Apunts Sports Medicine 59 (2024) 100450

apunts
SPORTS MEDICINE
www.apunts/org

ORIGINAL ARTICLE

Normalization of rapid force to peak force in an isometric hamstring assessment using force plates

R. Barber[a], J.T. Fahey[a], P. Comfort[a,b], N.J. Ripley[a,*]

[a] School of Health and Society, University of Salford, Salford, United Kingdom
[b] School of Medical and Health Sciences, Edith Cowan University, Joondalup, Australia

Received 26 April 2024; accepted 5 June 2024
Available online xxx

KEYWORDS
Relative to peak force;
Hamstring injury;
Training;
Monitoring;
Force at set time

Abstract
Purpose: The aim of this investigation was to determine the reliability of normalizing rapid force (RF) production to peak force assessed during an isometric knee flexor assessment, and to present a novel method of classifying athletes' potential training needs within the 90–90 isometric hamstring assessment.
Procedures: Twenty elite female soccer players (age: 20.7 ± 4.7 years; height: 168.2 ± 5.5 cm; body mass: 62.8 ± 7.0 kg), with no recent (>6 months) history of hamstring strain injury, volunteered to participate in the study. Following a standardized warm-up, each participant performed three maximal isometric hamstring contractions, with their heel resting on a force plate, elevated on a box, to ensure that their hips and knees were at 90° Data was analyzed to determine peak for (PF), RF was established as force expressed at 100 ms (F100) and force expressed at 200 ms (F200), with force at each time-point subsequently normalized to a percentage of PF.
Findings: F100 and F200 normalized to PF demonstrated good absolute reliability (%CV = 6.12–7.62) and moderate relative reliability (ICC = 0.689–0.703). Concurrently observing PF and normalized F100 and F200 could provide clear training and monitoring goals.
Conclusions: Normalizing measures of RF production, including F100 and F200, to PF can be performed reliability. Therefore, could be tracked overtime to identify changes as an effect of training or for fatigue monitoring purposes. However, further research is required to determine how knee flexor force-time characteristics change in relation to focused training and how these characteristics change in response to fatiguing activities.

Introduction

Hamstring strain injuries (HSI) can have a substantial impact in team sports, representing 10 % of all team-based field sport injuries.[26] In elite soccer hamstring injuries can account for 20 %

* Corresponding author.
E-mail address: n.j.ripley@salford.ac (N.J. Ripley).

https://doi.org/10.1016/j.apunsm.2024.100450

of the absence days caused by injury across the sport,[15] with an increasing occurrence rate.[17] The hamstrings' ability to produce a large force during the terminal swing phase of running is crucial to mitigating injury risk. However, due to the high knee angular velocities during the terminal swing phase (>1000°/s),[7] the hamstrings also need to produce a large proportion of this force rapidly. Eccentric exercise has been shown to result in positive changes in modifiable risk factors for HSI.[12] The results of pre-season eccentric strength testing, however, have provided minimal insight into HSI incidence,[31] with poor adoption in team sports highlighting the need to consider alternative hamstring assessment methods and regular monitoring.[31] Hence, there is a gap in the research regarding methods of assessing peak force (PF) and rapid force (RF) production characteristics of the hamstring to inform practice, while maximizing compliance, feasibility, and useability. It is worth noting that the established gold standard for single joint isometric assessment of force, isokinetic dynamometry could also be used to inform practice on an individual's PF and RF.[2,18,33] However, despite being gold standard isokinetic dynamometry is expensive and time consuming and lacks feasibility within applied settings including team sports, while force plates can be used more effectively.

The increased availability of force plate systems is making single joint isometric strength testing more feasible,[11,29,35] and can be used to monitor changes in hamstring force production characteristics to provide objective training recommendations.[34] Tracking changes in performance and monitoring acute player fatigue through isometric hamstring strength testing could identify high risk situations and may help coaches and practitioners to optimize performance and reduce the likelihood of injury through appropriate training modification and intervention strategies.[32]

The 90–90 isometric hamstring strength assessment (90° hip flexion and 90° knee flexion) has been found to be reliable for both PF and RF generating measures (e.g., force at 100 ms [F100], force at 200 ms [F200] and average rate of force development (RFD) over 100 and 200 ms).[35] Force at set time points within single joint tasks (F100 and F200) have been shown to have a strong relationship with PF.[1,4,35] Interestingly, normalizing RF to PF may enhance the useability of RF measures within practice, to aid in programme design.[40] Comfort et al[8] proposed the no4rmalization of RF to PF to provide potential training recommendations for the lower body, for instance when using the isometric mid-thigh pull to observe rapid force measures.[13,19] If practitioners can determine the magnitude of force an athlete can produce rapidly and relate it to their PF this could offer insights into training prescription of training modification. To date, PF and RF within the 90–90 isometric hamstring assessment have displayed very large relationships,[35] however, normalization of RF to PF has not been reported. Therefore, the purpose of this study was to identify the reliability of normalizing RF to PF and to present a novel method of classifying athletes' potential training needs within the 90–90 isometric hamstring assessment.

Materials and methods

Participants

Twenty elite female soccer players from a single Super League squad (age: 20.7 ± 4.7 years; height: 168.2 ± 5.5 cm; body mass: 62.8 ± 7.0 kg) participated in the study, classification of athletes was based on.[28] Participants were required to have had no hamstring related injuries for ≥6 months prior to taking part. All participants provided written informed consent, or parental/guardian assent where required. Ethical approval was granted by the institutional ethics committee (HSR1819-037) in accordance with the declaration of Helsinki.

Experimental design

An observational design was used to assess isometric hamstring strength of female soccer players, to permit calculation of PF, RF and normalization of RF to PF (force at set time points (F100 and F200) made relative to PF). Participants completed the tests prior to their normal training day. The assessment session was carried out 72 h after a competitive fixture (match day +3), allowing at least 48 h recovery prior to their next competitive fixture. A standardized warm up was performed by all subjects including body weight squats, lunges, hip thrusts, following which three submaximal isometric trials was performed prior to any maximal trials, at 50 %, 75 % and 90 % of perceived maximum effort.

The 90–90 isometric assessments were measured using a force plate (Kistler 9286AA: Kistler Instruments Inc, Amherst, NY, USA), sampling at 1000 Hz. Only force in vertical vector was used for analysis which is consistent with uniaxial force plates which are frequently used within practice.[11,29,35] The force plate was placed upon a wooden box at an appropriate height to achieve the desired 90° knee and hip joint angle for each participant using a goniometer with their heel resting on the box (Fig. 1). The test was performed unilaterally with the non-testing leg being placed fully extended next to the box and arms placed across the chest. Three maximal trials for each leg were executed by instructing the participants to push their heel down into the force plate "hard and fast" for 3–5 s with strong verbal encouragement. Participants were instructed to remain as still as possible to permit the calculation of limb weight and associated force-time data, including the onset of force production.

Raw force-time data for each trial were analyzed using a customized Microsoft Excel spreadsheet (Version 2019, Microsoft Corp., Redmond, WA, USA), raw force-time data was down sampled to 250 Hz via a simple filter in order to reduce noise and improve the reliability of RF measures (F100 and F200).[36] PF, F100 and F200 (i.e. RF) following onset were calculated from the net force values (excluding limb weight) for each trial. Onset of force was identified as 5 standard deviations (SD) from the one second quiet period.[13] For normalization procedures, RF was expressed as a percentage of peak force, as previously described.[8]

Statistical analysis

Normality was verified using the Shapiro–Wilk's test. Absolute reliability was calculated using coefficient of variance (CV%), interpreted as upper bound 95 % confidence interval (95 %CI), <5.00 %, 5.00–9.99 %, 10.00–14.99 % and >15 % as excellent, good, moderate and poor, respectively. Relative reliability was assessed using intraclass correlation coefficients (ICC), interpreted based on the lower bound 95 %CI as poor <0.49, moderate 0.50–0.74, good 0.75–0.89 and

Fig. 1 90:90 Isometric hamstring assessment using force plates.

excellent>0.90.[24] The mean PF and F100 and F200 of the three trials were taken and used for further analysis.

A paired samples *t*-test and Hedge's *g* effect sizes were used to compare PF, F100 and F200 between limbs to determine if data could be pooled. Hedge's *g* was interpreted using (0.00–0.19 = trivial, 0.20–- 0.59 = small, 0.60–1.19 = moderate and >1.20 = large. All statistical analyses were conducted using JASP (Version 0.18.2 [Computer software]) and a customized Microsoft Excel spreadsheet (Version 2019, Microsoft Corp., Redmond, WA, USA).

Pooled scatter plots are presented with the mean PF and normalized F100 and F200. Each plot is separated into four quadrants based off the mean value for PF and normalized F100 and F200. The four quadrants represent force characteristics; Q1: low PF and low RF, Q2: high PF and low RF, Q3: low PF and high RF, Q4: high PF and high RF.

Results

Good-excellent absolute and moderate relative reliability were observed for F100 and F200 and normalized F100 and F200, with excellent absolute and good relative reliability observed for PF (Table 1). The mean ± SD PF, F100, F200 and RF normalized to peak force are presented in Table 1. No significant or meaningful differences were observed between limbs for PF and RF measures (*p = 0.826–0.919*, Hedge's *g* = 0.11–0.24)

Left and Right limb data was pooled and individual scatter plots with associated quadrants are presented in Fis. 2& 3, the scatter plots present the potential applications of training and monitorin.

Discussion

The purpose of this study was to establish the reliability of normalizing RF (F100 and F200) to PF assessed during the 90–90 isometric hamstring strength assessment and present a novel method of classifying athletes based off normalized RF to PF. Good-excellent absolute and moderate relative reliability were observed for F100 and F200 and normalized RF to PF (<7.62CV%, ICC >0.689), with excellent absolute and good relative reliability observed for PF (3.05CV%, ICC = 0.887) (Table 1). Additionally, no significant or meaningful differences were observed between limbs for PF and RF measures (*p* = 0.826–0.919, *g* = 0.11–0.24) (Table 1). Using a quadrant system to plot individuals PF and RF (Figs. 2& 3) could enable a rapid decision making by practitioners to inform best practice, if used for training needs identification or if used for monitoring purpose used for training modification.

Regular performance assessment is commonplace within elite sport, however, for the hamstrings currently pre-season eccentric strength assessment provides minimal insight into HSI incidence.[31] Moreover, the use of Nordic hamstring

Table 1 Descriptive statistics for the 90:90 Isometric hamstring assessment.

	PF Right (N)	F100 Right (N)	F200 Right (N)	N-F100 Right (%)	N-F200 Right (%)	PF left (N)	F100 Left (N)	F200 Left (N)	N-F100 Left (%)	N-F200 Left (%)
Avg	218.51	120.24	153.85	54.99	70.32	213.09	113.24	147.24	52.85	68.15
SD	46.24	34.48	40.25	9.80	9.13	49.17	43.84	48.41	11.54	8.61
CV% (95CI)	2.25 (0.62−3.88)	5.62 (4.76−6.48)	7.44 (5.64−9.24)	6.12 (5.14−7.10)	7.62 (5.46−9.78)	3.05 (2.18- 3.92)	5.51 (4.87−6.18)	7.12 (5.26−8.98)	6.28 (4.68−7.88)	7.32 (5.39−9.25)
ICC (95CI)	0.917 (0.882−0.952)	0.726 (0.635−0.821)	0.711 (0.593−0.829)	0.721 (0.601−0.841)	0.715 (0.590−0.840)	0.887 (0.824−0.950)	0.766 (0.675−0.857)	0.712 (0.595−0.829)	0.703 (0.589−0.817)	0.689 (0.547−0.836)

PF = peak force, F100 = force at 100 ms, F200 = force at 200 ms, N-F100 = normalized force at 100 ms to peak force, N-F200 = normalized force at 200 ms to peak force, Avg = average, SD = Standard deviation, CV% = coefficient of variation percentage, ICC = intraclass correlation coefficients, 95CI = 95 % confidence intervals.

exercise as a monitoring tool or training exercise has poor adoption in team sports,[14,16] highlighting the need to consider alternative hamstring assessment practice. Isometric hamstring assessments using force plates have consistently demonstrated sensitivity to detect change following a fatiguing activity in both PF and RFD.[5,9,27] Bettariga et al[5] observed a reduction in RFD following a fatiguing protocol, however, the increased variability in RFD measures should be considered, hence the use of force at set time points (e.g. F100 and F200). However, normalizing PF to RF offers a greater understanding of the implications of fatigue activity (i.e., match play or training) where there could be differentiating factors in performance including mechanical, neuromuscular or metabolic fatigue.[39] For instance, as F100 explains around 50−55 % of PF; decreases in PF could be related to decreases in RF, however, if RF can be maintained but PF is reduced there are potentially other mechanisms interacting with the hamstrings' ability to produce force (e.g. neuromuscular or metabolic fatigue). Tracking changes in performance could identify high risk situations and may help coaches and practitioners to reduce the likelihood of injury through appropriate training modification and intervention strategies.[32,39]

The use of faster movement patterns within training and moving with intent has been shown to be an effective approach to targeting RF.[6] Within trained athletes, high intensity compound resistance training has been shown to impact RF positively.[21] Maximal strength training (MST) and explosive strength training (EST) can both have positive impacts on RF development,[25] MST appears to favor late RF, via positive changes in maximal voluntary contraction and cross-sectional area.[3] EST favors early RF with positive neural changes.[3] It is recommended that for performance adaptations, the entire force velocity curve must be developed (MST & EST).[10,20] Many exercise types have been identified to improve hamstring strength, but combined training approaches have been advocated more recently as a more effective strategy in tacking common HSI risk factors.[37,38] It could be potentially effective to prescribe training based on an athlete's individual needs, specifically to target PF or RF capabilities. The quadrant system (Figs. 2& 3) based off the 90:90 isometric hamstring assessment allows for identification of an athlete's needs and specific training can be applied to target those physical qualities. However, further research is required to determine how knee flexor force time characteristics change in relation to focused training and how these characteristics change in response to fatiguing activities.

Currently, the methods used for single joint isometric assessments using force plates has limited consistency,[5,9,27,30,35,36] with variations in the test set up where hip and knee angles of 30−30 and standing 90−20 have been used with force plates. Despite this consistently demonstrated sensitivity to detect change following a fatiguing activity in both PF and RFD.[5,9,27] Within the present study, only the 90−90 isometric hamstring assessment was used, despite high reliability and the potential for practitioners to use the information for appropriate prescription for EST or MST. The 90−90 isometric hamstring assessment may lack specificity to the mechanism of HSI, which are proposed to occur at longer muscle lengths within the descending limb of the force-length curve.[22,23] Therefore, future

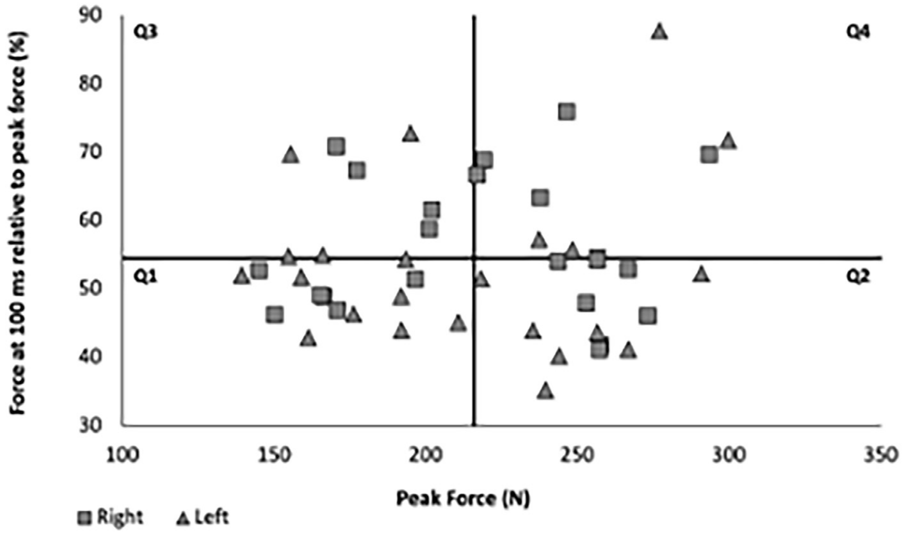

Fig. 2 Scatter plot illustrating peak force (N) and force at 100 ms relative to peak force (%) with four quadrants. Q1: low peak force and low rapid force, Q2: high peak force and low rapid force, Q3: low peak force and high rapid force, Q4: high peak force and high rapid force.

research should look to observe the validity of hamstring force production (though electromyography) within the various methods of assessing single joint isometric assessments using force plates. It is also recommended that future research observes the reliability of RF and the reliability of normalizing RF to PF within isometric hamstring assessments that assess the muscle at linger lengths (e.g. 30–30 and standing 90–20 assessments). It also worth noting that the warmup protocol used may not have been sufficient in preparing the participant to maximally perform the assessment, however, as all participants performed the same standardized warmup protocol it's influence could be considered negligible.

The results of the present study indicate that normalizing RF to PF can be performed reliably, hence it could be used to monitor changes in RF in relation to PF production overtime. This could be used to inform specific training practices (i.e. the inclusion of EST or MST) as required, it could also be used to inform fatigue monitoring, especially post-match. As changes in RF could be present without a reduction in PF could be indicative of specific neuromuscular fatigue requiring specific recovery strategies. Moreover, reductions in RF could also be indicative of increased risk HSI incidence, therefore, signaling to practitioners that adaptations in training volumes (specifically high-speed running) maybe required. However, the application of these applied practices to acute fatigue monitoring does need further investigation. Similarly, practioners could use the normalized RF to PF by taking a quadrant approach (e.g. Figs. 2& 3) aiding in the identification of training priorities. The priority for practitioners should be to ensure athletes that can produce both high RF and PF (Q4). If an athlete can

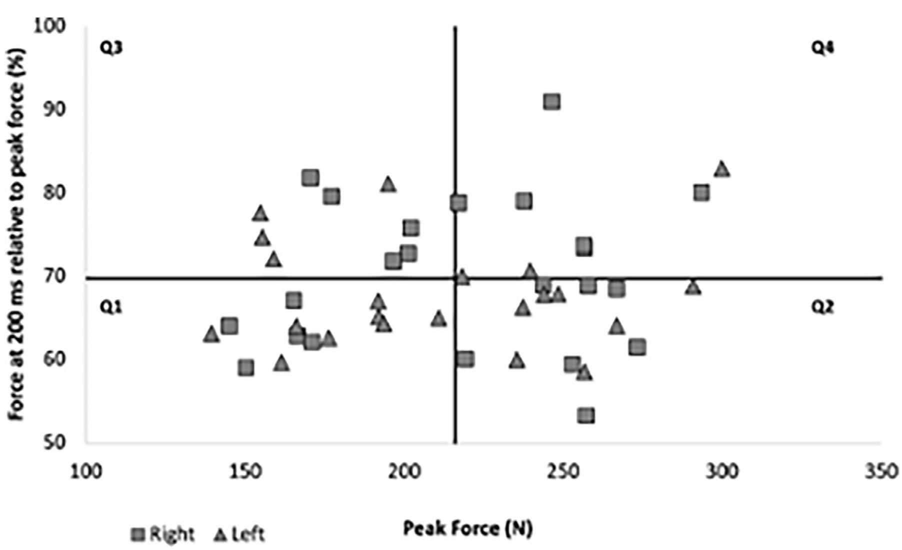

Fig. 3 Scatter plot illustrating peak force (N) and force at 200 ms relative to peak force (%) with four quadrants. Q1: low peak force and low rapid force, Q2: high peak force and low rapid force, Q3: low peak force and high rapid force, Q4: high peak force and high rapid force.

produce high force but can only express it slowly (Q2), this may present an opportunity when programming should focus on EST. Conversely, if an athlete has a low PF, a focus on MST appears the most obvious route forward, even if they can produce force quickly. It's important to note, that as PF has a strong relationship with voluntary activation, if in doubt practitioners should focus on PF. Expressing RF as a percentage of PF during the 90:90 isometric hamstring strength assessment is reliable and may go some way to explain timing related aspects of force production and ultimately help inform programme design.

Conflicts of interest

The authors declare no conflict of interest.

References

1. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. J Appl Physiol. 2002;93:1318−26.
2. Alt T, Komnik I, Severin J, et al. Swing phase mechanics of maximal velocity sprints − does isokinetic thigh muscle strength matter? *Int J Sports Physiol Perform*. 2021;16:974−84.
3. Andersen JL, Aagaard P. Effects of strength training on muscle fiber types and size;consequences for athletes training for high-intensity sport. Scand J Med Sci Sports. 2010;20:32−8.
4. Andersen LL, Aagaard P. Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. Eur J Appl Physiol. 2006;96:46−52.
5. Bettariga F, Bishop C, Martorelli L, et al. Acute effects of a fatiguing protocol on peak force and rate of force development of the hamstring muscles in soccer players. J Sci Sport Exerc. 2024;6:177−85.
6. Blazevich AJ, Wilson CJ, Alcaraz PE, Rubio-Arias J. Effects of resistance training movement pattern and velocity on isometric muscular rate of force development: a systematic review with meta-analysis and meta-regression. Sports Med. 2020;50: 943−63.
7. Chumanov ES, Heiderscheit BC, Thelen DG. Hamstring musculotendon dynamics during stance and swing phases of high-speed running. Med Sci Sports Exerc. 2011;43:525−32.
8. Comfort P, Dos'Santos T, Jones PA, et al. Normalization of early isometric force production as a percentage of peak force during multijoint isometric assessment. Int J Sports Physiol Perform. 2019;15:1−5.
9. Constantine E, Taberner M, Richter C, Willett M, Cohen DD. Isometric posterior chain peak force recovery response following match-play in elite youth soccer players: associations with relative posterior chain strength. Sports. 2019;7:1−12.
10. Cronin JB, Hansen KT. Strength and power predictors of sports speed. J Strength Cond Res. 2005;19:349−57.
11. Cuthbert M, Comfort P, Ripley N, McMahon JJ, Evans M, Bishop C. Unilateral vs. bilateral hamstring strength assessments: comparing reliability and inter-limb asymmetries in female soccer players. J Sports Sci. 2021;39:1481−8.
12. Cuthbert M, Ripley N, McMahon J, Evans M, Haff GG, Comfort P. The effect of nordic hamstring exercise intervention volume on eccentric strength and muscle architecture adaptations: a systematic review and meta-analyses. Sports Med. 2020;50:83−99.
13. Dos'Santos T, Jones PA, Comfort P, Thomas C. Effect of different onset thresholds on isometric midthigh pull force-time variables. J Strength Cond Res. 2017;31:3463−73.
14. Ekstrand J, Bengtsson H, Walden M, Davison M, Hagglund M. Still poorly adopted in male professional football: but teams that used the Nordic Hamstring Exercise in team training had fewer hamstring injuries − a retrospective survey of 17 teams of the UEFA Elite Club Injury Study during the 2020−2021 season. Br Med J Open Sport Exerc Med. 2022;8:1−8.
15. Ekstrand J, Bengtsson H, Waldén M, Davison M, Khan KM, Hägglund M. Hamstring injury rates have increased during recent seasons and now constitute 24% of all injuries in men's professional football: the UEFA Elite Club Injury Study from 2001/02 to 2021/22. Br J Sports Med. 2023;57:292−8.
16. Ekstrand J, Hallén A, Gauffin H, Bengtsson H. Low adoption in women's professional football: teams that used the Nordic Hamstring Exercise in the team training had fewer match hamstring injuries. BMJ Open Sport Exerc Med. 2023;9:1−7.
17. Ekstrand J, Walden M, Hagglund M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. Br J Sports Med. 2016;50:731−7.
18. Guex K, Gojanovic B, Millet GP. Influence of hip-flexion angle on hamstrings isokinetic activity in sprinters. J Athl Train. 2012;47:390−5.
19. Guppy S, Kotani Y, Brady CJ, Connolly S, Comfort P, Haff GG. The reliability and magnitude of time-dependent force-time characteristics during the isometric midthigh pull are affected by both testing protocol and analysis choices. J Strength Condition Res. 2022;36:1191−9.
20. Haff G, Nimphius S. Training principles for power. Strength Cond J. 2012;34:2−12.
21. James LP, Suchomel TJ, Comfort P, Haff GG, Connick MJ. Rate of force development adaptations after weightlifting-style training: the influence of power clean ability. J Strength Condition Res. 2022;36:1560−7.
22. Kellis E, Blazevich AJ. Hamstrings force-length relationships and their implications for angle-specific joint torques: a narrative review. BMC Sports Sci Med Rehabil. 2022;14:1−34.
23. Kenneally-Dabrowski C, Brown NA, Lai A, Perriman D, Spratford W, Serpell BG. Late swing or early stance? A narrative review of hamstring injury mechanisms during high-speed running. Scand J Med Sci Sports. 2019;29:1083−91.
24. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15. 166-163.
25. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin NA, Duchateau J. Rate of force development: physiological and methodological considerations. Eur. J. Appl. Physiol. 2016;116: 1091−116.
26. Maniar N, Carmichael DS, Hickey JT, et al. Incidence and prevalence of hamstring injuries in field-based team sports: a systematic review and meta-analysis of 5952 injuries from over 7 million exposure hours. Br J Sports Med. 2023;57:109−16.
27. McCall A, Nedelec M, Carling C, Le Gall F, Berthoin S, Dupont G. Reliability and sensitivity of a simple isometric posterior lower limb muscle test in professional football players. J Sports Sci. 2015;33:1298−304.
28. McKay AKA, Stellingwerff T, Smith ES, et al. Defining training and performance caliber: a participant classification framework. Int J Sports Physiol Perform. 2022;17:317−31.
29. McMahon JJ, Ripley NJ, Comfort P, et al. The kneeling isometric plantar flexor test: preliminary reliability and feasibility in professional youth football. J Funct Morphol Kinesiol. 2023;8:1−11.
30. Moreno-Perez V, Mendez-Villanueva A, Soler A, Del Coso J, Courel-Ibanez J. No relationship between the nordic hamstring and two different isometric strength tests to assess hamstring muscle strength in professional soccer players. Phys Ther Sport. 2020;46:97−103.
31. Opar T, Behan H, van Dyk P, Maniar. Is pre-season eccentric strength testing during the nordic hamstring exercise associated

with future hamstring strain injury? A systematic review and meta-analysis. Sports Med. 2021;51. 1935-1945.
32. Opar W, Shield. Hamstring strain injuries: factors that lead to injury and re-injury. Sports Med. 2012;42:209—26.
33. Opar W, Timmins D, Shield. Rate of torque and electromyographic development during anticipated eccentric contraction is lower in previously strained hamstrings. Am J Sports Med. 2013;41:116—25.
34. Pizzari T, Green B, van Dyk N. Extrinsic and intrinsic risk factors associated with hamstring injury. In: Thorborg K, Opar D, Shield AJ, eds. Prevention and Rehabilitation of Hamstring Injuries, Cham, Switzerland: Springer; 2020:83—116.
35. Ripley N, Fahey JT, Cuthbert M, McMahon J, Comfort P. Rapid force generation during unilateral isometric hamstring assessment: reliability and relationship to maximal force. Sports Biomech. 2023; 1—12.
36. Ripley N, McMahon JJ, Comfort P. Effect of sampling frequency on a unilateral isometric hamstring strength assessment using force plates. J Sci Sport Exerc. 2024.
37. Ripley NJ, Cuthbert M, Comfort P, McMahon JJ. Effect of additional Nordic hamstring exercise or sprint training on the modifiable risk factors of hamstring strain injuries and performance. PLoS One. 2023;18:e0281966.
38. Schneider C, Van Hooren B, Cronin J, Jukic I. The effects of training interventions on modifiable hamstring strain injury risk factors in healthy soccer players: a systematic review. Strength Cond J. 2023;45:207—27.
39. Thorpe R. Post-exercise recovery: cooling and heating, a periodized approach. Front Sports Active Liv. 2021;3:707503.
40. Tillin NA, Pain MT, Folland J. Explosive force production during isometric squats correlates with athletic performance in rugby union players. J Sports Sci. 2013;31:66—76.