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Section I – Kinesiology

Normative Concentric Knee Torque Values and Performance Categories in Male Soccer Players Aged 15–17 Years

by
Koulla Parpa [1,], Ana Carolina Paludo [2], Govindasamy Karuppasamy [3], Magdalena Kobus [4], Cíntia França [5,6], Marcos Michaelides [1]*

Isokinetic dynamometry is widely used to evaluate knee strength and muscular balance, yet normative benchmarks for late-adolescent soccer players are lacking. The present study establishes comprehensive age-specific reference values for concentric quadriceps and hamstring torque performance in male soccer players aged 15–17 years tested at both 60°·s^{-1} and 300°·s^{-1} using a HUMAC Norm dynamometer. The 60°·s^{-1} testing included 502 players (15 years, n = 106; 16 years, n = 175; 17 years, n = 221), while the 300°·s^{-1} testing was performed on a voluntary subsample of 260 players (15 years, n = 49; 16 years, n = 74; 17 years, n = 137) drawn from the same cohort. Torque was expressed in absolute (Nm) and body-mass normalized (Nm·kg^{-1}) values, converted into z-scores and T-scores [T = 50 + (10 × z)], and classified into performance categories ranging from very low to very high. Age effects were tested with one-way analysis of variance (ANOVA). It was indicated that across all age groups, most players (60–74%) showed average torque performance, with smaller proportions classified as high (9–19%), low (10–17%), very high (<5%), and very low (<3%). Mean values (at 60°·s^{-1}) increased from the age of 15 to 16 and plateaued by the age of 17, suggesting near-mature neuromuscular development. Until now, these data provide one of the largest age-specific benchmarks available for late adolescent soccer players, addressing a gap between existing pediatric and adult reference standards. These dual-velocity normative datasets provide unique reference bands that enable precise classification of performance, aiding in screening, load monitoring and rehabilitation.

Keywords: *isokinetic concentric knee testing; youth; adolescent performance; T-scores; 300°·s–1 isokinetic testing*

Introduction

Isokinetic dynamometry is widely used to evaluate muscular strength and detect strength imbalances, especially in the quadriceps and hamstrings (Asimakidis et al., 2024; Bishop et al., 2021; Parpa and Michaelides, 2022). In pediatric and adolescent populations, isokinetic testing, when appropriately adapted and supported by familiarization, offers reliable insights into strength development, training responses and injury risk (Mandroukas et al., 2023). Normative reference values for isokinetic peak torque have been established in children aged 6–13 across both sexes (Wiggin et al., 2006), as well as in adult populations (Chena et al., 1991; Van Melick et al., 2022; Zakas et al., 1995). However, there remains a lack of standardized benchmarks for older adolescents, especially those engaged in high-demand sports such as soccer.

The adolescent years are characterized by rapid changes in growth, maturation, bone mineral density and neuromuscular coordination, all of which strongly influence strength development

[1] *Faculty of Sports and Exercise Science, University of Central Lancashire, Pyla, Cyprus.*
[2] *Department of Psychology, University of Cyprus, Nicosia, Cyprus.*
[3] *Department of Sports Recreation and Wellness, Symbiosis International (Deemed University), Hyderabad Campus, Hyderabad, India.*
[4] *Research Institute, Polish Mother's Memorial Hospital-Research Institute in Lodz, Lodz, Poland.*
[5] *Department of Physical Education and Sport, University of Madeira, Funchal, Portugal.*
[6] *LARSYS, Interactive Technologies Institute, Funchal, Portugal.*
* Correspondence: kparpa@uclan.ac.uk

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(Brown et al., 2017; Seabra et al., 2012). For youth soccer players, these developmental factors occur alongside intensive sport-specific training, which places unique demands on the lower limbs through frequent accelerations, decelerations, changes in direction and kicking actions required during play (Castagna et al., 2025; Dellal et al., 2011; Oliva-Lozano et al., 2020). While normative isokinetic values for younger children provide an essential reference point (Wiggin et al., 2006), they cannot be generalized to older adolescents who undergo significant changes in strength capacity during and after puberty. Similarly, adult reference values may not account for the unique transitional stage of mid-to-late adolescence. This leaves a critical gap for practitioners seeking age-appropriate standards to evaluate strength in competitive soccer players aged 15–17 years. Furthermore, recent evidence suggests that structured training in youth soccer players can result in measurable improvements in physical performance and physiological adaptations (Fernández-Rio et al., 2019), reinforcing the importance of objective benchmarks such as isokinetic torque values to monitor strength and neuromuscular development during this critical stage.

Standardized scores, including *z*- and *T*-scores, enable individual torque output to be expressed relative to group means, allowing for categorization into performance bands ranging from very low to very high. This type of classification has been successfully applied in other performance assessments, such as countermovement jump profiling in rugby league athletes, where normative datasets were combined with standardized scoring to create clear benchmarks for applied practice (McMahon et al., 2022). Translating this approach to isokinetic strength testing can provide a uniform practical framework for coaches, medical staff, and sport scientists working with adolescent soccer players.

Previous studies have primarily focused on lower angular speeds ($60°·s^{-1}$ and $180°·s^{-1}$), while higher testing speeds, such as $300°·s^{-1}$, which better reflect power-oriented performance and may more closely replicate functional movement speeds in soccer, have not been extensively documented (Michailidis, 2025). The selection of $300°·s^{-1}$ is supported both theoretically and empirically by a recent study of U17 soccer players, which demonstrated that knee flexor torque at this speed was significantly associated with position-specific match-running performance variables tracked by the GPS across 16 competitive games (Michailidis, 2025).

Therefore, this study aimed to establish normative values for isokinetic knee torque performance in male soccer players aged 15, 16, and 17 years at both $60°·s^{-1}$ and $300°·s^{-1}$. Using standardized *z*- and *T*- score conversions, individual performances were classified into meaningful categories (very low, low, average, high and very high), providing practitioners with a reference system to monitor strength development, identify deficits, and optimize training and rehabilitation strategies in youth soccer. We hypothesized that the isokinetic knee extensor and flexor peak torque (Nm/kg) would be significantly higher in 16- and 17-year-old players compared to 15-year-old players at both testing speeds.

Methods

Participants

A total of 502 male academy soccer players (15 years, n = 106, body height 174.6 ± 6.09 cm, body mass 65.04 ± 6.73 kg; 16 years, n = 175, body height 177.00 ± 5.80 cm, body mass 68.53 ± 7.62 kg; 17 years, n = 221, body height 175.84 ± 12.14 cm, body mass 69.48 ± 6.76 kg) completed testing procedures at $60°·s^{-1}$. The $300°·s^{-1}$ test was only administered to a voluntary subsample of 260 players (15 years, n = 49, body height 174.5 ± 5.6 cm, body mass 65.00 ± 6.30 kg; 16 years, n = 74, body height 178.50 ± 6.00 cm, body mass 69.90 ± 8.40 kg; 17 years, n = 137, body height 176.40 ± 5.30 cm, body mass 69.70 ± 6.60 kg) selected from the same cohort of 502 participants who completed the testing procedures at $60°·s^{-1}$. As the isokinetic testing sessions were integrated within a broader performance evaluation battery performed during the academy schedule, some coaching staff preferred to limit the duration of the testing protocol to avoid excessive fatigue prior to subsequent assessments. Consequently, only players whose coaches approved the additional testing time completed the $300°·s^{-1}$ condition. Exclusion criteria included recent musculoskeletal injury (within six weeks), surgery, or inability to complete the isokinetic testing. Also, eligibility was limited to players with at least 2 years of experience in structured training

and official games. Parental consent was obtained for all participants prior to testing. The study met the ethical standards for research involving human subjects (Harriss and Atkinson, 2015), adhered to the principles of the Declaration of Helsinki, and received approval from the National Committee of Bioethics, Nicosia, Cyprus (approval code: ΕΕΒΚ/ΕΠ/2024/12; approval date: 13 December 2024).

Design and Procedures

Participants completed 5 min of cycling on a mechanically braked ergometer (Monark 894E Peak Bike, Vansbro, Sweden) at 100 W and 70 rpm, followed by a 5-min self-selected warm-up routine. Torque (Nm) was assessed concentrically for both quadriceps and hamstrings on the HUMAC Norm isokinetic device (CSMi, Stoughton, MA, USA). Previous studies had primarily focused on lower angular speeds ($60°\cdot s^{-1}$) (Beato et al., 2021b), whereas higher testing speeds, such as $300°\cdot s^{-1}$, had been less frequently reported, although they had been used in prior research to assess power-oriented performance (Michailidis, 2025).

Players were seated with the thigh at 85° relative to the trunk, and the dynamometer's axis was aligned with the lateral epicondyle of the knee, as described in previously published studies (Parpa et al., 2024; Parpa and Michaelides, 2025). Knee range of motion was set to 0–100°. The thigh and the torso were secured with straps and a belt, and the ankle was fixed with an adjustable strap. Each player completed a familiarization session that included three submaximal flexion-extension trials at $60°\cdot s^{-1}$ on each leg. Testing included three maximal repetitions at $60°\cdot s^{-1}$ and five maximal repetitions at $300°\cdot s^{-1}$. For the $300°\cdot s^{-1}$ condition, participants performed five maximal repetitions following familiarization to ensure consistent performance at a higher testing velocity. For the $300°\cdot s^{-1}$ condition, the highest peak torque was recorded within the achieved isokinetic range of motion (IROM), as identified by the dynamometer software during the constant-velocity phase. This ensured that peak torque values reflected true isokinetic performance rather than acceleration and deceleration phases. Both dominant and non-dominant limbs were tested individually. The dominant limb was defined as the preferred leg used to kick the ball, and the contralateral limb was considered non-dominant. Players were verbally encouraged to exert maximal effort. Gravity correction and lever-arm measurements were performed per the manufacturer's guidelines.

Statistical Analysis

Statistical tests were conducted in SPSS (version 28; SPSS Inc., Chicago, IL, USA). Quadriceps and hamstring concentric peak torque were recorded for both limbs in absolute (Nm) and relative (Nm/kg) terms. Normality and homogeneity of variance were verified by the Shapiro-Wilk and Levene's tests, respectively. Descriptive statistics (mean, *SD*) were calculated for each age group. Raw values were converted into *z*-scores and then to *T*-scores using $T = 50 + (10 \times z)$. The converted *T*-scores were classified into five categories to aid in the interpretation: scores below 30 were considered very low, scores ranging from 30 to 39 were classified as low, scores between 40 and 59 were regarded as average, scores from 60 to 69 were classified as high, and scores equal to or above 70 were classified as very high. To create benchmarks for the isokinetic data, *T*-score performance bands were established as previously mentioned and then translated back into raw torque values, providing normative reference bands for training and clinical use. To compute raw torque cutoffs (Torque = $\bar{X} + z \times SD$), each *T*-score range corresponded to a *z*-score range (supplementary Table 1).

One-way analysis of variance (ANOVA) was used to assess the effects of age on each outcome, with η^2 reported as the effect size and the Tukey's *HSD* test used for pairwise comparisons ($\alpha = 0.05$). Test-retest reliability of the isokinetic knee torque measurements was evaluated in a sample of 20 male youth soccer players, who were assessed on two separate occasions approximately 7 days apart. Torques were measured using the same testing conditions during both sessions. Reliability was examined using the two-way random-effects absolute agreement single-measure intraclass correlation coefficient (*ICC*), as described by McGraw and Wong (1996). The *ICC* was calculated to assess the consistency of repeated measurements, and the 95% confidence intervals (*CI*s) were reported to indicate the precision of the estimates. The standard error of measurement (*SEM*) was calculated to quantify the amount of measurement error using the formula $SEM = SD \times \sqrt{(1 - ICC)}$, where *SD* represented the standard

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deviation of the measurements. Based on *SEM*, the minimal detectable change at the 95% confidence level (MDC_{95}) was determined using the formula $MDC95 = SEM \times 1.96 \times \sqrt{2}$, representing the smallest change that could be interpreted as an actual difference beyond measurement error. Interclass correlation coefficients (*ICC*s) were used to assess relative reliability, with values <0.50 indicating poor, 0.50–0.75 moderate, 0.75–0.90 good, and >0.90 excellent reliability (Koo and Li, 2016).

Results

Reliability Analysis

Test-retest reliability analysis demonstrated excellent consistency across all torque measurements collected from the 20 youth soccer players. The *ICC* values ranged from 0.97 to 0.99, indicating excellent reliability according to the established criteria. The standard error of measurement ranged from 3.24 to 5.24, and the minimal detectable change at the 95% confidence level (MDC_{95}) ranged from 8.97 to 14.51. Overall, these findings confirm the high reproducibility and stability of the muscle strength (torque) assessment protocol used when applied to trained soccer players over a 7-day test-retest period.

Table 1 presents the age-specific knee torque values, both in absolute terms and relative to body weight, for $60°\cdot s^{-1}$ and $300°\cdot s^{-1}$. The corresponding hamstring-to-quadriceps ratios are presented in Table 2. Tables 3 and 4 present the age-specific normative isokinetic knee torque bands at $60°\cdot s^{-1}$ in absolute and relative terms, respectively. Lastly, Tables 5 and 6 present the age-specific normative isokinetic knee torque bands at $300°\cdot s^{-1}$ in absolute and relative terms, respectively.

Across all age groups, most players (60–74%) showed average torque performance, with smaller proportions classified as high (9–19%), low (10–17%), very high (<5%), and very low (<3%). Overall, these findings indicate that most players produced torque values within the normative range, with only a small minority demonstrating exceptionally high or below-average strength performance.

One-way ANOVA demonstrated that there was a significant main effect of age when it comes to quadriceps torque production at $60°\cdot s^{-1}$ [F (2, 498) = 15.92, p = 0.000]. Post-hoc analysis indicated that the mean torque significantly increased from 178 ± 25.5 Nm at the age of 15 to 198.1 ± 28.4 at the age of 16 ($p < 0.05$, $\eta^2 = 0.06$, small-to-medium effect) and then plateaued at the age of 17 (194.4 ± 31.3, $p = 0.42$). Regarding the hamstring, there was also a significant main effect of age at $60°\cdot s^{-1}$ [F (2, 498) = 10.04, p = 0.001], with torque significantly increasing from 130.8 ± 21.0 Nm to 142.0 ± 21.4 Nm from 15 to 16 years ($p = 0.003$, $\eta^2 = 0.04$), followed by a smaller and non-significant increase at the age of 17 (143.2 ± 22.5 Nm). When the analysis was performed on the normalized torque values, a significant main effect of age for the quadriceps relative torque at $60°\cdot s^{-1}$ [F (2, 498) = 6.93, p = 0.001] was found. In this case, however, post-hoc analysis indicated that relative quadriceps torque increased significantly from the age of 15 to 16 and then was significantly different at the age of 17, although the difference between ages 15 and 17 was not statistically significant. Regarding the hamstrings, a one-way ANOVA revealed that age did not have a statistically significant main effect on relative hamstring torque at $60°\cdot s^{-1}$. When examining age differences in absolute torque production at $300°\cdot s^{-1}$, a one-way ANOVA revealed a significant main effect [F (2, 259) = 3.80, p = 0.024], with the only significant difference observed between the 15- and 17-year-old players in the quadriceps muscle only. No significant main effect for age was indicated in relative quadriceps values. In contrast, there was a significant main effect of age for hamstring relative torque at $300°\cdot s^{-1}$ [F (2, 259) = 4.12, p = 0.017]. Post-hoc analysis showed that relative hamstring torque increased significantly from age 15 to 16 and from age 15 to 17, whereas the differences between ages 16 and 17 were not statistically significant.

Discussion

The present study established comprehensive normative reference values for concentric quadriceps and hamstring torque (at $60°\cdot s^{-1}$ and $300°\cdot s^{-1}$) in competitive male soccer players aged 15–17 years, expressed in both raw torque bands and standardized performance categories. Our findings demonstrate that most players exhibited torque within the average range, with smaller proportions classified as high or low, and very few demonstrating exceptionally high or very low torque. Until now, these data provide one of the largest age-specific benchmarks available for late adolescent soccer players, addressing a gap between existing pediatric and adult reference standards.

Table 1. Age-specific knee torque values at 60°·s⁻¹ and 300°·s⁻¹ (absolute and relative to body weight).

		60°·s⁻¹		300°·s⁻¹	
Age (years)	Measure	Mean ± *SD* (Absolute, Nm)	Mean ± *SD* (Relative Nm·kg⁻¹)	Mean ± *SD* (Absolute, Nm)	Mean ± *SD* (Relative Nm·kg⁻¹)
15	Dominant Quadriceps	178.72 ± 25.53	2.75 ± 0.28	103.67 ± 15.80	1.59 ± 0.18
	Non-dominant Quadriceps	180.12 ± 28.72	2.77 ± 0.33	101.61 ± 15.61	1.56 ± 0.18
	Dominant Hamstring	130.79 ± 20.96	2.01 ± 0.24	85.65 ± 13.59	1.32 ± 0.17
	Non-dominant Hamstring	133.73 ± 22.87	2.06 ± 0.29	86.61 ± 14.15	1.33 ± 0.18
16	Dominant Quadriceps	198.10 ± 28.44	2.90 ± 0.33	108.61 ± 17.06	1.56 ± 0.18
	Non-dominant Quadriceps	193.74 ± 29.36	2.83 ± 0.27	101.31 ± 16.85	1.45 ± 0.20
	Dominant Hamstring	142.04 ± 21.42	2.08 ± 0.26	86.20 ± 14.56	1.24 ± 0.17
	Non-dominant Hamstring	141.91 ± 18.95	2.08 ± 0.23	89.50 ± 15.89	1.28 ± 0.20
17	Dominant Quadriceps	194.39 ± 31.32	2.80 ± 0.39	110.26 ± 16.46	1.58 ± 0.18
	Non-dominant Quadriceps	192.43 ± 33.67	2.77 ± 0.42	103.15 ± 15.10	1.48 ± 0.18
	Dominant Hamstring	140.75 ± 22.89	2.03 ± 0.27	84.90 ± 14.04	1.22 ± 0.18
	Non-dominant Hamstring	144.24 ± 23.23	2.08 ± 0.30	89.37 ± 13.52	1.29 ± 0.18

Table 2. Hamstring-to-quadriceps ratios at 60°·s⁻¹ and 300°·s⁻¹ (H:Q ratio).

		60°·s⁻¹	300°·s⁻¹
Age (years)	Measure	Mean ± *SD* Ratio (H: Q)	
15	H: Q ratio Dominant (%)	73.45 ± 9.96	83.09 ± 9.89
	H: Q ratio Non-dominant (%)	74.70 ± 10.57	85.52 ± 8.37
16	H: Q ratio Dominant (%)	72.22 ± 9.29	79.77 ± 9.20
	H: Q ratio Non-dominant (%)	74.17 ± 9.97	89.13 ± 13.99
17	H: Q ratio Dominant (%)	73.05 ± 9.70	77.46 ± 10.12
	H: Q ratio Non-dominant (%)	75.83 ± 11.27	87.15 ± 10.35

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Table 3. Age-specific normative isokinetic knee torque bands at 60°·s^{-1} (absolute, Nm).

Measure	Age (years)	Very low	Low	Average	High	Very high
Dominant Quadriceps	15	<127.7	127.7–153.2	153.3–204.2	204.3–229.7	≥229.8
Non-dominant Quadriceps		<122.7	122.7–151.4	151.5–208.8	208.9–237.6	≥237.7
Dominant Hamstring		<88.9	88.9–109.8	109.9–151.8	151.9–172.7	≥172.8
Non-dominant Hamstring		<88.0	88.0–110.9	111.0–156.6	156.7–179.5	≥179.6
Dominant Quadriceps	16	<141.2	141.2–169.7	169.8–226.5	226.6–255	≥255.1
Non-dominant Quadriceps		<135	135–164.4	164.5–223.1	223.2–252.4	≥252.5
Dominant Hamstring		<99.2	99.2–120.6	120.7–163.5	163.6–184.9	≥185
Non-dominant Hamstring		<104	104–123	123.1–160.9	161–179.8	≥179.9
Dominant Quadriceps	17	<131.8	131.8–163.1	163.2–225.7	225.8–257	≥257.1
Non-dominant Quadriceps		<125.1	125.1–158.8	158.9–226.1	226.2–259.8	≥259.9
Dominant Hamstring		<95	95–117.9	118–163.6	163.7–186.5	≥186.6
Non-dominant Hamstring		<97.8	97.8–121	121.1–167.5	167.6–190.7	≥190.8

Table 4. Age-specific normative isokinetic knee torque bands at 60°·s^{-1} (relative to body weight, Nm·kg^{-1}).

Measure	Age (years)	Very low	Low	Average	High	Very high
Dominant Quadriceps	15	<2.18	2.18–2.46	2.47–3.03	3.04–3.32	≥3.33
Non-dominant Quadriceps		<2.11	2.11–2.44	2.45–3.1	3.2–3.43	≥3.44
Dominant Hamstring		<1.52	1.52–1.77	1.78–2.25	2.26–2.5	≥2.51
Non-dominant Hamstring		<1.48	1.48–1.77	1.78–2.35	2.36–2.63	≥2.64
Dominant Quadriceps	16	<2.24	2.24–2.57	2.58–3.22	3.23–3.55	≥3.56
Non-dominant Quadriceps		<2.21	2.21–2.47	2.48–3.2	3.21–3.57	≥3.58
Dominant Hamstring		<1.57	1.57–1.82	1.83–2.33	2.34–2.59	≥2.60
Non-dominant Hamstring		<1.62	1.62–1.85	1.86–2.31	2.32–2.54	≥2.55
Dominant Quadriceps	17	<2.02	2.02–2.41	2.42–3.19	3.20–3.58	≥3.59
Non-dominant Quadriceps		<1.93	1.93–2.35	2.36–3.19	3.20–3.61	≥3.62
Dominant Hamstring		<1.48	1.48–1.75	1.76–2.30	2.31–2.58	≥2.59
Non-dominant Hamstring		<1.49	1.49–1.78	1.79–2.38	2.39–2.67	≥2.68

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Table 5. Age-specific normative isokinetic knee torque bands at 300°·s^{-1} (absolute, Nm).

Measure	Age (years)	Very low	Low	Average	High	Very high
Dominant Quadriceps	15	<72.1	72.1–87.9	87.91–119.5	119.6–135.3	≥135.4
Non-dominant Quadriceps		<70.4	70.4–86.0	86.1–117.2	117.3–132.8	≥132.9
Dominant Hamstring		<58.5	58.5–72.1	72.2–99.2	99.3–112.8	≥112.9
Non-dominant Hamstring		<58.3	58.3–72.5	72.6–100.8	100.9–114.9	≥115.0
Dominant Quadriceps	16	<74.5	74.5–91.5	91.6–125.7	125.8–142.7	≥142.8
Non-dominant Quadriceps		<67.6	67.6–84.5	84.6–118.2	118.3–135.0	≥135.1
Dominant Hamstring		<57.1	57.1–71.6	71.7–100.8	100.9–115.3	≥115.4
Non-dominant Hamstring		<57.7	57.7–73.6	73.7–105.4	105.5–121.3	≥121.4
Dominant Quadriceps	17	<77.3	77.3–93.8	93.9–126.7	126.8–143.2	≥143.3
Non-dominant Quadriceps		<73.0	73.0–88.1	88.2–118.3	118.4–133.4	≥133.5
Dominant Hamstring		<56.8	56.8–70.9	71.0–98.9	99.0–113.0	≥113.1
Non-dominant Hamstring		<62.3	62.3–75.9	76.0–102.9	103.0–116.4	≥116.5

Table 6. Age-specific normative isokinetic knee torque bands at 300°·s^{-1} (relative to body weight, Nm·kg^{-1}).

Measure	Age (years)	Very low	Low	Average	High	Very high
Dominant Quadriceps	15	<1.24	1.24–1.42	1.43–1.77	1.78–1.95	≥1.96
Non-dominant Quadriceps		<1.20	1.20–1.38	1.39–1.74	1.75–1.92	≥1.93
Dominant Hamstring		<0.98	0.98–1.15	1.16–1.49	1.50–1.65	≥1.66
Non-dominant Hamstring		<0.98	0.98–1.16	1.17–1.51	1.52–1.69	≥1.70
Dominant Quadriceps	16	<1.20	1.20–1.38	1.39–1.74	1.75–1.92	≥1.93
Non-dominant Quadriceps		<1.05	1.05–1.25	1.26–1.66	1.67–1.86	≥1.87
Dominant Hamstring		<0.90	0.90–1.07	1.08–1.41	1.42–1.57	≥1.58
Non-dominant Hamstring		<0.88	0.88–1.08	1.09–1.49	1.50–1.69	≥1.70
Dominant Quadriceps	17	<1.22	1.22–1.40	1.41–1.76	1.77–1.95	≥1.96
Non-dominant Quadriceps		<1.13	1.13–1.30	1.31–1.66	1.67–1.83	≥1.84
Dominant Hamstring		<0.85	0.85–1.04	1.05–1.40	1.41–1.59	≥1.60
Non-dominant Hamstring		<0.92	0.92–1.10	1.11–1.47	1.48–1.66	≥1.67

Torque production increased from the age of 15 to 16, followed by a relative plateau at 17 years. This aligns with previous findings by Forbes et al. (2009) who reported no significant differences in relative knee torque between U18 players compared to U16 and U15 groups, suggesting a plateau in strength development during late adolescence. The observed increase from 15 to 16 years likely reflects the influence of rapid neuromuscular and hormonal adaptations associated with the growth spurt, as testosterone and muscle mass increase markedly around peak height velocity (Badenhorst, 2017). The minimal differences between 16- and 17-year-olds may therefore indicate the onset of neuromuscular maturity and strength stabilization, which is consistent with findings showing that torque production per muscle cross-sectional area of knee extensors and flexors reaches adult levels by approximately 16 years of age (De Ste Croix, 2008). Together, these findings suggest that by 17 years of age, strength gains are increasingly influenced by sport-specific training rather than continued biological maturation, reflecting a shift from developmentally driven to training-driven adaptations. Although several age-related differences reached statistical significance, the reported effect sizes were generally small to moderate, indicating that some statistically significant differences may have limited practical relevance. This is particularly evident in the comparison between the 16- and 17-year-old players, where torque values showed minimal change, suggesting a plateau in strength development during late adolescence.

Most previous normative studies have focused on children under 14 years (Wiggin et al., 2006) or adult professionals (Chena et al., 1991), leaving limited data for players aged 15–17 years. The present results help fill this gap and show that by the age of 17, youth players reach torque levels close to the lower range of adult values. Earlier data on 13-year-old soccer players reported quadriceps torque values of approximately 99.5–104.5 Nm (50^{th} percentile) for the quadriceps at $60°·s^{-1}$ (Wiggin et al., 2006), while the 17-year-old group in this study produced mean torques ranging from 159 to 226 Nm, corresponding to an increase of approximately 60–116%. This progression reflects both biological maturation and the cumulative effects of regular soccer-specific training, including repeated accelerations, decelerations and kicking actions. These findings provide valuable reference points for coaches and practitioners working with players transitioning from the academy to senior levels.

Classifying torque values into standardized performance bands offers immediate translational value. Players categorized as "low" or "very low" represent a potentially at-risk subgroup who may lack adequate lower-limb strength for the demands of competitive soccer (Beato et al., 2021a). Deficits in hamstring torque, in particular, have been associated with increased susceptibility to hamstring strain injuries and anterior cruciate ligament ruptures when hamstring-to-quadriceps ratios fall below accepted thresholds (60–70%) (Ruas et al., 2019). Recent evidence also demonstrates that strength measures around the hip can show acute and residual changes following game play in youth soccer players, further emphasizing the importance of appropriately timed and repeated neuromuscular assessments throughout the competitive schedule (Hamad et al., 2025). By identifying players in the lower bands, coaches and clinicians can implement target eccentric and concentric strengthening programs to restore muscular balance and reduce injury risk (Beato et al., 2021b). Conversely, players categorized as "high" or "very high" may benefit from maintenance programming to preserve torque capacity while focusing on other performance determinants such as power and acceleration. Integrating this torque classification into periodic monitoring systems could thus facilitate the development of individualized training programs.

The predominance of athletes in the average torque range suggests balanced neuromuscular development across the sample, reflecting structured academy-level training and the cumulative effects of resistance and on-field conditioning. However, the existence of small subgroups at both extremes highlights the heterogeneity which is common in adolescence. Concurrently, players in the "very low" category may be late maturers, while those in the "very high" category may be early maturers or individuals with many years of professional experience. Understanding these biological differences is essential for contextualizing performance and setting realistic developmental

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expectations. The interpretation of youth athletes' strength profiles should also consider their broader training background, as patterns of sport specialization, training characteristics and injury occurrence may differ between athletes participating in team and individual sports (Wilczyński et al., 2026). Therefore, it is recommended that future studies consider biological maturity markers, such as peak height velocity or the Tanner stage, to provide more precise insight into maturation-adjusted normative profiles.

It should be noted that the normative values presented in this study are based on chronological age rather than biological maturity status. This distinction is especially important in youth soccer, where performance characteristics may vary according to both chronological age and bio-banded competitive grouping (Konarski et al., 2026). Adolescents of the same age may differ considerably in their stage of biological maturation, particularly between 15 and 17 years, a period characterized by substantial inter-individual variability in the timing of peak height velocity and pubertal development (Sullivan et al., 2023). Consequently, players classified in the "very low" performance category may include late-maturing individuals who have not yet reached their full neuromuscular development, while players categorized as "very high" may represent early-maturing individuals with enhanced biological development. Therefore, the normative bands proposed in this study should be interpreted as age-specific reference values rather than maturity-adjusted standards.

The inclusion of the 300°·s^{-1} condition is particularly novel, as no prior normative data exist for this velocity in adolescent athletes. This range is functionally relevant to soccer-specific movements (Michailidis, 2025) such as decelerations and controlled kicking, making it highly applicable for performance monitoring and return-to-play evaluations.

From a practical standpoint, the normative bands and *T*-score categories established can serve as screening and benchmarking tools for coaches, physical therapists, and sports scientists. By aligning individual player data with reference categories, coaches can identify underdeveloped players requiring targeted strength interventions, monitor progress longitudinally against age-appropriate norms, and support return-to-play decisions, ensuring torque production remains within normative limits after rehabilitation. Including these data into performance management systems or athlete monitoring systems could facilitate real-time feedback and enhance communication between medical and coaching staff. Furthermore, the categorical structure (very low to very high) simplifies interpretation.

Although the hamstring-to-quadriceps (H:Q) ratio is commonly reported as an indicator of muscle balance, it is a derived measure that reflects the relationship between two torque outputs rather than an independent strength capacity. Consequently, a ratio may appear "normal" even when both hamstring and quadriceps torque are low, which can limit its value as a standalone normative classification metric (Ruas et al., 2019). Recent work using interpretable machine learning on simulation-derived running biomechanics has also highlighted that the hamstring-quadriceps imbalance may be better understood through a broader biomechanical framework rather than through a single derived ratio alone (Mănescu et al., 2025). In the present study, we therefore focused on the *T*-score and the performance-band framework on absolute and relative torque values and reported H:Q ratios descriptively to provide complementary information. Future research could extend standardized classification approaches to ratio-based indicators. However, developing meaningful ratio categories would benefit from validation against clinically relevant outcomes such as injury occurrence or return-to-play benchmarks, to ensure practical interpretability in adolescent athletes.

The present study reports normative values for both dominant and non-dominant limbs because limb-to-limb interpretation is frequently required in applied soccer settings. At the group level, dominant and non-dominant mean torque values were generally comparable in magnitude; however, group-level similarity does not exclude the possibility of meaningful asymmetries at the individual level. For practitioners, bilateral assessment remains important when monitoring youth players, identifying potential strength deficits, and informing training or rehabilitation decisions. Accordingly, we provide limb-specific

normative bands for dominant and non-dominant limbs to support the interpretation of each limb separately. While pooling limb values may be reasonable for broad descriptive benchmarking at the group level, limb-specific evaluation is recommended when profiling individual athletes.

Several limitations should be acknowledged. The cross-sectional design prevents inference of individual growth and biological maturity. The sample consisted of male soccer players; therefore, generalization to female athletes or other sports should be made cautiously. In addition, the subsample of players assessed at 300°·s^{-1} was smaller than the group tested at 60°·s^{-1}, which might have reduced the precision of the normative values at the higher angular velocity. Future research should also examine how these normative torque levels relate to functional outcomes, such as sprint performance and change-of-direction ability, thereby providing an integrated profile of lower limb function. Expanding the database to include assessment of asymmetry indices, the rate of torque development, and eccentric measures would further enhance the ecological validity and clinical relevance of these norms. Nevertheless, this study is the first to provide an extensive normative framework for interpreting quadriceps and hamstring torque in adolescent male soccer players.

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ORCID ID:

Koulla Parpa: https://orcid.org/0000-0002-1139-7731

Ana Carolina Paludo: https://orcid.org/0000-0001-8771-4580

Govindasamy Karuppasamy: https://orcid.org/0000-0002-3019-5545

Magdalena Kobus: https://orcid.org/0000-0001-9586-5389

Cíntia França: https://orcid.org/0000-0001-8364-6832

Marcos Michaelides: https://orcid.org/0000-0002-9226-4657

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Supplementary Table 1. *T*-score range, *z*-score range and the corresponding description.

Category	*T*-score range	*z*-score range	Description
Very low	<30	$z < -2.0$	Below average
Low	30–39	$-2.0 \leq z < -1.0$	Slightly below average
Average	40–59	$-1.0 \leq z \leq +1.0$	Within normal range
High	60–69	$+1.0 < z \leq +2.0$	Above average
Very high	≥70	$z > +2.0$	Exceptional