

Article

Conventional Ratio Scaling Overcorrects for Body Mass When Evaluating Isokinetic Knee Strength in Elite Female Soccer Players

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Abstract

Isokinetic knee strength is commonly normalized to body mass, although this assumes that torque increases in direct proportion to mass. This study tested whether conventional ratio scaling removed body-mass dependence from concentric knee-extensor and knee-flexor peak torque in elite female soccer players. Sixty-seven preseason assessments from 46 players were analyzed. Bilateral mean peak torque was calculated at $60^{\circ}\cdot\text{s}^{-1}$ and $300^{\circ}\cdot\text{s}^{-1}$, and log-linear models estimated the exponent b in $\text{torque} = a \cdot \text{mass}^b$ using player-clustered standard errors. Player-mean sensitivity analyses and leave-one-player-out internal cross-validation were also performed. Body mass was positively associated with absolute torque but negatively associated with torque divided by body mass. The estimated exponents were 0.562 and 0.551 for quadriceps and hamstring torque at $60^{\circ}\cdot\text{s}^{-1}$ and 0.349 and 0.374 at $300^{\circ}\cdot\text{s}^{-1}$. All confidence intervals excluded 1.00. Player-mean estimates were similar, and cross-validated residuals showed little remaining linear association with body mass within this cohort. Knee torque increased with body mass, but less than proportionally. Direct division by body mass therefore overcorrected for size and tended to favor lighter players. Absolute torque should continue to be reported, while the sample-specific exponents require external validation before broader application.

Keywords: women's football; isokinetic dynamometry; peak torque; allometric scaling; strength normalization

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1. Introduction

Isokinetic dynamometry provides a controlled measure of knee-extensor and knee-flexor torque at prescribed angular velocities [1]. In soccer, these measures are used to describe strength capacity, monitor rehabilitation and training, and examine bilateral or agonist–antagonist differences [1–3]. Their interpretation, however, depends on whether the purpose is to describe total torque or to compare strength after accounting for body size.

Evidence specific to female soccer remains limited and methodologically heterogeneous. Studies on knee isokinetic testing in female players vary with respect to contraction mode, angular velocity, range of motion, and reported outcomes, which restricts direct comparison across settings [4]. Studies in professional female players have reported absolute and body-mass-normalized peak torque [5,6], while angle-specific knee-extensor and knee-flexor torque has also been examined [7]. Recent work has further linked lower-body strength with body composition and explosive performance in female soccer players [8].

Absolute torque generally rises with body size because larger athletes tend to possess more contractile tissue and may have larger joint moment arms. A common adjustment is to divide torque by body mass and report $\text{N}\cdot\text{m}\cdot\text{kg}^{-1}$. This procedure assumes direct proportionality. In the allometric model $Y = aX^b$, Y is torque, X is body mass, a is a constant, and b is the scaling exponent. Ratio scaling fixes b at 1.00. This is appropriate only when a given percentage difference in body mass is accompanied by the same percentage difference in torque.

Theoretical and empirical work has proposed an exponent near 1.00 for torque in relatively lean populations [9,10]. Other work has shown that the appropriate exponent depends on the strength measure and the body composition characteristics of the sample [11]. Folland et al. [11], for example, reported lower body mass exponents when fat mass contributed more strongly to variation in total mass. Previous isokinetic research has also used allometric models across different testing velocities [12]. More generally, a normalized score should be judged by whether it removes residual body size dependence rather than by whether the denominator is familiar [13,14].

When a true exponent is below 1.00, torque increases with body mass but less than proportionally. Dividing by the full body mass can then create an inverse association: a heavier athlete may produce greater absolute torque but receive a lower $\text{N}\cdot\text{m}\cdot\text{kg}^{-1}$ score. A sample-derived exponent will remove the fitted linear association in the sample data by construction, so an in-sample residual check is not sufficient. More credible evaluation requires player-level sensitivity analysis and the calculation of adjusted scores for players excluded from model development.

Two related but distinct questions should therefore be considered. The first is whether direct normalization of knee torque to total body mass is appropriate in this population. The second is whether body mass is the biologically optimal variable for scaling knee torque compared with measures of body composition. The present study was designed primarily to address the first question because conventional reporting in female soccer commonly expresses torque relative to total body mass. Body composition was therefore examined in sensitivity analyses rather than used as the primary scaling variable.

The primary aim of this study was therefore to test whether the exponent of 1.00 imposed by conventional ratio scaling was supported for concentric knee-extensor and knee-flexor peak torque at $60^\circ\cdot\text{s}^{-1}$ and $300^\circ\cdot\text{s}^{-1}$. Although limitations of simple ratio scaling have been demonstrated in other strength and athletic populations, the appropriate scaling exponent cannot be assumed to be identical across populations, strength measures, or testing conditions. In female soccer, isokinetic knee strength is commonly reported in absolute terms or normalized directly to body mass, but whether the exponent of 1.00 is appropriate for knee-extensor and knee-flexor torque at commonly used low and high angular velocities has not been directly established. The present study therefore addresses a population- and test-specific question rather than proposing a new general principle of strength scaling. Secondary aims were to examine the stability of the estimates when each player contributed equally, evaluate residual body-mass dependence using leave-one-player-out internal cross-validation, and test whether the scaling exponent differed between angular velocities. We hypothesized that torque divided by body mass would remain inversely associated with body mass when the observed exponent was below 1.00,

whereas cross-validated allometric residuals would show little remaining size dependence.

2. Materials and Methods

A retrospective repeated-assessment observational design was used. The dataset comprised routine preseason isokinetic assessments of female players competing in the highest national division. Assessments were conducted during the preseason periods preceding the 2022–2023 ($n = 10$), 2023–2024 ($n = 16$), 2025–2026 ($n = 20$), and 2026–2027 ($n = 21$) competitive seasons. Assessments with complete body-mass data and bilateral knee-extension and knee-flexion peak torque values at both angular velocities were retained, resulting in 67 assessments from 46 individual players. Twenty-nine players contributed one assessment, 15 contributed two assessments, and two contributed four assessments. The sample included players aged 18–34 years who had body mass and bilateral values available at both angular velocities. The sample comprised 5 goalkeepers, 11 defenders, 12 midfielders and 18 forwards. Body composition was assessed using bioelectrical impedance analysis as part of the routine preseason anthropometric assessment. Body mass and body-fat percentage were recorded for each assessment. Assessments were performed at approximately the same time of day for this team and, across seasons, were scheduled at approximately the same point of the preseason period each year. All players were injury-free at the time of testing and were competing in Division 1. Players who reported a knee musculoskeletal injury or knee surgery during the preceding six months were excluded. No a priori sample size calculation was performed because the study used a retrospective convenience sample comprising all eligible assessments available during the study period. The study was conducted in accordance with the Declaration of Helsinki and was approved by the National Committee of Bioethics.

2.1. Isokinetic Assessment

Isokinetic testing was performed using a HUMAC NORM isokinetic dynamometer (CSMi, Stoughton, MA, USA), following procedures previously used in our laboratory [15]. Gravity correction and dynamometer calibration were applied according to the manufacturer's recommendations. Participants were seated with the trunk positioned at approximately 85° relative to the thigh, and the axis of rotation of the dynamometer was aligned with the lateral femoral epicondyle. The knee range of motion was set at 100° . The thigh, ankle and upper body were secured using straps to minimize compensatory movement. All players were familiar with the testing procedures, as isokinetic assessment formed part of their routine performance monitoring.

Before testing, the players completed a 5 min warm-up on a mechanically braked cycle ergometer. The dominant leg was tested first in all participants to ensure a consistent testing order. Once positioned on the dynamometer, participants performed three sub-maximal concentric knee extension and flexion repetitions for familiarization at both $60^\circ \cdot s^{-1}$ and $300^\circ \cdot s^{-1}$. After a 1 min rest period, participants completed three maximal concentric knee extension and flexion repetitions at $60^\circ \cdot s^{-1}$. Following a further 1 min rest, they completed five maximal concentric knee extension and flexion repetitions at $300^\circ \cdot s^{-1}$. Standardized verbal encouragement was provided throughout all tests, and all assessments were conducted by the same experienced examiner. The highest peak torque recorded for the knee extensors and flexors at each angular velocity was retained for subsequent analysis.

Players with relevant musculoskeletal injuries or recent surgery, as well as assessments showing substantial inter-limb strength asymmetry, were excluded from the analysis. For each assessment, bilateral mean peak torque was calculated as $(\text{right} + \text{left})/2$ for the quadriceps and hamstrings at each angular velocity. Bilateral means were used

because the research question concerned player-level body-size scaling rather than limb asymmetry. The four outcomes were quadriceps and hamstring peak torque at $60^\circ\cdot\text{s}^{-1}$ and $300^\circ\cdot\text{s}^{-1}$. Conventional ratio scaling was calculated as bilateral mean torque divided by body mass.

2.2. Statistical Analysis

Continuous variables were summarized as mean $\pm$ standard deviation, median [interquartile range], and range. The scaling analysis was based on the allometric model $\text{torque} = a \cdot \text{mass}^b$, where torque was the bilateral mean peak torque, mass was body mass in kilograms, a was a proportionality constant, and b was the body-mass scaling exponent. The exponent b describes the percentage change expected in torque for a 1% change in body mass. An exponent of 1.00 represents direct proportionality: for example, a 10% greater body mass would be expected to correspond to approximately 10% greater torque. An exponent below 1.00 indicates that torque increases with body mass, but less than proportionally. The allometric equation was converted to a linear form by taking natural logarithms of torque and body mass: $\ln(\text{torque}_{ij}) = \beta_0 + b \cdot \ln(\text{body mass}_{ij}) + \varepsilon_{ij}$, where $\beta_0 = \ln(a)$, i denotes an assessment, and j denotes a player. In this log–log regression, b is the slope of the fitted line. It was estimated by ordinary least squares as the change in $\ln(\text{torque})$ associated with a one-unit change in $\ln(\text{body mass})$. This formulation also allows b to be interpreted as an elasticity: a 1% difference in body mass is associated with an expected $b\%$ difference in torque. For a larger difference in mass, the exact expected percentage difference in torque can be obtained from $[(\text{mass ratio})^b - 1] \times 100$.

Four separate models were fitted: quadriceps and hamstring peak torque at $60^\circ\cdot\text{s}^{-1}$ and $300^\circ\cdot\text{s}^{-1}$. All 67 retained assessments were included in the primary models. The assessment-level analysis was used because each preseason assessment provided a distinct observed combination of body mass and knee torque. The resulting exponent was interpreted as describing the torque–body-mass relationship across the observed assessments and not as an estimate of within-player longitudinal change in torque with changing body mass. Averaging repeated assessments within players before fitting the model would remove this assessment-level variation and would instead describe the relationship between each player's mean body mass and mean torque. Because some players contributed more than one assessment, observations from the same player were not treated as independent. Regression coefficients, including b , were estimated by ordinary least squares, with player-clustered robust standard errors used to account for repeated observations within players. Confidence intervals and Wald tests used a t distribution with 45 degrees of freedom, corresponding to the 46 player clusters. Conventional ratio scaling was evaluated directly by testing $H_0: b = 1.00$. Dividing torque by body mass is mathematically equivalent to fixing the mass exponent at 1.00 because $\text{torque}/\text{body mass} = \text{torque} \cdot \text{mass}^{-1}$. Ratio scaling can therefore be considered body-size neutral only when the observed torque–mass relationship is compatible with direct proportionality. When the estimated exponent is below 1.00, division by the full body mass applies a stronger correction than the observed relationship supports and can create an inverse association between the ratio score and body mass.

To describe body-mass dependence without treating repeated measurements as independent, Pearson correlations were calculated from one averaged value per player. These correlations examined the association of body mass with absolute torque and with torque divided by body mass. They were used to show whether conventional normalization removed, retained or reversed the association with body size; they were not used to estimate the allometric exponent.

Two robustness analyses were performed. First, repeated assessments were averaged within player, and the log–log regression was refitted using the 46 player means. This

gave each player equal weight and allowed us to examine whether the primary estimates were materially affected by the unequal number of assessments contributed by individual players. Similar exponents in the assessment-level and player-mean analyses were taken as evidence that the main conclusion was not driven by players who contributed more than one assessment. Second, leave-one-player-out internal cross-validation was used to assess whether the allometric adjustment removed body-mass dependence for players who had not contributed to the equation used to evaluate them. Each player, together with all of her assessments, was omitted in turn. The allometric equation was then estimated from the remaining 45 players, and the omitted player's predicted $\ln(\text{torque})$ was calculated from her $\ln(\text{body mass})$. Her held-out residual was defined as observed $\ln(\text{torque})$ minus predicted $\ln(\text{torque})$. A positive residual indicated torque above that expected for body mass, whereas a negative residual indicated torque below that expected. When a player had repeated assessments, her held-out residuals and $\ln(\text{body mass})$ values were averaged so that she contributed only once to the final correlation. The correlation between these cross-validated residuals and $\ln(\text{body mass})$ was then examined. A correlation close to zero indicated little remaining linear body-mass dependence. This procedure reduced the circularity of assessing residuals in the same observations used to estimate the equation, although it remained an internal rather than an external validation.

Because body-fat percentage varied considerably within the sample, an additional sensitivity analysis was performed to examine whether body composition influenced the estimated body-mass scaling relationship. Body-fat percentage was first added as a covariate to each log–log model. A second model included a body mass $\times$ body-fat percentage interaction to test whether the association between body mass and torque differed according to body-fat percentage. Player-clustered robust standard errors were retained for these analyses.

Differences between angular velocities were examined separately for quadriceps and hamstrings using a combined model containing $\ln(\text{body mass})$, velocity, and their interaction, with player-clustered standard errors. The interaction coefficient represented the difference between the exponent at $300^\circ\cdot\text{s}^{-1}$ and the exponent at $60^\circ\cdot\text{s}^{-1}$. Model form and residual behavior were examined using log–log scatterplots, residual-versus-fitted plots and quantile–quantile plots. Diagnostic plots for the four primary log–log models are provided in Supplementary Figures S1–S12. To further examine the potential influence of body composition, estimated fat-free mass was calculated as body mass $\times (1 - \text{body-fat percentage}/100)$. The four log–log models were then refitted with fat-free mass in place of total body mass as the scaling variable. The exponent was estimated using the same assessment-level approach and player-clustered robust standard errors as in the primary analysis, and direct proportionality was evaluated by testing $H_0: b = 1.00$. Statistical significance was set at $p < 0.05$, but interpretation prioritized the estimated exponents, confidence intervals, consistency across analyses, and external validity. Statistical analyses were performed using Python version 3.13.5 with pandas version 2.2.3, NumPy version 2.3.5, SciPy version 1.17.0, and statsmodels version 0.14.6.

3. Results

The analysis included all 67 assessments from 46 individual players. Mean age was 23.9 ± 4.7 years, stature was 166.9 ± 5.4 cm, and body mass was 61.4 ± 6.8 kg. The characteristics in Table 1 describe assessments rather than 67 independent players. The bilateral mean concentric peak torque values at both angular velocities are presented in Table 2.

Table 1. Record-level characteristics of the 67 retained assessments.

Variable	Mean $\pm$ SD	Range
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Age (years)	23.9 ± 4.7	18–34
Stature (cm)	166.9 ± 5.4	157.0–184.0
Body mass (kg)	61.4 ± 6.8	49.4–77.7
Body fat (%)	18.2 ± 5.8	7.1–33.5

Table 2. Bilateral mean concentric peak torque in the 67 retained assessments.

Isokinetic Peak Torque	Mean ± SD (N·m)	Range (N·m)
Quadriceps, 60°·s ^{−1}	143.3 ± 20.6	103.5–202.0
Hamstrings, 60°·s ^{−1}	104.5 ± 15.1	73.0–137.0
Quadriceps, 300°·s ^{−1}	75.7 ± 8.1	57.5–93.5
Hamstrings, 300°·s ^{−1}	66.0 ± 9.3	46.5–91.5

3.1. Primary Body-Mass Allometric Models

Body mass was positively related to each absolute torque outcome. All four estimated exponents were below 1.00, and every 95% confidence interval excluded 1.00. The direct-proportionality assumption imposed by conventional ratio scaling was therefore not supported in this cohort (Table 3).

Table 3. Log-linear body-mass exponents from 67 assessments. Confidence intervals and tests use player-clustered standard errors and 45 degrees of freedom.

Isokinetic Peak Torque	Exponent b (95% CI)	<i>p</i> for b = 1	Model R ²
Quadriceps, 60°·s ^{−1}	0.56 (0.29–0.83)	0.002	0.19
Hamstrings, 60°·s ^{−1}	0.55 (0.26–0.84)	0.003	0.18
Quadriceps, 300°·s ^{−1}	0.35 (0.06–0.64)	<0.001	0.13
Hamstrings, 300°·s ^{−1}	0.37 (0.13–0.62)	<0.001	0.09

3.2. Body-Mass Dependence Before and After Adjustment

At player level, absolute torque showed small-to-moderate positive associations with body mass. Dividing torque by body mass reversed the direction of the relationship and produced negative associations for all four outcomes. The association was strongest for quadriceps torque at 300°·s^{−1}. Leave-one-player-out residuals showed little remaining linear association with body mass, with all correlations having absolute values below 0.05 (Table 4).

Table 4. Player-level association based on 46 player means (leave-one-player-out internal cross-validation).

Outcome	Absolute Torque: <i>r</i> (<i>p</i>)	Torque/Body Mass: <i>r</i> (<i>p</i>)	LOPO Residual vs. ln(Mass): <i>r</i> (<i>p</i>)
Quadriceps, 60°·s ^{−1}	0.39 (0.008)	−0.34 (0.022)	−0.01 (0.950)
Hamstrings, 60°·s ^{−1}	0.42 (0.003)	−0.38 (0.009)	−0.02 (0.890)
Quadriceps, 300°·s ^{−1}	0.31 (0.034)	−0.58 (<0.001)	−0.04 (0.799)
Hamstrings, 300°·s ^{−1}	0.23 (0.124)	−0.49 (0.001)	−0.04 (0.789)

3.3. Player-Level Sensitivity Analysis

When repeated assessments were averaged within player, the exponents remained below 1.00 and were close to the primary estimates. All four player-mean exponents remained significantly below 1.00, consistent with the primary analysis (Table 5).

Table 5. Sensitivity analysis based on one averaged observation per player (*n* = 46).

Outcome	Player-Mean Exponent b (95% CI)	<i>p</i> for b = 1	Model R ²
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Quadriceps, 60°·s ⁻¹	0.55 (0.18–0.93)	0.022	0.17
Hamstrings, 60°·s ⁻¹	0.52 (0.18–0.86)	0.007	0.18
Quadriceps, 300°·s ⁻¹	0.31 (0.01–0.61)	<0.001	0.09
Hamstrings, 300°·s ⁻¹	0.32 (−0.05–0.69)	<0.001	0.07

3.4. Body-Composition Sensitivity Analyses

Including body-fat percentage as a covariate did not materially change the estimated body-mass exponents. The adjusted exponents were 0.608 and 0.596 for quadriceps and hamstring torque at 60°·s⁻¹ and 0.429 and 0.479 at 300°·s⁻¹, respectively. Body-fat percentage was not independently associated with torque in any model (all $p \geq 0.226$). There was also no evidence that body-fat percentage modified the relationship between body mass and torque, with all body mass $\times$ body-fat interactions being non-significant (all $p \geq 0.346$). When estimated fat-free mass was used instead of total body mass as the scaling variable, the exponents were 0.568 (95% CI 0.246–0.889) and 0.555 (95% CI 0.184–0.926) for quadriceps and hamstring torque at 60°·s⁻¹, respectively, and 0.419 (95% CI 0.134–0.705) and 0.474 (95% CI 0.144–0.804) at 300°·s⁻¹. These values were slightly closer to 1.00 than the corresponding body-mass exponents, particularly at 300°·s⁻¹, but all four confidence intervals remained below 1.00 (all $p < 0.020$ for $b = 1.00$).

3.5. Comparison Between Angular Velocities

The estimated exponent was lower at 300°·s⁻¹ than at 60°·s⁻¹ for both muscle groups. The body mass $\times$ velocity interaction was not statistically significant for quadriceps (difference −0.213, 95% CI −0.455 to 0.029; $p = 0.083$) or hamstrings (difference −0.177, 95% CI −0.469 to 0.116; $p = 0.230$). There was therefore no statistical evidence that the body-mass scaling exponent differed between the two angular velocities.

4. Discussion

The main finding was that dividing isokinetic knee torque by body mass did not produce a body-size-independent measure of strength in this cohort of elite female soccer players. Absolute quadriceps and hamstring torque generally increased with body mass, but the increase was less than proportional at both testing velocities. As a result, expressing torque as N·m·kg⁻¹ produced relative scores that remained negatively associated with body mass in this cohort, with heavier players tending to receive lower values. This does not mean that heavier players were weaker. It means that torque did not increase as rapidly as body mass. The estimated exponents ranged from 0.349 to 0.562, and all four confidence intervals excluded 1.00. However, the width of these confidence intervals indicates greater certainty that direct proportional scaling is inappropriate than in the precise numerical value of the scaling exponent. The estimated exponents should therefore be regarded as cohort-specific estimates rather than definitive scaling coefficients for elite female soccer players. An exponent of 1.00 assumes that a 10% increase in body mass is accompanied by an approximately 10% increase in torque. In this sample, a 10% greater body mass corresponded to an expected increase in torque of only about 3.4–5.5%. The negative correlations between body mass and N·m·kg⁻¹ confirmed that direct division by body mass applied a greater correction than the observed torque–mass relationship supported.

This finding agrees with the broader principle that a normalized score should be judged by whether it removes its association with body size [9,10,13,14]. Similar problems with ratio scaling have been reported in other athletic populations [16–19]. Oba et al. [16] found population-specific exponents between 0.287 and 0.559 for strength exercises in collegiate American football players, with fitted allometric scores showing substantially less association with body mass than conventional scaling methods. Suchomel et al. [17]

likewise reported that absolute isometric force was positively related to body mass, whereas ratio-scaled force was negatively related to body mass; fitted allometric values showed little remaining association. Crewther et al. [18] showed that the effectiveness of ratio and allometric scaling differed across strength, power, and speed measures in elite rugby players. A similar pattern was reported by Kulkamp et al. [19], who found that conventional ratio scaling did not adequately remove the influence of body mass on hand-grip strength, whereas allometric scaling provided a more appropriate adjustment within the groups studied. Although these studies used different populations and strength tests, they support evaluating scaling assumptions rather than assuming that a fixed denominator is appropriate across populations.

The robustness analyses strengthened the main result. When repeated assessments were averaged so that every player contributed once, the estimated exponents remained close to those from the full dataset. The findings were therefore not driven by players who contributed several assessments. In the leave-one-player-out analysis, each player was evaluated using an equation developed without her own observations. The resulting residuals showed little remaining linear association with body mass, whereas the conventional $\text{N}\cdot\text{m}\cdot\text{kg}^{-1}$ scores remained negatively associated with mass. Within this dataset, the allometric adjustment showed less residual association with body mass than simple ratio scaling. Recent sex-specific strength research has similarly shown that regression residual normalization can markedly reduce the remaining association between body mass and normalized strength [20]. That study examined resistance-exercise strength rather than isokinetic knee torque, so the comparison is methodological rather than directly physiological. However, the present leave-one-out analysis was still an internal validation and does not confirm that the equations will perform equally well in another club or population.

The present exponents were lower than the value near 1.00 previously proposed for muscle torque in relatively lean populations [9,10]. This difference is not necessarily contradictory because scaling exponents depend on the strength measure, the selected body-size variable, and the characteristics of the sample. Folland et al. [11] found that fat-free mass explained more variance in knee-extensor torque than total body mass and that lower body-mass exponents were more appropriate when fat mass contributed more strongly to differences in total mass.

Body-fat percentage in the present dataset ranged from 7.1% to 33.5%, indicating considerable variation in body composition. Including body-fat percentage as a covariate did not change the interpretation of the body-mass scaling relationship, and there was no evidence that body-fat percentage modified the association between body mass and torque. When estimated fat-free mass was used as the scaling variable, the exponents moved slightly closer to 1.00, particularly at $300^\circ\cdot\text{s}^{-1}$, but remained below direct proportionality for all four outcomes. This finding is broadly consistent with previous work showing that body composition can influence the scaling of strength measures [11,21], but the FFM-based analysis did not eliminate the sub-proportional scaling observed in this cohort. Estimated fat-free mass derived from bioelectrical impedance is not equivalent to a direct measure of the muscle tissue contributing to knee torque. Thigh lean mass, muscle cross-sectional area, and muscle volume were not available and may provide more specific scaling variables in future studies. The relatively modest R^2 values are also important. Body mass explained only 8.8–18.7% of the variance in torque. Most of the variation was therefore related to other factors, which may include muscle size, muscle architecture, neural activation, joint moment arms, training status, fatigue, and measurement variability [22–24]. Reducing the residual association with body mass may improve the interpretability of between-player comparisons, although it does not account for all determinants of knee strength.

Direct comparison with the Nebraska Wrestling Study requires caution. Weir et al. [12] examined young male wrestlers and considered isokinetic torque mainly in relation to fat-free mass. Their population, developmental stage, sport, and scaling variable differed from those in the present study. Their findings nevertheless reinforce the point that scaling relationships depend on both the population and the body-size measure selected. Studies in female soccer commonly report both absolute torque and torque relative to body mass. Brígido-Fernández et al. [6] provided absolute and body-mass-normalized knee torque values in professional female soccer players, while França et al. [8] examined lower-body strength and body composition in semiprofessional female players. These studies offer useful descriptive information, but they were not designed to test whether $\text{N}\cdot\text{m}\cdot\text{kg}^{-1}$ was independent of body mass. The contribution of the present study is therefore not to establish a new limitation of ratio scaling, but to test directly whether the conventional exponent of 1.00 is appropriate for isokinetic knee-extensor and knee-flexor torque in elite female soccer players across two commonly used angular velocities. This was uncertain a priori because scaling exponents are known to depend on the population, strength measure, body-size variable, and testing conditions.

The estimated exponents were lower at $300^\circ\cdot\text{s}^{-1}$ than at $60^\circ\cdot\text{s}^{-1}$ for both muscle groups. However, the body mass $\times$ velocity interactions were not statistically significant. There was therefore no statistical evidence that the body-mass scaling exponent differed between the two angular velocities. Folland et al. [11] also found that testing velocity did not materially alter the torque-scaling exponent in their sample. Brown et al. [25] showed that the portion of the movement completed at the preset isokinetic velocity decreases as testing velocity increases. This may affect high-velocity torque measurement, but it cannot explain the present exponent differences because the velocity interaction was not significant. The numerically lower exponents at $300^\circ\cdot\text{s}^{-1}$ should therefore be treated as a descriptive observation rather than evidence of a velocity-specific effect.

Performance measures in female soccer should be interpreted according to the specific physical quality they are intended to represent. Previous work in elite female youth soccer has also shown that relationships with physical performance can differ depending on the assessment measure examined [26]. In the present context, absolute and size-adjusted torque answer different questions. Absolute torque describes the total rotational output produced at the knee and is particularly useful when monitoring the same player over time, whereas a size-adjusted value is intended to support comparisons between players of different body sizes. Conventional $\text{N}\cdot\text{m}\cdot\text{kg}^{-1}$ values may still be useful for comparison with the existing female soccer literature, but they should not be considered independent of body mass in this cohort. An allometric residual may provide a less biased comparison, although it does not explain why a player performs above or below the value predicted from body mass. It should therefore not be interpreted as an injury risk, weakness, or return-to-play threshold.

4.1. Practical Application

Absolute peak torque should remain part of routine reporting because it describes the actual torque produced and is useful for monitoring changes within a player. When $\text{N}\cdot\text{m}\cdot\text{kg}^{-1}$ is reported, practitioners should recognize that it remained negatively associated with body mass in this cohort and therefore tended to favor lighter players. For exploratory comparisons between players, an appropriately validated allometric score may provide a less body-mass-dependent comparison than simple division by body mass. The present exponents should be treated as club-specific estimates and should not be used as normative cutoffs, injury-risk thresholds, or return-to-play criteria.

4.2. Strengths and Limitations

A strength of this study is that it directly tested the conventional body-mass normalization assumption for isokinetic knee torque in elite female soccer players using repeated assessments and internal validation. The repeated-assessment structure was addressed using player-clustered standard errors. The main analysis was repeated using one averaged value per player, and leave-one-player-out cross-validation evaluated each player using an equation developed without her own data. The consistent findings across both muscle groups, both velocities, and the sensitivity analyses support the conclusion that direct division by body mass overcorrected for body size. The dataset combined cross-sectional differences between players with repeated longitudinal observations from some players, and these components were not separated analytically. In addition, the sample comprised only injury-free players from one elite club, which limits generalization to injured players, other teams, and other competitive settings. The equations should not be applied outside the observed body-mass range of approximately 49–78 kg. Although the data covered four preseason periods, season, playing position, and longitudinal changes were not modeled. Bilateral averaging may also have concealed limb-specific relationships. Body composition was assessed using bioelectrical impedance, and estimated fat-free mass was derived from body mass and body-fat percentage rather than measured directly. Segmental muscle mass, thigh lean mass, muscle cross-sectional area, and muscle volume were not available as alternative scaling variables. In addition, years of soccer training experience were not systematically recorded in the retrospective dataset and therefore could not be reported. Although playing position was available and described, the sample was not large enough to support reliable position-specific scaling analyses. Training load and strength-training exposure preceding the assessments were not standardized across preseason periods and may have contributed to variability in the measured strength outcomes. Furthermore, although players were instructed to arrive adequately hydrated, hydration status was not objectively assessed prior to bioelectrical impedance measurement. Reliability was not estimated from the present dataset, and some variation in peak torque may reflect measurement error as well as genuine differences in strength. Finally, leave-one-player-out analysis provided internal validation only. Independent testing in larger, multicenter samples is required before the equations are applied outside this club.

5. Conclusions

In this repeated-assessment sample of elite female soccer players, quadriceps and hamstring torque increased with body mass, but less than proportionally. Dividing torque by body mass therefore applied a greater adjustment than the observed relationship supported and produced lower relative scores in heavier players. The results remained similar when every player contributed equally, while the internally derived allometric adjustment showed little remaining linear association with body mass in this cohort. Absolute torque should continue to be reported, particularly when monitoring changes within the same player. When comparing players of different body sizes, practitioners should be cautious when interpreting torque expressed simply as $\text{N}\cdot\text{m}\cdot\text{kg}^{-1}$, as this measure remained associated with body mass in the present cohort. Size-adjusted measures should be validated before being used for between-player comparisons, and the present exponents require independent confirmation before they are applied as reference values.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app16189373/s1>, Figure S1: Log–log relationship between body mass and quadriceps peak torque at $60^\circ\cdot\text{s}^{-1}$; Figure S2: Residuals versus fitted values for quadriceps peak torque at $60^\circ\cdot\text{s}^{-1}$; Figure S3: Normal Q–Q plot of residuals for quadriceps peak torque at

60°·s⁻¹; Figure S4: Log–log relationship between body mass and hamstring peak torque at 60°·s⁻¹; Figure S5: Residuals versus fitted values for hamstring peak torque at 60°·s⁻¹; Figure S6: Normal Q–Q plot of residuals for hamstring peak torque at 60°·s⁻¹; Figure S7: Log–log relationship between body mass and quadriceps peak torque at 300°·s⁻¹; Figure S8: Residuals versus fitted values for quadriceps peak torque at 300°·s⁻¹; Figure S9: Normal Q–Q plot of residuals for quadriceps peak torque at 300°·s⁻¹; Figure S10: Log–log relationship between body mass and hamstring peak torque at 300°·s⁻¹; Figure S11: Residuals versus fitted values for hamstring peak torque at 300°·s⁻¹; Figure S12: Normal Q–Q plot of residuals for hamstring peak torque at 300°·s⁻¹.

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