INFORMATION TECHNOLOGY IN SPORTS SESSION

INTEGRATED NEUROMUSCULAR PROFILING IN PROFESSIONAL SOCCER: A PRE-SEASON STRENGTH–POWER–ASYMMETRY MODEL BASED ON ISOKINETIC AND FORCE-PLATE TESTING

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Abstract:

Objective: This study investigated the relationship between isokinetic knee strength and concentric impulse during Countermovement Jump (CMJ) in professional team-sport athletes, with particular focus on the predictive role of hamstring peak torque. Methods: Sixteen professional players underwent isokinetic knee testing at 60°/s and bilateral force-plate CMJ assessment. Mean quadriceps peak torque (PT Quad), hamstring peak torque (PT Ham), hamstring-to-quadriceps ratio (H/Q), and CMJ concentric impulse were analysed using Pearson correlations and multiple linear regression. Results: Mean PT Quad was 187.41 ± 25.70 Nm, PT Ham 173.47 ± 25.37 Nm, and H/Q ratio 71.25% ± 8.32%. CMJ concentric impulse (207.88 ± 19.39 N·s) showed a very strong positive correlation with PT Ham ($r = 0.774$, $p < .001$) and a strong correlation with PT Quad ($r = 0.728$, $p = .001$). Multiple linear regression explained 69.9% of CMJ impulse variance ($R^2 = 0.699$), with PT Ham emerging as the only significant independent predictor ($p = .024$), whereas PT Quad ($p = .070$) and H/Q ratio ($p = .852$) were not significant. Conclusions: Hamstring strength appears to be a primary determinant of dynamic force production during CMJ, supporting the functional role of the posterior chain in explosive multi-joint performance. These findings suggest that isokinetic hamstring strength may represent a key parameter in neuromuscular pre-season profiling. Limitations: a small sample size (N = 16), a cross-sectional design, and testing at a single low isokinetic velocity (60°/s). Approximately 30% of CMJ variance remained unexplained, indicating additional neuromuscular determinants.

Keywords:

Isokinetic, Sport, Force-plate, CMJ, SJ.

INTRODUCTION

Modern football requires intense physical preparation. Players must meet high performance demands. Explosive lower limb strength is crucial for top performance. High-intensity actions like sprinting, jumping, accelerations, decelerations, and ball striking all require quick, forceful exertion. Proper diagnostics are essential to assess neuromuscular capacity, optimise training, and prevent injuries.[1], [2].

Isokinetic testing is a gold standard and a widely used method for assessing muscle function in sports and medical research. It provides objective measurements of peak torque produced under controlled conditions [3].

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Key parameters include knee extensor and flexor torque, quadriceps and hamstring strength, and their H/Q ratio. This ratio often indicates muscle balance and may help prevent injuries, especially in the hamstrings. These are a common site for non-contact injuries in football [4], [5]. Many studies have explored the relationship between knee flexor and extensor torque from isokinetic testing [6]. Their results suggest this ratio might predict which players are at risk of injury [2], [4], [5], [7]. Players with bilateral strength asymmetries at the season's start show a higher rate of non-contact injuries [4], [8].

In addition to devices used for assessing maximal muscle strength under isolated conditions, it is also necessary to include tests that evaluate functional performance relevant to sport-specific demands. One of the most commonly used tests for assessing explosive lower-body power is the countermovement jump (CMJ). Analysis of vertical jumps performed on force platforms enables a detailed insight into biomechanical parameters, including peak ground reaction force, force impulse, duration of the concentric phase, as well as asymmetries between lower limbs [2], [5], [6], [8]. Force impulse, as a component of the concentric phase of the jump, has been increasingly studied in recent years, as it allows for a more comprehensive assessment of an athlete's ability to generate force throughout the entire movement. Compared to jump height, impulse provides a more accurate evaluation of neuromuscular characteristics, as it incorporates both the magnitude of force and the duration of its application.

The use of isokinetic testing to assess muscle strength and the analysis of vertical jumps are key components in the neuromuscular evaluation of athletes. However, the relationship between isolated knee joint muscle strength and explosive performance characteristics remains insufficiently explored. Some studies indicate a significant influence of greater extensor and flexor torque on superior jump performance, yet it remains unclear to what extent this isolated measure of torque contributes to force production during complex, sport-specific movements [2], [6].

Maximal muscle force represents one of the key variables alongside explosive characteristics obtained during jump testing [2]. However, other factors—such as the efficiency of the stretch–shortening cycle (SSC), tendon stiffness, and intermuscular coordination—also significantly contribute to force production independently of maximal strength measured during isokinetic testing. Therefore, for a more comprehensive understanding of the neuromuscular profile of football players, the integration of isokinetic testing and force plate-based jump analysis is of great importance [2].

Based on the aforementioned findings, the aim of this study was to examine the relationship between knee joint muscle strength assessed by isokinetic testing and variables of dynamic force production during vertical jumping in professional football players at the beginning of the preseason period. The focus was on analysing the associations between peak torque of knee extensors and flexors, their ratio (H/Q), and CMJ-derived parameters, with the goal of identifying variables that most strongly contribute to impulse generation during the concentric phase of the jump.

2. METHODS

A quasi-experimental design was applied in this study, where the relationship between muscle force and its influence on jump performance in professional football players was examined through the analysis of measured variables using appropriate statistical procedures. With regard to measurement procedures, a laboratory testing method was employed.

2.1. PARTICIPANTS

The study was conducted on a sample of 16 professional football players prior to the start of the competitive season. The average body height was 197.4 cm, while the average body mass was 76.1 kg. The age of the participants ranged from 17 to 26 years. All participants were healthy and, at the time of testing, free from injuries that could affect test performance. The study was conducted with the informed consent of all participants and in accordance with the ethical principles outlined in the Declaration of Helsinki.

2.2. TESTING PROCEDURE

Testing was conducted using a randomised crossover design. Participants were randomly assigned so that one group first performed testing on the isokinetic dynamometer, followed by force plate testing (VALD) after a 15-minute rest period. The scheduling of participants was coordinated with strength and conditioning coaches in accordance with the ongoing training process. Prior to testing, body composition was assessed. All testing procedures were conducted under standardised conditions. Participants were tested in the morning hours, were well-rested, healthy, and had not performed any training 24 hours prior to testing. All measurements were carried out by experienced assessors. Testing and measurements were conducted in the Research Laboratory of the sports rehabilitation centre Fizio Group in Belgrade.

2.2.1. Body Composition Assessment

Body composition was assessed using the InBody 270 (Biospace, California, USA). Participants remained in a standing position for 5 minutes prior to the measurement [9]. All participants were familiarised with the testing procedure. Measurements were conducted in the morning, with participants wearing sports shorts, after abstaining from food and fluid intake for at least two hours.

During the measurement, participants were instructed to stand upright, remain still and relaxed, avoid contracting the muscles of the arms, legs, and trunk, look straight ahead, breathe normally, and refrain from speaking. The arms were positioned approximately 15 cm away from the trunk [9]. Additionally, participants had not engaged in training the day before testing, in accordance with standardisation recommendations.

The InBody 270 provides an accurate assessment of body mass, body fat percentage, and muscle mass, enabling the evaluation of the morphological status of athletes [10]. Never add tables as images into the paper body. All tabular content must be prepared as a proper text table.

2.2.2. Jump Testing (Squat Jump, Countermovement Jump)

Squat Jump (SJ) and Countermovement Jump (CMJ) tests were performed on a force platform system - VALD ForceDecks (VALD Performance, Brisbane, Australia). All jumps were executed with hands placed on the hips, in accordance with the official VALD protocol. The SJ was performed without a preparatory countermovement to assess pure concentric power, while the CMJ included a rapid eccentric phase activating the stretch–shortening cycle. Three trials of each test were performed, with rest intervals of 5–7 seconds between attempts. The force platforms enable the assessment of jump height, impulse, relative power, and rate of force development (RFD), making them a gold standard for evaluating explosive performance [11], [12].

2.2.3. Isokinetic Dynamometry

In addition to the previously described tests, knee joint assessment was conducted using the isokinetic dynamometer HUMAC NORM (CSMi Medical Solutions, Stoughton, MA, USA), a successor to the Cybex NORM system, widely used in sports science and clinical practice. Participants first performed a standardised warm-up on a cycle ergometer (5 minutes), followed by the testing protocol. The right leg was tested first in a concentric contraction mode at an angular velocity of 60°/s, and after a 1-minute rest period, the same protocol was repeated for the left leg. Participants were positioned in a seated posture, with the backrest adjusted to approximately 85–90° relative to the seat. The pelvis and trunk were stabilised using straps across the chest, hips, and thigh to minimise compensatory movements and ensure isolation of the knee extensors and flexors. Participants held the side handles throughout the test. The dynamometer axis was aligned with the lateral epicondyle of the femur. The lever arm was positioned on the lower leg, with the padded attachment secured 2–3 cm above the medial malleolus. The range of motion was individually adjusted. The testing protocol was as follows: at 60°/s: 5 submaximal familiarisation repetitions (performed at approximately 50–70% of maximal effort), followed by 5 maximal repetitions; rest interval of 1 minute. The isokinetic dynamometer demonstrates high reliability in assessing peak torque [13].

2.3. VARIABLES

A total of 22 variables were analysed, including morphological characteristics and muscle contraction variables obtained from isokinetic testing and jump performance.

Morphological variables included:

- Body height – BH (cm) and body mass – BW (kg).

Isokinetic dynamometry variables (for both limbs – right and left) included:

- PTQ60 (Nm) – peak torque of knee extensors at 60°/s, and
- PTH60 (Nm) – peak torque of knee flexors at 60°/s.

The jump variables obtained from testing on the VALD ForceDecks platforms included:

- CMJ Power (W) – mechanical power produced during the countermovement jump, expressed in watts (W), representing the total amount of energy generated during the propulsive phase of the jump.

- CMJ Relative Power (W/kg) – relative power during the countermovement jump, expressed in watts per kilogram of body mass (W/kg), indicating efficiency in power production relative to body mass.
- CMJ Height (cm) – jump height achieved during the countermovement jump, expressed in centimetres, calculated based on flight time and force production during the jump.
- CMJ Concentric RFD (N/s) – rate of force development during the concentric phase of the countermovement jump, representing the athlete's ability to rapidly generate maximal force within a short time interval.
- SJ Power (W) – mechanical power during the squat jump, expressed in watts, reflecting explosive capability in an isolated concentric movement (without a preceding eccentric phase).
- SJ Relative Power (W/kg) – relative power during the squat jump, expressed in watts per kilogram of body mass (W/kg), indicating the level of explosiveness relative to body mass.
- SJ Height (cm) – jump height achieved during the squat jump, expressed in centimetres, as an indicator of concentric explosive force.
- SJ Concentric RFD (N/s) – rate of force development during the concentric phase of the squat jump, measuring the ability of the muscles to rapidly increase force within a very short time period.

2.4. STATISTICAL ANALYSIS

Statistical analysis was performed using standard parametric methods. Descriptive statistics were expressed as mean (Mean), standard deviation (SD), and 95% confidence interval (95% CI). The normality of data distribution was assessed using the Shapiro–Wilk test, with the level of significance set at $p > .05$. The relationships between variables were examined using the Pearson correlation coefficient (r), along with the corresponding level of statistical significance (p) and 95% confidence intervals. The predictive value of independent variables was analysed using multiple linear regression analysis. For the regression model, R, R^2, and adjusted R^2 values were reported, along with the F statistic and model significance level. For individual predictors, regression coefficients (β/Estimate), standard error (SE), t values, and p values were presented. The level of statistical significance for all analyses was set at $p < .05$. Data analysis was performed using the R statistical software package [13].

3. RESULTS

The study involved a sample of 16 participants (N = 16). Descriptive statistics of strength, performance, and neuromuscular variables are presented in Table 1. Maximal quadriceps strength (PT Quad) was 187.41 ± 25.70 Nm (95% CI [173.71, 201.10]), while hamstring strength (PT Ham) reached 173.47 ± 25.37 Nm (95% CI [159.95, 186.99]). The mean H/Q ratio was 71.25% ± 8.32% (95% CI [66.82, 75.68]).

Regarding jump performance, concentric impulse in the CMJ was 207.88 ± 19.39 N·s (95% CI [197.55, 218.21]), compared to 200.12 ± 19.30 N·s (95% CI [189.83, 210.41]) in the SJ. The SSC ratio averaged 1.04 ± 0.03 (95% CI [1.03, 1.05]), indicating limited elastic contribution. Contraction Time was 703.94 ± 71.24 ms (95% CI [665.98, 741.90]). All variables met normality assumptions based on the Shapiro–Wilk test ($p > .05$), supporting the use of parametric analyses (Table 1). The Pearson correlation matrix (Figure 1) revealed strong positive associations between isokinetic strength and dynamic performance. CMJ impulse showed a very strong correlation with PT Ham ($r = 0.774$, $p < .001$, 95% CI [0.451, 0.918]) and a strong correlation with PT Quad ($r = 0.728$, $p = .001$, 95% CI [0.363, 0.899]).

No significant relationships emerged between CMJ impulse and H/Q ratio ($r = -0.107$, $p = .694$) or SSC ratio ($r = 0.048$, $p = .859$), suggesting that elastic utilisation and strength balance do not directly influence impulse production in this sample. Contraction Time also showed no significant associations with either quadriceps ($r = 0.305$, $p = .250$) or hamstring strength ($r = 0.306$, $p = .250$).

A multiple linear regression model (Table 2) was conducted to determine the contribution of strength variables to CMJ impulse. The model explained 69.9% of the variance ($R = 0.836$, $R^2 = 0.699$), indicating a strong predictive capacity. Among the predictors, only PT Ham emerged as a statistically significant independent contributor (Estimate = 0.40, $p = .024$). PT Quad showed a trend toward significance ($p = .070$), whereas H/Q ratio did not contribute meaningfully to the model ($p = .852$). An additional regression model using the SSC ratio as the dependent variable demonstrated substantially lower explanatory power ($R^2 = 0.263$), with no predictors reaching statistical significance, further supporting the relative independence of elastic performance from maximal strength.

Table 1. Descriptive statistics of strength, performance, and neuromuscular variables in the experimental group (N = 16)

					95% CI						Shapiro-Wilk	
	Group	N	Missing	Mean	Lower	Upper	Median	SD	Minimum	Maximum	W	p
PT Quad 60°/s (Nm)	Exp	16	0	187.41	173.71	201.10	183.25	25.6951	148.500	254.00	0.934	.286
PT Ham 60°/s (Nm)		16	0	173.47	159.95	186.99	173.25	25.3735	124.000	228.00	0.982	.977
H/Q Ratio		16	0	71.25	66.82	75.68	68.50	8.3227	61.500	90.50	0.907	.102
Concentric Impulse CMJ (N·s)		16	0	207.88	197.55	218.21	210.85	19.3902	170.600	241.10	0.975	.917
Contraction Time (ms)		16	0	703.94	665.98	741.90	707.50	71.2371	572	816	0.959	.639
Concentric impulse SJ (N·s)		16	0	200.12	189.83	210.41	200.35	19.3045	168.300	236.80	0.976	.930
SSC Ratio (CMJ/SJ impulse)		**16**	**0**	**1.04**	**1.03**	**1.05**	**1.04**	**0.0269**	**0.980**	**1.10**	**0.947**	**.448**

Note: The confidence interval (CI) of the mean assumes that sample means follow a t-distribution with N – 1 degrees of freedom.

Table 2. Linear regression analysis predicting concentric impulse during countermovement jump (CMJ)

Predictor	Estimate	SE	t	p
Intercept	75.7383	39.495	1.918	.079
PT Quad 60°/s (Nm)	0.3077	0.155	1.989	.070
PT Ham 60°/s (Nm)	0.3999	0.155	2.583	.024
H/Q Ratio	0.0715	0.376	0.190	.852

Note: R = 0.836, R^2= 0.699 . N = 16; $p < .05$

4. DISCUSSION

The present study investigated the relationship between knee isokinetic strength and dynamic force production in professional soccer players during the pre-season period. The main finding is the strong association between CMJ concentric impulse and both quadriceps and hamstring peak torque. However, when accounting for shared variance, only hamstring strength remained a significant independent predictor (Table 2), explaining a substantial portion of performance variability. Similar relationships between lower-limb strength and neuromuscular performance have been reported in previous research involving professional soccer players [1], [2].

This result suggests that while global knee strength is relevant for performance, only hamstring peak torque demonstrates independent predictive capacity, highlighting the posterior chain as the primary functional driver of impulse generation. From a neuromechanical perspective, hamstrings contribute not only to knee flexion but also to hip extension and force transmission along the posterior kinetic chain, which are critical during the propulsive phase of vertical jumping. Previous research has highlighted the importance of hamstring strength in both performance and injury prevention in professional soccer players [2], [3].

The strong relationships observed between isokinetic peak torque and concentric impulse reinforce the role of maximal strength as a key determinant of explosive performance. As shown in Table 1, the relatively high absolute strength values correspond to high impulse outputs, supporting the concept that force production capacity under controlled conditions transfers to multi-joint dynamic tasks. Previous studies have shown that lower-limb strength assessed through isokinetic dynamometry is strongly associated with explosive performance and injury risk monitoring in elite athletes [3], [4]. In this context, impulse-based metrics provide a more comprehensive representation of performance than jump height alone, as they integrate both force magnitude and application time. Recent investigations using force platforms have emphasised the importance of impulse-based metrics in neuromuscular profiling and monitoring of elite soccer players [7].

The regression model (Table 2) further refines this interpretation by demonstrating that not all strength components contribute equally. Despite similar correlation magnitudes, only PT Ham retained significance, suggesting a hierarchical contribution within lower-limb musculature. This aligns with the concept that multi-joint performance is not merely the sum of isolated joint outputs, but rather the result of coordinated force transmission across segments. Similar conclusions were reported in studies investigating strength asymmetries and neuromuscular performance in soccer players [1], [5].

Conversely, the absence of significant relationships between isokinetic variables and SSC ratio indicates that elastic efficiency represents a distinct neuromuscular quality. As highlighted in Figure 1, the SSC ratio does not cluster strongly with strength variables, and the regression analysis confirms its independence. This suggests that stretch–shortening cycle utilisation depends more on factors such as tendon stiffness, neuromuscular coordination, and timing rather than maximal force production alone. Previous studies investigating CMJ variables in elite soccer players have similarly reported that elastic utilisation depends on neuromuscular coordination and mechanical factors rather than maximal strength alone [6], [7]. The relatively low SSC ratio observed (Table 1) further supports this interpretation, indicating a limited contribution of elastic mechanisms in this cohort. This profile may be described as predominantly "force-driven," where performance is primarily determined by concentric force production rather than elastic energy reutilization. The lack of association between Contraction Time and performance variables suggests that, within a homogeneous elite sample, temporal characteristics of the concentric phase may have reduced discriminative value. It is plausible that technical execution is highly standardised in professional athletes, limiting variability in movement strategies.

Overall, the integration of findings across Table 1, and Table 2 supports a coherent interpretation: maximal strength, particularly of the hamstrings, is strongly linked to dynamic impulse production, whereas elastic efficiency emerges as an independent performance dimension. These results reinforce the importance of combining isokinetic and force platform assessments in neuromuscular profiling of elite athletes [4], [7]. The present study investigated the relationship between knee isokinetic strength and dynamic force production in professional soccer players during the pre-season period. The main finding is the strong association between CMJ concentric impulse and both quadriceps and hamstring peak torque, as evidenced by the correlation matrix (Figure 1).

However, when accounting for shared variance, only hamstring strength remained a significant independent predictor (Table 2), explaining a substantial portion of performance variability. This result suggests that while global knee strength is relevant for performance, the posterior chain plays a more determinant functional role in impulse generation. From a neuromechanical perspective, hamstrings contribute not only to knee flexion but also to hip extension and force transmission along the posterior kinetic chain, which are critical during the propulsive phase of vertical jumping. The strong relationships observed between isokinetic peak torque and concentric impulse reinforce the role of maximal strength as a key determinant of explosive performance. As shown in Table 1, the relatively high absolute strength values correspond to high impulse outputs, supporting the concept that force production capacity under controlled conditions transfers to multi-joint dynamic tasks. In this context, impulse-based metrics provide a more comprehensive representation of performance than jump height alone, as they integrate both force magnitude and application time.

5. STUDY LIMITATION

Despite the relevance of the findings, the small sample size (N = 16) and cross-sectional design limit generalizability and preclude causal inference. The use of isokinetic testing at 60°/s, lower than sport-specific velocities, may explain the lack of association with SSC-related variables. Although the regression model explained approximately 70% of the variance in CMJ impulse, a substantial portion remains unexplained, likely due to factors such as movement technique, muscle-tendon properties, and intermuscular coordination.

6. CONCLUSION

Hamstring peak torque emerged as the only independent predictor of CMJ impulse, highlighting the central role of posterior chain strength in explosive performance. The absence of associations between strength variables and SSC ratio suggests that elastic performance represents a distinct neuromuscular dimension. From a practical perspective, these findings support the integration of isokinetic and force plate assessments, with targeted development of hamstring strength.

Future research should adopt longitudinal and sport-specific approaches to further clarify the determinants of lower-limb power in elite athletes.

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