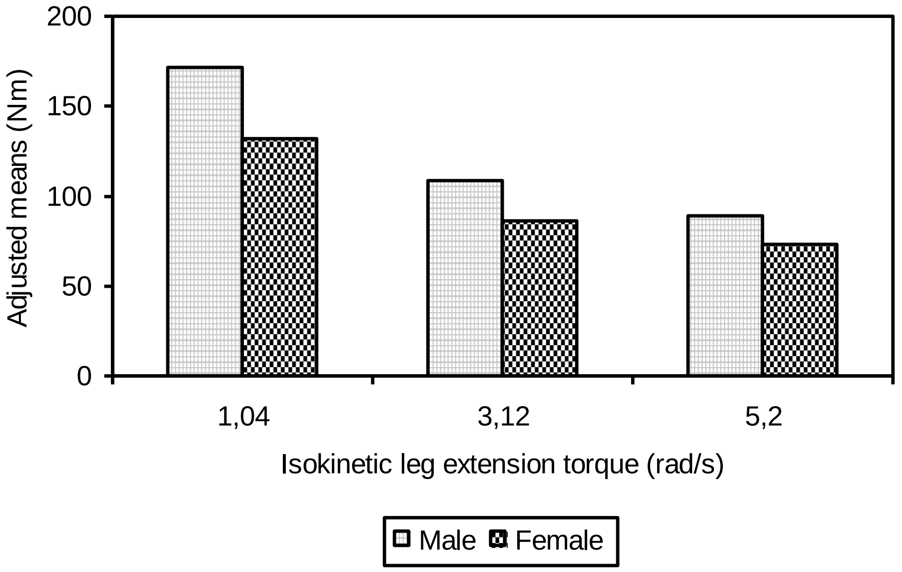

Fig. 1
Allometrically adjusted means of leg extension torque of women and men at 1.04, 3.12 and 5.20 rad·s^{-1}; Data show that men had significantly ($p<0.05$) greater isokinetic leg extension torque than women at 1.04, 3.12 and 5.20 rad·s^{-1}.

Discussion

Participant characteristics: Results showed that men were significantly older, taller, had greater body mass and lower body mass index than women. These anthropometric data are in agreement with the age and sex specific data reported in a National Health Survey in Singapore [9].

Peak isokinetic leg extension torque: In the extant literature, peak leg extension or leg flexion torques at multiple velocities [5,12] or single velocity [1] have been used to describe lower limb muscle strength.

Peak composite isokinetic torque generated at 60^0 (1.04 rad), 180^0 (3.12 rad) and 300^0 (5.20 rad·s^{-1}) in men and women mirror findings reported in the literature. Absolute torque in Newton metre (Nm) generated at a lower angular velocity (i.e. 1.04 rad·s^{-1}) was significantly higher than the torque generated at a higher angular velocity (i.e. 5.20 rad·s^{-1}) [5,8] in men and in women.

In the study, peak isokinetic leg extension torque generated at 1.04 rad·s^{-1} was 50.0-54.5% higher than at 3.12 rad·s^{-1}, which in turn was 16.9-29.2% higher than torque generated at 5.20 rad·s^{-1} in men and women. These results are in accord with findings reported by De Ste Croix *et al.* [5] in young people and by Weir *et al.* [12] in adults.

Sex difference in isokinetic leg extension torque: Sex difference in isokinetic leg extension torque in absolute terms at 1.04, 3.12 and 5.20 rad·s^{-1} were significant, with women generating 61.5%, 59.8% and 66.1% of the torque attained by men at the same angular velocities. These results are in accord with those reported in the literature where sex-related differences in muscle strength have been reported at between 40% and 80% depending upon the measurement protocol used, the participants tested and the body segment tested [8].

The magnitude of sex differences in isokinetic torque or muscle strength varies across different studies depending on whether the torque data are normalized or non-normalised. When the data are normalized, the sex difference also depends on the choice of the body size descriptor (e.g. body mass, muscle cross-sectional surface area, thigh muscle volume, etc), and the method used to normalized the data (e.g. ratio standards, linear regression adjustment or allometric scaling).

In the present study, when the isokinetic leg extension torque was allometrically adjusted for body mass at the specific angular velocities, the sex difference in torque was reduced but remained significant. Women generated 76.8%, 79.2% and 82.1% of the values attained by men for allometrically adjusted isokinetic leg extension torque at 1.04, 3.12 and 5.20 rad·s^{-1}, respectively.

These findings are in accord with the findings of others who reported on sex difference in isokinetic torque among athletes [6,12] and non-athletes [5], albeit the comparisons between male and female performance were reported in absolute terms and ratio-scaled to body mass or fat-free body mass. Like the results of the present study, the sex differences in isokinetic torque were reduced when attempts at normalizing the torque for differences in body size were made.

Weir *et al.* [12] demonstrated an age effect for peak isokinetic leg extension in 72 competitive female gymnasts (mean age 15.7 years) and 150 male high school wrestlers (mean age 16.6 years), using multivariate allometric scaling to control for differences in body size. The age and fat free mass-adjusted sex differences in leg extension torque were reported as 14.9, 16.7 and 13.6% at angular velocities- 1.04, 3.12 and 5.20 rad·s^{-1}, respectively. In the present study, it is plausible that some of the sex difference in composite isokinetic torque could be attributed to an age effect since the men were significantly older than the women.

Differences in the magnitude of the sex differences across different studies could be attributed to the scaling methods used to normalize the torque data, the angular velocities and muscle groups tested, differences in participant characteristics such as entry level of strength fitness, body composition or to the choice of the body size descriptor such as body mass, fat free mass, muscle cross-sectional area or thigh muscle volume.

Allometric scaling of isokinetic leg extension torque in relation to body mass: Allometric scaling of isokinetic torque is infrequently practiced but there is growing conviction among researchers that the technique can more appropriately produce a body size-independent variable [7,13] and can more exactly explain the relationship between the performance descriptor (e.g. composite torque) and the body size descriptor (e.g. body mass) [4].

In the study, common b exponents identified for men and women between isokinetic torque and body mass were 0.89, 1.13 and 0.97, respectively for torque assessed at angular velocities of 1.04, 3.12 and 5.02 $rad \cdot s^{-1}$. In essence, where the b exponent is less than 1.0, torque increases slower for an equivalent increase in body mass and where the b exponent is greater than 1.0, then torque increases faster for an equivalent increase in body mass.

It is noteworthy that for the isokinetic leg extesnion torque at the three tested angular velocities, the identified *b* exponent included 1.0 within the 95% confidence interval for the identified *b* exponent, in agreement to that predicted by geometric similarity theory [7]. However, it is important to note that human beings are not and do not behave as geometrically similar entities because of differences in body composition and differences in tissue density between individuals [4]. This would plausibly explain why the derived mean common *b* exponents were not exactly 1.0.

Conclusion

The present study examined the isokinetic leg extension torque of the right lower limb in relation to body mass using allometric scaling. Results showed that men generated significantly higher leg extension torque than women in absolute terms but the sex differences were reduced when the torque data were allometrically adjusted for differences in body mass.

Common *b* exponents identified for isokinetic leg extension torque included 1.0 within the 95% confidence interval in agreement to geometric similarity theory. Differences in common *b* exponents identified across studies could be attributed to the muscle segments assessed, the angular velocities tested, the choice of the body size descriptor and participant heterogeneity.

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