



Research Article

Neuromuscular hamstring profile based on strength imbalance as a basis for injury prevention in youth football players

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ABSTRACT

Background: Hamstring strength imbalance between the left and right sides has been identified as a factor contributing to increased injury risk in athletes. However, few studies have evaluated not only bilateral strength differences but also the magnitude of clinically significant imbalances in various hamstring strength parameters. Objective: This study aims to analyze bilateral hamstring muscle asymmetry in terms of maximum, average, and maximum impulse strength, and to evaluate whether the distribution of high imbalances reaches clinically relevant thresholds associated with potential injury risk. Methods: This study is a cross-sectional observational study. Twenty athletes ($n = 20$) underwent hamstring strength measurements using the NordBord Hamstring Testing System. The parameters analyzed included maximum force, average force, and maximum impulse on the left and right sides. Normality was assessed using the Shapiro–Wilk test. Bilateral comparisons were analyzed using paired t-tests or Wilcoxon signed-rank tests, depending on data distribution, and accompanied by effect size calculations (Cohen's d). Imbalance (%) was calculated for each parameter and classified into low-, moderate-, and high-risk categories. Risk category distribution was analyzed using a binomial test with a clinical reference value of 20%. Result: There were significant bilateral differences in several hamstring strength parameters ($p < 0.05$) with moderate to large effect sizes. The imbalance analysis showed that the proportion of athletes with high max impulse imbalance (45%) was significantly higher than the clinical threshold ($p = 0.010$). Conversely, the proportion of high imbalance in maximum force and average force did not differ significantly from the clinical reference value ($p > 0.05$). Conclusion: Although bilateral hamstring strength differences were found, only maximum impulse imbalance showed clinically relevant significance regarding potential injury risk. These findings emphasize the importance of including impulse analysis, in addition to force, in hamstring injury risk screening using NordBord.

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Introduction

The majority of injuries in young male football players occur in the lower extremities, with a variation of 2.0 to 26.6 injuries per 1,000 hours of play (Brink et al., 2010; Ferdinand et al., 2025; Le Gall et al., 2006). When players burst forward quickly, twist suddenly, or give full effort on the field, a specific type of injury occurs more often. This happens mainly in muscles behind the knee - the hamstrings - and it is tied closely to long, stretching movements, doing challenging work (Huygaerts et al., 2020; Loose et al., 2019; Morgans et al., 2025). Because these actions require strong pulling without releasing, tension builds to a high level. That pressure can tear muscle fibers, leading to pain and downtime.

Recovery tends to take longer than expected, sometimes weeks rather than days (Altarriba-Bartés et al., 2024). On top of slow healing, coming back strong after such damage becomes tricky for many. Without spotting the real causes behind repeats, the cycle keeps going. So preventing problems matters most, starting with tests that check how muscles in the legs work together. When these tests look at movement control by muscle groups, they spot uneven patterns early. That kind of insight helps guide safer routines before strain sets in. Prevention works better when it follows real physical signals instead of guesses.

One side of the body's muscles might work harder than the other when controlling movement - this imbalance occurs because nerves send uneven signals to both sets of muscles (Benson et al., 2024; Canton et al., 2019). Take the quadriceps: if one half pushes stronger than the other, it could shift how stable the knee feels or put extra strain on nearby structures like ligaments or tendons. That kind of imbalance often develops after injury, even if rehab was not fully completed. Sometimes the body adjusts how it controls movement over time due to repeated demands. Studies show that differences of 10 to 15 percent or more tend to go hand in hand with poorer training results and a greater risk of long-term damage, especially in activities involving quick starts or stops (Franklin et al., 2020). Around here, folks often talk about 10 to 15 percent as a rough guide - it helps spot who might be more likely to get hurt during games or workouts. It is not set in stone, yet it becomes a shared way to check how well muscles and nerves are working. Coaches, doctors, and trainers find it helpful when planning exercises meant to reduce harm while boosting results.

When studying sprinters, experts examine how fast they move and how much force they exert. Speed near the end of a run often indicates top-level ability, as it marks the point where power matters most (Andrzejewski et al., 2015; Carling et al., 2015). Still, just measuring the quickest part ignores what happens earlier in the dash. Acceleration builds momentum, yet standard methods usually ignore this phase entirely. That means something important can be missed if you focus only on the peak number. Because of this, scientists now often look at factors such as average speed change and total energy output during a sprint. How fast an athlete builds continuous bursts of speed early in the race gives clues about their progress (Carling et al., 2015). Energy output, calculated by combining applied force with movement speed, shows how well the body delivers power across short distances. Focusing only on top-end velocity might miss subtle issues in movement efficiency that emerge under closer scrutiny.

Ahead of its peers in sports analysis, the GPS tracker stands out by reliably tracking an athlete's effort during workouts and games (Hanief et al., 2026). Built to capture detailed information on speed, distance, and rapid changes in movement, it provides researchers with clear views of physical strain over time. When it comes to team events such as rugby or football, where managing intensity matters, this tool helps coaches measure both personal and team-level performance signs (Colby et al., 2014; Mitrotasios et al., 2024; Osondu & Hiba, 2025; Piłka et al., 2023). Though often overlooked, these devices play a key role in shaping strategy based on real-time activity levels. Movement data is processed using sophisticated methods, helping trainers spot weaknesses while refining drills. Notably, GPS-tracked location details help spot weariness or strain before they worsen, prompting early action. Young players benefit when coaching tools adapt to how their bodies respond differently from adults', building stronger futures in sport. Using location data in their planning, those who work with athletes now gain clearer insights into results and health.

Although several studies have examined hamstring strength in football players, most have focused on comparing group averages or on statistically significant bilateral differences (Copland et al., 2009; Coto Martín et al., 2025; Elliott et al., 2011; Garcia et al., 2022; Hides et al., 2011; Small et al., 2009; Yu et al., 2008). Highlighting the clinical relevance of these findings can help the audience feel more confident in applying research insights to real-world settings. This approach provides important information about the general characteristics of the population, but is relatively limited in describing

the distribution of imbalance levels at the individual level. In addition, assessments often emphasize statistical significance, without explicitly considering the clinical relevance of the proportion of players at a certain level of imbalance. In the context of football, hamstring imbalance analysis is also often performed based on a single strength parameter, such as maximum force, thus not fully reflecting the complexity of neuromuscular function. Therefore, an approach that evaluates hamstring imbalance using several strength parameters simultaneously and describes the distribution of risk categories descriptively is still needed to provide a more comprehensive picture of the neuromuscular profile of football players.

Referring to this issue, this study investigates bilateral hamstring differences in 14-16 year old youth football players using NordBord-based neuromuscular measurements. Specifically, this study evaluates the magnitude of strength imbalances on several parameters, namely maximum force, average force, and maximum impulse, in order to describe the neuromuscular profile of the hamstrings more comprehensively. Additionally, this study assesses whether the proportion of athletes in the high imbalance category reaches a clinically relevant level in the context of potential injury risk. This approach offers advantages by not only emphasizing statistical differences between sides, but also integrating risk distribution analysis based on clinical thresholds and utilizing reliable and objective NordBord instruments, thereby supporting a more applicable understanding of the neuromuscular profile of the hamstrings in the youth football population. The practical use of these measurements must be taken into account because screening many athletes can be costly and time-consuming; thus, field-based assessments are probably more suitable for football academies.

Method

Research Design

This study used a cross-sectional observational design to describe the neuromuscular profile of the hamstrings in youth football players.

Participants

Participants in this study were youth football players aged 14–16 years (height 164.68 ± 6.66 , weight 50.67 ± 1.53 , BMI 19.24 ± 2.66) who actively participated in a structured training program and had no lower extremity injuries at the time of data collection. All subjects participated voluntarily after receiving an explanation of the study's purpose and procedures. This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and was approved by the Ethics Committee of Universitas Negeri Malang (Protocol No. 30.10.07/UN32.14.2.8/LT/2025).

Research Instruments

Hamstring strength was measured using the NordBord Hamstring Testing System, which is a reliable and widely used instrument for assessing bilateral eccentric hamstring strength. The parameters analyzed include maximum force (N), average force (N), and maximum impulse (Ns) on the left and right sides. Bilateral imbalance is calculated as a percentage based on the absolute difference between the two sides normalized to each individual's maximum value.

Data Analysis

Data analysis started with descriptive statistics and Shapiro–Wilk normality testing to clarify the process. The comparison of hamstring strength between the left and right sides was analyzed using a paired t-test or a Wilcoxon signed-rank test, depending on the data distribution, with the effect size reported as Cohen's d. Imbalance (%) was then classified into low risk ($\leq 10\%$), moderate risk (10–15%), and high risk ($> 15\%$) categories. The clinical relevance of the proportion of athletes in the high-risk category was analyzed using a binomial test with a clinical reference value of 20%. All statistical analyses were performed using JASP software, with a significance level set at $p < 0.05$.

Results and Discussion

Results

This study involved 20 male athletes aged 14-16 years. This study measured maximum force, average force, and maximum impulse. Descriptive data of the measurement results can be seen in [Table 1](#). Normality tests are conducted to determine the distribution of data ([Table 2](#)).

Table 1. Descriptive Statistics of maximum force (N), average force (N), and maximum impulse (Ns)

Item Test	Mean	Std. Deviation	Minimum	Maximum
L Max Force (N)	209.44	39.68	137.5	278.5
R Max Force (N)	222.31	37.50	163.8	301.8
L Max Torque (Nm)	75.58	21.95	4.880	104.0
R Max Torque (Nm)	82.53	15.39	59.68	112.7
L Avg Force (N)	188.05	35.81	128.3	256.8
R Avg Force (N)	204.20	35.81	149.3	272.8
L Max Impulse (Ns)	27.69	13.45	8.610	61.37
R Max Impulse (Ns)	31.87	15.63	11.90	66.48

Table 2. Results of Normality Test (Shapiro–Wilk) for Left and Right Hamstring Strength Variables (n = 20)

Variable	Side	Mean ± SD	Shapiro–Wilk	p-value	Interpretation
Max Force (N)	Left	209.4 ± 39.68	0.970	0.762	Normal
	Right	222.3 ± 37.50	0.965	0.638	Normal
Max Torque (Nm)	Left	75.58 ± 21.95	0.860	0.008	Not normal
	Right	82.53 ± 15.39	0.953	0.409	Normal
Average Force (N)	Left	188.0 ± 35.81	0.976	0.865	Normal
	Right	204.2 ± 35.81	0.951	0.382	Normal
Max Impulse (Ns)	Left	27.69 ± 13.45	0.940	0.238	Normal
	Right	31.87 ± 15.63	0.913	0.072	Normal

The Shapiro–Wilk normality test shows that the Max Force, Average Force, and Max Impulse data on the left and right sides are normally distributed ($p > 0.05$). Conversely, the distribution of Max Torque on the left side does not meet the normality assumption ($p = 0.008$), while the right side remains normally distributed.

Table 3. Paired T-Test dan Effect Size (Cohen's d)

Measure 1	Measure 2	t	df	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d	
							Lower	Upper
L Max Force (N)	R Max Force (N)	-2.459	19	0.024	-0.550	0.145	-1.015	-0.072
L Avg Force (N)	R Avg Force (N)	-3.246	19	0.004	-0.726	0.156	-1.213	-0.224
L Max Impulse (Ns)	R Max Impulse (Ns)	-3.072	19	0.006	-0.687	0.097	-1.169	-0.191

The results of the paired samples t-test show a significant difference between the left and right sides in the variables of Max Force ($t(19) = -2.459$; $p = 0.024$), Average Force ($t(19) = -3.246$; $p = 0.004$), and Max Impulse ($t(19) = -3.072$; $p = 0.006$). In general, the values on the right tended to be higher than those on the left.

Effect size analysis using Cohen's d indicated that the difference in hamstring strength between the left and right legs had moderate to considerable practical significance. The comparison of left and right Max Force resulted in a moderate effect size (Cohen's $d = -0.55$; 95% CI: -1.45 to -0.072), indicating

a practically significant difference in maximum strength. For Average Force, a moderate to large effect size was obtained (Cohen's $d = -0.726$; 95% CI: -1.213 to -0.224), indicating that the difference in average force between the two sides is relatively more consistent and functionally relevant. Meanwhile, Max Impulse also showed a moderate effect size (Cohen's $d = -0.687$; 95% CI: -1.169 to -0.191), indicating a difference in the ability to generate force impulse between the left and right sides.

Overall, even though the subjects were young athletes, the effect sizes in the moderate-to-near-large range indicate that left-right differences are not only statistically significant but also have practical implications for performance and the potential risk of hamstring injury.

Table 4. Paired T-Test dan Effect Size (Cohen's d)

Variable	Low n (%)	Moderate n (%)	High n (%)
Max Force (N)	10 (50%)	7 (35%)	3 (15%)
Average Force (N)	10 (50%)	6 (30%)	4 (20%)
Max Impulse (Ns)	8 (40%)	3 (15%)	9 (45%)

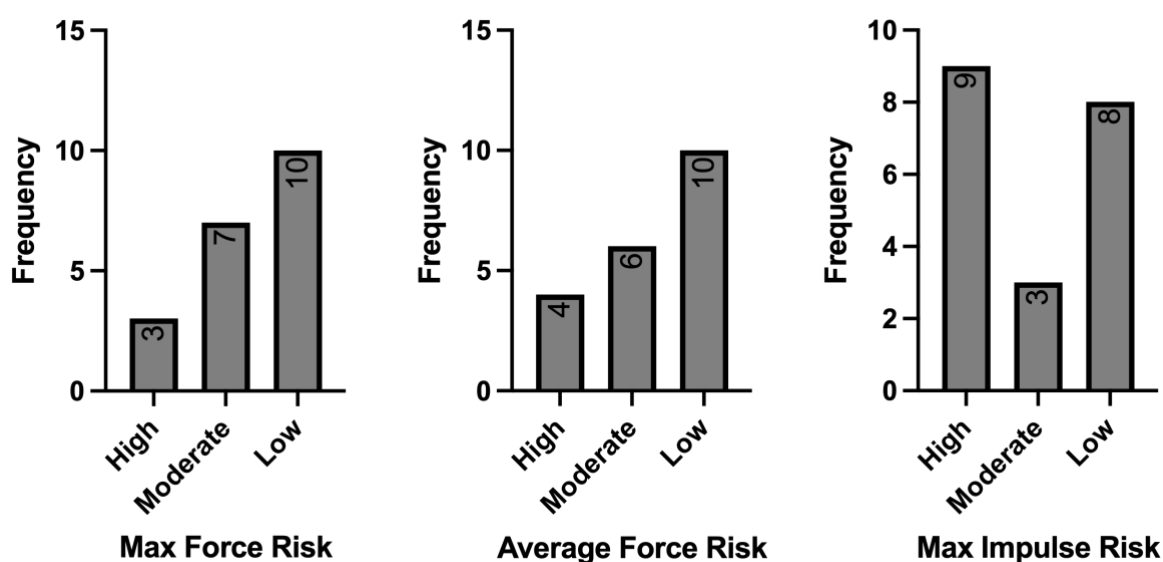


Figure 1. Distribution of injury risk categories based on bilateral hamstring strength imbalance across maximum force, average force, and maximum impulse parameters.

Referring to Table 4 and Figure 1, it can be seen that only the Max impulse Risk variable component has a high risk factor (9).

Table 5. Distribution of Hamstring Strength and Impulse Imbalance Risk and Binomial Test against the 20% Clinical Threshold

Variable	Risk Categories	n	%	p-value	Statistical Interpretation
Max Force (N)	Low	10	50.0	0.003	Higher than 20% (significant)
	Moderate	7	35.0	0.098	Not significant
	High	3	15.0	0.782	Not significant
Average Force (N)	Low	10	50.0	0.003	Higher than 20% (significant)
	Moderate	6	30.0	0.265	Not significant
	High	4	20.0	1.000	Same as the clinical threshold
Max Impulse (Ns)	Low	8	40.0	0.044	Higher than 20% (significant)
	Moderate	3	15.0	0.782	Not significant
	High	9	45.0	0.010	Higher than 20% (significant)

Risk distribution analysis based on hamstring strength and impulse imbalances revealed different patterns among components (Table 5). Regarding maximum strength imbalance (Max Force), only 15% of athletes were classified as high risk, and this proportion did not differ significantly from the clinical threshold of 20% ($p = 0.782$). Conversely, the low-risk category dominated the distribution (50%). It was found to be significant ($p = 0.003$), indicating that maximum strength imbalance is not commonly observed at clinically meaningful levels in this cohort.

For average force imbalance, the proportion of athletes at high risk was precisely at the clinical threshold (20%) and did not differ significantly ($p = 1.000$). The risk distribution was again dominated by the low-risk category (50%, $p = 0.003$), indicating that average force imbalance did not show a tendency toward increased injury risk at the group level.

Conversely, a different pattern was found in maximum impulse imbalance (Max Impulse). A total of 45% of athletes were classified as high risk, a proportion significantly greater than the clinical threshold of 20% ($p = 0.010$). These findings indicate that nearly half of the athlete population experiences an impulse imbalance that may be clinically relevant, suggesting neuromuscular control disorders or asymmetry in impulse-generating capacity that could contribute to increased injury risk. Overall, these results suggest that impulse-based imbalance, compared to static or average strength, is more sensitive in identifying the proportion of athletes with clinically meaningful injury risk.

Discussion

This research found that though differences exist in how strong the bilateral hamstrings are across different methods, how serious these mismatches are depends on which tests you look at. What stands out is that far more athletes show very large imbalances in maximum impulse - beyond what's considered safe - which points toward higher chances of harm in groups. On the flip side, differences measured by peak power or steady-state force tend to land in safe zones, staying under established health markers. Looking at things this way shows that even though gaps in strength between limbs show up in data, not all methods carry equal weight when judging risk from hamstring strains. Of those used, peak impulse stands out as the most relevant indicator.

This study's outcomes back up earlier discoveries showing typical imbalance among adolescent athletes (Abate Daga et al., 2021), a condition tied to higher injury adolescent (Kolodziej et al., 2021). When balance is off, movement loses smoothness, speed drops, agility weakens, and landing precision suffers during play.

Thus, maintaining excellent physical fitness and neuromuscular coordination is crucial for young athletes, particularly in team or situational sports. Research indicates that neuromuscular and biomechanical risk factors can be improved through INT programs (Hübscher et al., 2010), which have been shown to directly lower injury rates in athletes (Herman et al., 2012). Furthermore, there is a recognized connection between the timing of INT program implementation and a decrease in anterior cruciate ligament (ACL) injuries related to age (Myer et al., 2013). This suggests that the impact of puberty on the neuromuscular system can be mitigated. Since puberty involves significant musculoskeletal growth that often lacks adequate neuromuscular adjustment, it can result in abnormal movement patterns during sports. Therefore, starting INT programs with pre-pubertal athletes may be ideal to develop proper movement habits that help prevent motor deficits associated with puberty.

There are several recommendations for coaches to improve dynamic balance. Coaches can use FIFA 11+ as a way to improve dynamic balance to minimize the risk of injury to athletes (Hanief, Sannicandro, & Azidin, 2025). A reduction in stabilization time and an increase in core stability were reported in a 9-week RCT showing neuromuscular improvement and time-to-stabilization after FIFA 11+ (Jackson et al., 2022).

Limitations of Study

It is important to consider the constraints and limitations inherent to this investigation when interpreting its findings. These include: (1) relatively small sample size ($n = 30$); (2) cross-sectional study (3) potential neglect of between-subject variation for certain variables (4) use of accelerometer-derived biomechanical variables that are derived from movement patterns during a restricted range of task levels, and (5) use of an injury threshold that, although being one of the most frequently used in the literature, may not be relevant to all athletic groups.

Conclusions

At ages 14 to 16, adolescent football players' hamstring muscles often show uneven strength between legs. While differences in peak power and overall output usually fall into mild concern ranges, a few cases cross serious threshold lines. Still, when measuring sustained impulse speed, more players tend to fall near the higher-risk mark. That could mean trouble sustaining effort over time. Looking at things differently shows that evaluation is not just about the strongest contractions, but how impulses are set matter too. Using both legs during testing with NordBord brings up more precise details. This approach helps identify risks before harm occurs among adolescent football players.

Authors' contributions

YNH and KJ are contributed to the study conceptualization, study design, data collection, data analysis, and drafting of the manuscript. SS, SR, HS, and H are contributed to data analysis, interpretation of results, critical revision of the manuscript for important intellectual content, and overall methodological supervision. Both authors reviewed and approved the final version of the manuscript.

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Competing interests

The authors declare no competing interests.

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