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Original Article

Comprehensive isokinetic analysis of hamstring and quadriceps strength profiles in football players

MIGLENA TSVETKOVA-GABERSKA[1], MARIA GANEVA[2], NEVENA PENCHEVA[3]
[1,2,3]Department of Anatomy and Physiology, Faculty of Public Health, Health Care and Sports, South-West University "Neofit Rilski", BULGARIA

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Abstract:
Football players experience increased risks of lower limb injuries, particularly hamstring strains and knee ligament damage, often attributed to muscle imbalances. This study aimed to conduct a detailed isokinetic assessment of the knee joint, focusing on both kicking and supporting legs, involving 24 football players from the university football team of SWU "Neofit Rilski". The objective was to monitor the physiological and biomechanical characteristics of the thigh musculature. Isokinetic measurements of knee joint extensors (quadriceps) and flexors (hamstrings) strength were conducted bilaterally at angular velocities of 60, 180, and 300 °/s A comparative analysis included traditional parameters - peak torque (PT, Nm), average power (AP, W) and total work (TW, J) - together with additional parameters such as time to peak torque (TPT) and acceleration time (AcT). Conventional H/Q ratios were used for quadriceps and hamstring strength balance evaluation, and potential side-to-side strength deficits were calculated. Results indicated that the kicking leg (KL) demonstrated significant strength superiority (Wilcoxon, $p < 0.05$) compared to the supporting leg (SL). PT values in both antagonist groups were reduced when compared to those in other studies. Additionally, at low speeds (60 °/s), the time to PT was significantly prolonged, distinguishing these football players from their professional counterparts. Differences in time parameters, work capacity, and power at moderate velocity – 180°/s, were observed in both muscles' groups, with the SL having lower values compared to the KL. At 60o/s and 300o/s the extensors of the SL had a longer time to reach AcT and TPT and a more reduced AP than the KL. The TW of Q and H is greater in the KL compared to the SL. The H/Q ratios between KL and SL, at all three measured speeds, fell below normal balance values, with nearly 75% of players exhibiting unilateral asymmetry in the KL and approximately 85% in the SL. This study provides evidence that a comprehensive isokinetic assessment, considering both traditional and additional parameters, is beneficial for university footballers. The findings revealed potential risks and susceptibility to noncontact knee injuries, offering valuable insights for the development of targeted training and therapy programmes.
Key Words: **- isokinetic, knee, hamstrings and quadriceps muscles, strength, football players**

Introduction

Men in professional football are injured 8.1 times per 1000 hours of play (López-Valenciano et al., 2020). The most common injuries are to the lower limbs, most commonly the hamstrings (e.g., muscle strains) and knee joints (e.g., ligament tears) (Junge & Dvorak, 2004; Pfirrmann et al., 2016). According to the authors, most serious injuries are localised to the knee joint (Llana, Pérez, & Lledó, 2010) and the period of disability is longer. Almost half (47%) of non-contact anterior cruciate ligament (ACL) injuries occur during manoeuvres related to sudden changes of direction, sudden stops and incorrect landings after a fall (Della Villa et al., 2020). This suggests that the active stabilising muscles of the hip, which help to control these manoeuvres, are likely to be involved in the occurrence of such injuries. Strength imbalances in these muscle groups are associated with injuries to the biceps femoris of the hamstrings (Croisier et al., 2008) and an increased risk of ACL injury (Della Villa et al., 2020). All of this calls for systematic assessment and identification of athletes at higher risk of injury and is essential for proper training by coaches and timely prevention of subsequent injury. Muscle imbalance, in the form of changes in muscle strength (expressed as strength deficits and altered symmetry of force produced), is thought to be associated with an increased risk of overuse of compensatory muscle groups and the occurrence of injury or re-injury. Measurements of muscle strength balance are the subject of active research aimed at improving the functional assessment of athletes in disciplines associated with systematic asymmetric loading of the lower limb musculature.

Isokinetic variables related to muscle strength, such as peak torque (PT) and conventional hamstring/quadriceps (H: Q) torque ratio, are traditionally extracted from the isokinetic exam. However, it has been recommended that muscle imbalance assessments are not limited to strength but may also involve parameters capable of adding information on injury prevention and treatment (Maciel et al., 2020). Some of the additional parameters are: -Acceleration time (AcT) (ms)- which is an indicator of the reactivity of the

Corresponding Author: MIGLENA TSVETKOVA-GABERSKA, E-mail: miglena_tsvetkova@swu.bg

neuromuscular system to initiate limb movement at the initial moment from the range of motion in the joint to reach a constant velocity; criteria for explosive power; - Time to peak torque (TPT) (ms)- characterises the time required to develop maximal force, represents a physiological indicator of speed, and more precisely, the time to recruit fast motor units and develop explosive power; - Total work (TW) (J) - work performed at the specified number of repetitions of extension and flexion, a measure of endurance and work capacity - Average power (AP) (W) - indicates how quickly certain muscle groups can generate strength (i.e., work per unit time).

The conventional hamstring to quadriceps (H/Q) ratio is important in assessing muscle balance and injury prevention in athletes, including football players. Although it is essential to maintain balanced muscle strength in both legs, assessing the H/Q ratio specifically for the kicking leg (KL) and the supporting leg (SL) can provide valuable information about potential muscle imbalances and injury risk, as well as differences in force accuracy and joint position sense in the knee (Tsvetkova-Gaberska et al., 2023). Muscle strength imbalances typically refer to abnormal bilateral asymmetry (between homologous groups) and distortion of the agonist-antagonist ratio. Co-contraction of the hamstring musculature helps to prevent excessive action of the quadriceps, thereby improving knee joint stability and potentially reducing excessive abduction during landing motor tasks (Weiss & Whatman, 2015). Deficits in hamstring strength and activation limit the potential of these muscles to protect the knee ligaments (Hewett et al, 2008). This leads to a correlation between hamstring injuries and ACL injuries with strength imbalances between the knee flexors and extensors (Coombs & Garbutt, 2002). Isokinetic testing in the dynamic (concentric) mode allows the strength of these muscles to be determined and coefficients to be calculated to assess their strength balance. PT, or the maximum force a muscle can generate, is an important aspect of physical performance in football players, particularly in activities such as sprinting, jumping and tackling. However, specific norms for peak torque can vary depending on the muscle group being assessed, the player's position and other individual factors such as age and training history. However, isokinetic variables related to strength, such as PT, TW, AP and the conventional hamstring/quadriceps (H/Q) torque ratio, are traditionally extracted from isokinetic testing (Śliwowski et al., 2017; Clark et al., 2022). It is recommended that muscle imbalance assessments go beyond strength (Cozette et al., 2019; Schlumberger et al., 2006) and consider additional characteristics that could provide details on injury prevention and treatment. In the isokinetic evaluation of players, these coefficients, also called conventional H/Q ratios, have normal values close to 60% when tests are performed at low to moderate angular velocities (12-180°/s), while results around 70-80% can be expected in tests at high angular velocities (240-360°/s) (Baroni et al., 2018). A complex dynamometric assessment of football players also examines bilateral strength symmetry between the quadriceps (extensors at the knee joint) of the KL and SL, and between the hamstrings (flexors at the knee joint). Studies of athletes who have undergone ACL reconstruction have established a complex set of criteria, one of which is bilateral symmetry of quadriceps strength. Fulfilment of these criteria is an indicator of the degree of recovery and readiness to return to normal sporting activity. It is known that a more symmetrical strength of the m. quadriceps (greater than 90% symmetry) prior to returning to sports practice significantly reduces the incidence of knee ACL re-injury (Grindem et al., 2016).

In addition, some studies have investigated the PT of the knee extensor and flexor muscles across different field positions in order to provide a specific exercise prescription for each football player (Maciel et al., 2020; Dai et al., 2019; Aginsky et al., 2014; Knapik et al., 1991). On the other hand, a player's body composition is particularly important for performance. Since performance is so strongly dependent on body morphology and composition, it would also be relevant to evaluate the isokinetic profile and time parameters of the muscles that are most stressed during football play - the quadriceps and hamstrings (Bongiovanni et al., 2023).

The aim of the present study was to perform a comprehensive dynamometric evaluation of the knee joint of the kicking and supporting legs of football players from the university team of the South-West University "Neofit Rilski" in order to monitor the physiological and biomechanical characteristics of the thigh muscles and the knee joint in these athletes. To achieve this goal, the following steps were planned: (1) anthropometric measurements; (2) isokinetic measurements of dynamic strength characteristics, the time parameters AcT and TPT, as well as power and total work, of the knee joint extensors and flexors of the KL and SL; and (3) assessment of unilateral, flexors/extensors strength asymmetry by calculating the H/Q ratio and bilateral strength asymmetry by the coefficient of bilateral asymmetry (CBA), as criteria for muscle imbalance and risk of injury.

Material & methods

Participants and anthropometric measurements

The experiments were approved by the university's ethics committee. Twenty-four male semi-professional football players from the university football team voluntarily participated in the study. The study was conducted at the University Centre for Functional Research in Sports and Kinesitherapy, South-West University "Neofit Rilski"-Blagoevgrad. All athletes were fully informed of the purpose, procedures and protocols of the study and signed a written informed consent prior to the experimental session. Players were free of injury at the time of assessment and had no medical conditions or history of musculoskeletal, neurological or cardiorespiratory complaints that could compromise their participation in the study. Subjects with a history of lower extremity injury within the previous 6 months were excluded. Height was measured to the nearest 0.1 cm using a

stadiometer (Kern MPE 250K100HM, Germany) and body weight to the nearest 0.1 kg using an electronic weighing scale (Kern MPE 250K100HM, Germany). Body mass composition was measured in the standing position according to a standardized protocol using a bioimpedance analyzer (Jawon Medical IOI-353, Yuseong, South Korea; eight electrodes and pressure contacts). The following anthropometric and body mass characteristics were measured: height (cm), body mass (BM, kg), lean body mass (LBM, kg), mass of body fat (MBF, kg), percentage of body fat (PBF, %), soft lean mass (SLM, kg) and body mass index (BMI, kg/m^2).

Isokinetic testing procedures.

The isokinetic tests were performed with the Biodex System 4 Pro isokinetic dynamometer. The dynamometric recordings were performed with the following settings: - the dynamometer was oriented at 90° and tilted at 0°; - the seat of the dynamometer chair was placed at 90° and the seat back tilted at 85°; - the axis of rotation of the dynamometer was aligned with the transverse axis of the knee joint and related to the point of force application at the distal end of the lower leg; - the subjects were secured with shoulder, waist and thigh straps to limit any unwanted movement from adjacent joints. The knee attachment was adjusted to be proximal to the lateral malleolus and secured with a strap. Concentric muscle strength of the quadriceps and hamstrings was measured at the following three angular velocities 60°/s (low velocity) with 5 repetitions, 180°/s (medium velocity) with 10 repetitions, and 300°/s (high velocity) with 15 repetitions, with 90 s rest in between. The range of motion was set from a fully extended leg corresponding to a knee angle of 0° to a knee flexion of 110°. The performance of the concentric protocol for each velocity started with a knee flexion of 100°. During each test, the subjects were instructed to perform the tests with maximal effort and speed. To ensure maximal contraction, the footballers were verbally encouraged throughout the test. Prior to testing, the athletes warmed up on a bicycle ergometer at a self-selected speed (with a maximum speed limit of 6 km/h) and familiarised themselves with the test procedure. The knee joint muscles of both - KL and SL - were tested sequentially. The resulting dynamic concentric PT was recorded in Nm.

Data processing and statistics

After selection of the highest peak torque value (in Nm) between the five, ten, and fifteen concentric measurements for the velocities (^{o}/s) of 60, 180, and 300, respectively, we applied the descriptive statistics to evaluate for each knee velocity of the three chosen the means ± SD values. The approach was applied for KL and SL in Quadriceps and Hamstrings, as well as for: - the time indicators - AcT and TPT, and the indicators for Power and Total Work; and – the anthropometric indices with a coefficient of variation.

CBA was calculated as the ratio between the peak torque (Nm) of the extensors of the KL and SL in percent, using the formula ((PT of the stronger leg - PT of the weaker leg)/ PT of the stronger leg) *100 (Lockie et al., 2012). Unilateral, flexor/extensor strength asymmetry was calculated as H/Q ratio (percent) according to the formula of Willigenburg et al. (2014): (Hamstring peak torque / Quadriceps peak torque) *100.

GraphPad Prism (Ver 3.0) programme was used for statistical analysis of the data. The normality of the distribution was checked with the Shapiro-Wilk test ($p<0.05$). Since some of the samples did not show normal distribution and additionally, the sample size was <50, the comparative analyses between the variables of the strength characteristics of the Quadriceps and Hamstrings of KL and SL, were checked using the Wilcoxon test at $p<0.05$.

Results

The football players who participated in the study were of a high age (25.1±4.7 years). The comparative analysis of the anthropometric data presented in Table 1 showed high values of MBF (14.7±3.5 kg) and PBF (19.8±3.9%) above 6-13%, which does not correspond to high BMI and SLM. SLM showed values (54.8±4.1) in the lower range of SLM norms.

Table 1. Anthropometric characteristics and body composition of football players

Variable (N = 24)	Mean	±SD	V%
Age (years)	25.1	4.7	19.1**
Height (cm)	176.8	5.1	2.9
Body mass (BM) (kg)	73.8	5.2	7.1
Lean body mass (LBM) (kg)	59.1	4.3	7.3
Mass of body fat (MBF) (kg)	14.7	3.5	23.8**
Percent Body Fat (PBF)(%)	19.8	3.9	20.0**
Soft lean masa (SLM) (kg)	54.8	4.1	7.5
Body mass index (BMI) (kg/m^2)	23.6	1.6	7.1
Experience (years)	11.1	4.5	40.1**
Dominant limb*			
Right	80%		
Left	20%		

**Percentage of the categories are presented. ** Values over 15%.*

In general, isokinetic testing of the knee musculature of football players showed that the KL had higher strength and power characteristics compared to the SL ($p < 0.05$). This interlimb asymmetry is also detected in the additional isokinetic variables: acceleration time and time to peak torque, where the KL presents a shorter muscular reaction time than the SL (Table 2).

Table 2. Values of muscle strength and time indicators, working capacity and power of *m. quadriceps* and *m. hamstrings*, in the kicking and supporting legs, in the concentric mode of isokinetic testing of football players (mean± SD).

INDICATORS	KICKING LEG		SUPPORTING LEG	
	Quadriceps (mean± SD)	**Hamstrings** (mean± SD)	**Quadriceps** (mean± SD)	**Hamstrings** (mean± SD)
60°/s				
PT, (Nm)	212.8±30.1	104.5±28.1	204.3±31.2	92.9±18.8*
AcT, (ms)	36.2±30.7	48.7±30.9	44.0±32.6*	44.5±17.7
TPT, (ms)	684.2±147.4	613.8±216	737.5±161*	685±241
AP, (W)	132.8±22.1	65.1±15.3	123.5±21.1	59.8±14.6*
TW, (J)	1084±221	547±145	1046±212	513±157
H/Q ratio, (%)	49.2±12.8		45.5±6.2	
180°/s				
PT, (Nm)	141.1±26.4	76.9±14.6	129.5±23.8*	69.8±15.3*
AcT, (ms)	55.8±25.1	76.6±23.7	52.9±17.3	86.6±25.6*
TPT, (ms)	314.2±38.1	315.0±97.4	310.4±71.4	303.8±153
AP, (W)	234.7±43.9	119.1±24.3	217.9±42.1*	107.4±29.6*
TW, (J)	1697±268	886±196	1588±271*	798±210*
H/Q ratio, (%)	55.1±8.5		52.8±8.4	
300°/s				
PT, (Nm)	104.8±19.0	61.5±11.1	99.6±17.5*	59.0±11.9
AcT, (ms)	74.5±18.0	114±28.8	79.1±16.9	110±21.0
TPT, (ms)	207.5±62.6	234.2±126	230.4±80.1*	277.9±143
AP, (W)	238.8±48.8	107.8±31.4	228.4±42.1*	102.2±30.9
TW, (J)	2042±488	957±253	1964±484	918±274
H/Q ratio, (%)	59.5±10.6		59.9±11.1	

** Statistically significant difference ($p < 0.05$) as compared to the kicking leg (Wilcoxon); Peak Torque (PT), Acceleration Time (AcT), Time to Peak Torque (TPT), Average Power (AP), Total Work (TW), Hamstrings/Quadriceps ratio, (H/Q ratio).*

The hamstrings show higher PT values of the KL at low and moderate angular velocities ($p = 0.009$), while the quadriceps show a statistically significant increase at moderate and high velocities. Table 2 also shows a significantly higher quadriceps AcT in the SL ($p = 0.02$), but only during the 60°/s and longer TPT at low and high velocities ($p = 0.009$). Regarding the additional isokinetic variables of the hamstrings, differences were only found at 180°/s, where the KL showed a shorter time (ms) compared to the SL.

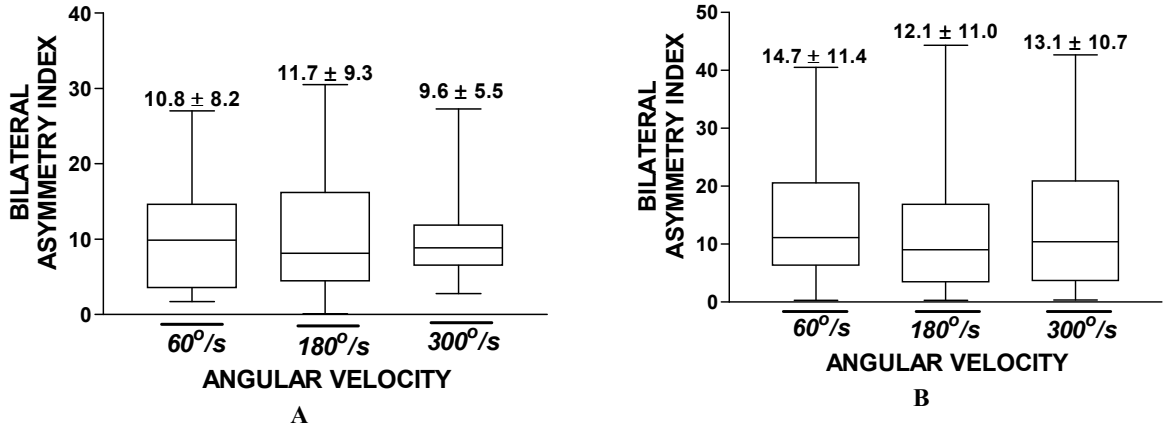

Figure 1 – Bilateral asymmetry index between kicking and supporting leg in football players calculated at three angular velocities 60°/s, 180°/s, 300°/s of **A** – quadriceps and **B** hamstrings muscles in the knee joint.

Power characteristics of SL were reduced at 180 and 300°/s for the quadriceps muscles and for the hamstrings at 60 and 180°/s, compared to the KL ($p = 0.02$). The TW performed during the test was greater for the KL (Table 2). This was statistically significant only at moderate velocity, both for the hamstrings and the quadriceps ($p = 0.01$). At 60^o/s and 300^o/s the extensors of the SL had more reduced indicators than the KL.

It was also observed that KL and SL had lower values of the conventional H/Q ratio compared to established norms. Side-to-side strength differences, as assessed by asymmetry indices, were greater than 10% for the quadriceps in 45% of the players tested. The hamstrings showed a CBA above this norm in 67% of cases at lower velocities (Fig. 1).

The coefficients for unilateral asymmetry between the KL and SL at the three measured velocities: low 60°/s, moderate 180°/s, and high 300°/s (Table 2), were below the normal values for balance, which were 62%, 72%, and 78%, respectively. This is a significant knee joint problem, and about 75% of the players have an H/Q ratio at the KL, and about 85% of the players have a H/Q ratio at the SL. Unilateral asymmetry, as a result of lower H/Q coefficient values, is more pronounced in the lower velocity tests when the Q PT is greater, especially in the SL.

Discussion

The present study aimed to assess the isokinetic profile of knee extensors and flexors in professional academic football players. Despite being part of the academy football team, each of the participants also trained in regional semi-professional teams, with an average of 11.1± 4.5 years. A football player's body composition is of particular importance for performance (Table 1 – Maciel et al., 2020; Dai et al., 2019; Aginsky et al., 2014; Knapik et al., 1991). Since performance is so strongly dependent on body morphology and composition, it would also be relevant to the evaluation of the isokinetic profile and time parameters of the muscles subjected to the greatest load during the football game - quadriceps and hamstrings. The age of 20 years could be taken as the lower limit for anthropometric comparison of adult football players because subjects younger than 20 years did not match anthropometrically with their older teammates. They had lower muscle and higher bone mass, which could be considered anthropometric indicators of the active growing process (Bongiovanni et al., 2023). In our study groups, the players are at an age where growth is considered complete. According to Human Kinetics, the body fat percentage for athletes, especially male football players, is 10-18%, without specifying the applied method. Regarding the body fat percent, the value of 14.7% found in this study was similar to the value found by Bongiovanni et al. The SLM showed lower values compared to professional football players. The large percentage of variation in indicators such as age, fat mass in kg, and percentages, and experience in football indicates that it would be good for the players participating in the study to be in the same playing position in order to be able to refine the obtained data on time characteristics in isokinetic dynamometry of Q and H.

Isokinetic profiles of Q and H were conducted on the traditional (PT, TW, AP) and additional isokinetic variables (AcT and TPT), and footballers' unilateral and bilateral asymmetries were evaluated (H/Q torque ratio, BA index). Although the tested football players show reduced PT compared to professional footballers, the PT of the KL is significantly higher than the SL. Compared to data reported in other studies involving professional football players, a reduced PT of KL (Q = 212.8±30.1 Nm and H = 104.5±28.1 Nm) and SL (Q = 204.3±31.2 Nm and H = 92.9±18.8 Nm) was estimated for both muscle groups (Parpa & Michaelides, 2017; Maciel et al., 2020). The strength of the quadriceps and hamstrings is considered to be an important parameter and is directly related to kicking performance. Maly et al. (2018) found that ball velocity generated by the instep kick of the kicking leg correlates with the quadriceps and hamstrings PT at 60, 180, and 300 °/s angular velocities, where the correlation coefficient ranges from 0.58 to 0.77. Also, the quadriceps muscle plays an important role in jumping and kicking, while the hamstrings muscles control running activities and stabilise knee bends or squats during play (Aginsky et al., 2014). Interestingly, while KL had a shorter reaction time in side-to-side analysis, the Q in 180^o/s and 300^o/s of the KL had higher indices in the traditional isokinetic variables (PT, total work, and power). SL extensors are responsible for stabilising the knee and supporting all body weight during the execution of tasks such as kicking, passing, or crossing, which is a prerequisite for the longer TPT, AcT and the lack of power in this muscle group. In our study, the PT of the KL was higher for both Q and H than data reported by others (Maciel et al., 2020). The analysis of strength profiles can assist in determining whether athletes have sufficient strength and endurance to perform the tasks required at a professional level. As well as identify if they have muscle imbalances that may predispose them to injury. A reduction in PT is an indication of reduced strength, which is a prerequisite for possible traumatism of the ligamentous apparatus of the knee joint during a dynamic football game. In recent years, data on knee muscles PT in football players has been published in the literature, but a more detailed examination of temporal metrics that directly correlate with the degree of motor control is beneficial in making a more comprehensive assessment (Maciel et al., 2020). Such objective indicators of the neuromuscular reactivity to initiate limb movement at the initial moment of the movement in the joint include average power output during the task as well as the work performed. In regard to AcT and TPT, our results showed that the extensors and flexors of the kicking leg reached shorter reaction times (lower AcT and TPT) compared to the supporting leg in the side-to-side analysis. AcT and TPT results could be attributed to the fact that the dominant limb is preferred by athletes to perform specific tasks in football, such as passes, throws, and kicks. The kick is an open kinetic chain multi-joint movement culminating with the explosive concentric

contraction of the knee extensors. The efficiency of the kicking action requires great acceleration and high recruitment speed in addition to force (Sarro et al., 2022; Maciel et al., 2020), which would explain the shorter reaction time found in the quadriceps. The authors have pointed out that the shortest muscular reaction time plays an important role in the prevention of musculoskeletal injuries, especially in the knee. The muscles should contract rapidly to stabilise the joint and the delay in this neuromuscular recruitment would make the joint more susceptible to injury. Comparisons between Q and H show greater differences in Q in the supporting leg compared to the kicking leg. In the low velocity (60°/s) measurements, the time to peak power of the tested players was significantly longer than that of professional players (Maciel et al., 2020). It has been suggested that in the hamstring muscles, a longer time to maximal strength may be an indicator of increased susceptibility to non-contact knee ligament trauma (Clark et al., 2022). On the other hand, at higher speeds, the H of the kicking and supporting legs show values in the normal range (below 320-350 ms). AcT, which is less than 50 ms when Q and H are measured at 60 °/s, is similar to that of professional football players, which is in the range of 24-35 ms for extensors and 30-40 ms for flexors (Maciel et al., 2020). The results of the temporal characteristics analysis indicate the need for targeted training to increase the explosive power and speed of mobilisation of the fast-twitch motor units of the two antagonistic knee muscle groups. The values of the work performed by the athletes of the academic team during the test at 60 o/s (1084±221 J and 1046±212 J for the extensors of the kicking and supporting leg and 547±145 J and 513±157 J for the flexors) were close to those of professional footballers, indicating that they had the work capacity and endurance required for this type of sport. The average power of the extensors and flexors, an indicator of the speed with which the muscles generate force, at low speeds is reliably lower than that measured in professional footballers and is recommended to be developed with appropriate loads (Maciel et al., 2020).

The H/Q ratio was between 49.2±12.8 and 45.5±6.2 at 60°/s for the KL and SL, respectively. These values are considered low and it is recommended that a normal balance between agonist and antagonist muscle groups be restored to significantly reduce the risk of injury. Conventional ratios below 60% measured at 60°/s (Dauty et al., 2003; Coombs et al., 2002) are associated with injury, while Croisier et al. (2008) suggest a cut-off of 55% for the H/Q ratio measured with Biodex isokinetic dynamometers. Approximately 75% of players have an H/Q ratio of the kicking leg and approximately 85% of players have a unilateral asymmetry of the supporting leg. This is associated with a risk of injury and growth, especially of the anterior cruciate ligament, the ligamentous apparatus and the soft tissues of the knee joint in general. Aginsky et al (2014) reported that the risk of hamstring injury in athletes increased 17-fold when the reciprocal ratio was less than 60%. Unilateral asymmetry as a result of lower H/Q coefficient values is more pronounced in lower speed tests when the E PT is greater, especially in the supporting leg. It is important to note that the ideal H/Q ratio may vary from individual to individual and factors such as the athlete's style of play, position and injury history may influence their specific needs. A well-balanced H/Q ratio in the kicking leg is critical for generating power, control and accuracy in kicking and passing.

Some authors (Knapik et al., 1991; de Lira et al., 2017) indicate values up to 15% as a norm for the CBA coefficient or as a threshold to distinguish normal from pathological. In athletes from different disciplines, a value of 10% is considered as a strong CBA (Kyritsis et al., 2015; Dai et al., 2019). Very few studies have attempted to explain the relationship between strength asymmetry and the risk of injury in players in a study in which side-to-side strength asymmetry is accepted as 10%. CBA is an important criterion for knee joint muscle stabilisation. At 60°/s, 45% of athletes had a CBA of Q above the norm and 66.7% of athletes had a CBA of H above the norm. At 180°/s, CBA of Q occurred in 45.8% of the athletes and of H in 47.6%. CBA was greater for H at the knee than for Q at all three velocities, requiring greater attention and training of the hamstrings by the coaching staff. Individually, the data show that in some individuals the CBA reaches about 30%, which is associated with disturbances in dynamic balance, leading to risks of injury, sprains, growths, etc. The authors reported that limb asymmetry is not uncommon in first-year professional football players and may also be related to the players' training experience (Knapik et al., 1991; Kyritsis et al., 2015). Aginsky et al. (2014) reported that CBA in elite football players might be an adaptation to the demands of the sport. In addition, during training and matches, players tend to perform many bilateral repetitions of starts, stops, jumps and other explosive activities. In addition, when players shoot at goal, their KL performs a propulsive movement while the SL acts as a support, thus involving the lower limb muscles.

The existence of strength and power variations is often observed in sports and is associated with a higher prevalence of injuries. Current research supports the recommendation of regular monitoring of strength, unilateral strength balance and bilateral asymmetry, which are potentially modifiable parameters related to physical training and injury risk, in order to better adapt training sessions to avoid strength imbalances and favouring the same limb in different sports (Sarro et al., 2022; Aginsky et al., 2014; Maciel et al., 2020; Dauty et al., 2003). The results obtained from the isokinetic strength profile data showed that some of the athletes had reduced strength characteristics and insufficient peak torque generation power. Improving these characteristics could support the better athletic performance of the individuals studied. This result is complemented by the muscular balance and asymmetry found, which could predispose them to traumatism during the performance of elements related to the demands of a football game.

Conclusions

In the current study, the knee joint strength of football players in the kicking and supporting leg was analysed by traditional and additional variables using isokinetic parameters. However, it was found that football players from the SWU "Neofit Rilski" Academy team had less strength than professional football players of the same age group, but had improved speed and power. Differences in time parameters, work capacity and power at moderate speed - 180o/s, were observed in both groups of muscles, with SL having lower values compared to KL. At 60^{o}/s and 300^{o}/s the extensors of the SL had more reduced indicators than the KL. Both unilateral and bilateral asymmetry via H/Q ratio and CBA confirmed the significance of knee joint strength abnormalities. These indices add depth to the complex analysis of Q and H strength profiles, highlight risks and predispositions to so-called non-contact knee injuries, and provide specific guidance for the development of training and therapy programmes. Together with the anthropometric characteristics of the players, the findings may be relevant for the design of position-specific training programmes that would help to exploit their high level of muscle mass by focusing on additional strength and power-based stimuli. The analysis provides fundamental recommendations for the interpretation of dynamometer results and has been instructive for coaches, players, therapists and sports physiology specialists. These measurements are physiological indicators of activation of the Q and H knee muscles, neuromuscular control, explosive power and work capacity. There is evidence that the addition of other variables to isokinetic testing can provide crucial details about the neuromuscular profile of football players.

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