

Asymmetry after hamstring injury in English Premier League: issue resolved, or perhaps not?

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Abstract

Hamstring injuries constitute one of the most concerning injuries in English Premier League football, due to its high primary incidence but also its recurrence. Functional methods assessing hamstring function during high-risk performance tasks such as sprinting are vital to identify potential risk factors. The purpose of this study was to assess horizontal force deficits during maximum sprint running on a non-motorized treadmill in football players with previous history of hamstring strains as a pre-season risk-assessment in a club setting. 17 male football players from one Premier League Club were divided into 2 groups, experimental (n= 6, age = 24.5 ± 2.3 years) and control (n= 11, age = 21.3 ± 1.2 years), according to history of previous hamstring injury. Participants performed a protocol including a 10 seconds maximum sprint on a non-motorized treadmill. Force deficits during acceleration phase and steady state phases of the sprint were assessed between limbs and between groups. The main outcome measures were horizontal and vertical peak forces during the acceleration phase or steady state. There were no significant differences in peak forces between previously injured and non-injured limbs, or between groups, challenging the ideas around functional force deficits in sprint running as a diagnostic measure of hamstring re-injury risk.

Keywords: biomechanics, multivariate statistics, vector-field analysis, random field theory, experimental error.

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1. Introduction

Hamstring strains are the most common and challenging injuries in professional football [28]. They represent about 12 to 17% of the total moderate and severe injuries (causing absence of 8-28 days and more than 28 days, respectively) in this sport, leading to the highest prolonged absence time from training and competition[7,8,9,11]. Hamstrings also present a high recurrence rate of 12-14% [20, 28], and re-injury on average requires six days longer absence from competition than the initial injury [6]. In fact, previous injury remains to be the strongest available predictor for hamstring injury [2, 8, 9, 17, 22, 28].

Considering the high re-injury rates, one of the biggest challenges professional football clubs face today is to prevent re-injury, starting with identifying functional deficiencies that are believed to lead to an increased risk of re-injury. Hamstring strain injury can result in a variety of functional deficiencies, altering aspects such as motor control [6], activation patterns [25,26], isokinetic torque development [19] and load distribution during contraction [24]. The most common way of addressing any such deficits is by observing asymmetries between the injured limb and the contralateral side. For example, sprint tests on a non-motorized treadmill (NMT) have revealed that previously injured players can achieve their pre-injured levels of speed, but this whilst employing compensation mechanisms from the non-injured limb [5]. If a treadmill-based sprint test can reveal inter-limb asymmetry in force generation, then this practical test has great potential to support rehabilitation processes that are aimed at preventing hamstring re-injury risk.

The assessment of functional asymmetry in a club context remains a challenge, even at the highest level such as in the English Premier League. The development of assessment protocols are subject to variations in available equipment, and time constraints on staff and players. This often makes it difficult, if not impossible, to replicate protocols exactly as

described in research that may have been conducted in a laboratory context. Support staff in a club is often forced to implement their assessment protocol under the assumption that they are still able to reveal the asymmetries, without having the opportunity to carefully consider the validity. Despite some studies using NMTs and sprint performance, especially in the context of reliability (13,14), there is however a lack of research validating the force output provided by these instruments relative to the forces generated whilst sprinting in a field. However, considering the potential value of assessing functional asymmetry in the prevention of re-injury, the authors therefore identified a need to investigate its robustness when implemented in a club setting.

The purpose of this study was to quantify functional asymmetry in English Premier League football players with previous history of hamstring strain, in a protocol involving sprinting on an instrumented NMT. Based on previous findings, we hypothesised that individuals with a previous hamstring strain would present functional asymmetry through force generating deficits in the injured limb.

2.0 Materials and methods

Protocol

Experimental trials were conducted as part of pre-season testing. After a familiarisation session, participants performed the protocol including a 10 seconds time period of maximal sprint running on a non-motorised treadmill (NMT; Woodway - Curve Model, Wisconsin, USA – Figure 1.). Following an initial 5 minute warm-up on a cycle ergometer, participants completed a protocol which included 10 seconds of maximum sprinting during which there was an acceleration to achieve maximum speed and maintaining speed during a brief steady state phase in the final seconds of the sprint. Horizontal and vertical forces were captured by

force transducers (Anyload 563 YH) located in the treadmill frame supporting the belt, and speed data of the complete protocol were collected at a sampling rate of 200 Hz.

With the foot moving through an arch rather than on a flat surface, the shear forces do not have the same meaning as in a flatbed treadmill. With force transducers built in the supports of the treadmill belt, overall, the forces measured in a horizontal direction represent force generation for propelling the treadmill and vertical forces represent forces to keep the body on average in the same vertical position throughout the trial.

A video recording of each sprint was made at 50 Hz, with inset of the treadmill clock to reliably separate left and right steps in the recorded force profiles.



Figure 1: Non-motorized treadmill

Data reduction

Two independent phases of the sprint were considered for analysis, the acceleration and the steady state period. The acceleration period included the first step from the beginning of the sprint until the first maximum speed step. During this phase the maximal propulsive horizontal force development was extracted. The steady state period consisted of the first eight steps after maximum speed was performed, including the maximum speed first step. Peak force values for all the steps of each leg prior to reaching maximum speed and in the eight steady state period steps were registered. Comparisons within individual participants (between legs) and between groups were performed for maximal horizontal and vertical peak force generated during acceleration and steady state phases of the sprint, as well as for the average of all peak force values per phase.

Some observations concerning force profiles as seen in Figure 2 deserve some prior technical considerations. The highest horizontal force development occurred in the initial stage of the sprint acceleration, rather than at the time of maximal sprinting. This is expected as horizontal force is related to acceleration rather than velocity. A previous study from Brughelli et al. [5] using a tethered NMT showed continued high horizontal forces with constant speed running, with force mean scores ranging from 175N to 325N, for the 2 limbs of the experimental group (previously injured and contralateral respectively). For a similar phase of a sprint action in the current study the mean scores for horizontal force ranged between 67,1 N and 72,4 N, in the dominant and non-dominant side of the control group, respectively. This suggests that their treadmill belt generated substantial resistance during constant speed running, to be overcome by continued propulsion forces of up to 20% of the vertical force generation. Horizontal forces observed with the curved NMT adopted in our study were only about 3% of the vertical forces during constant speed running. This results

contradicts the existent literature in which vertical and horizontal forces were analysed using a NMT. A previous study by Brughelli et al [4] showed that in a maximal sprint effort using a different NMT model mean maximum horizontal forces can represent around 18% of the mean maximum vertical forces during the same period. The latter authors analysed 80% max speed sprint efforts also on a NMT found this relation to range from around 13% in a control group up to 17% in the contralateral limb of subjects with previous history of unilateral hamstring strain [5] .

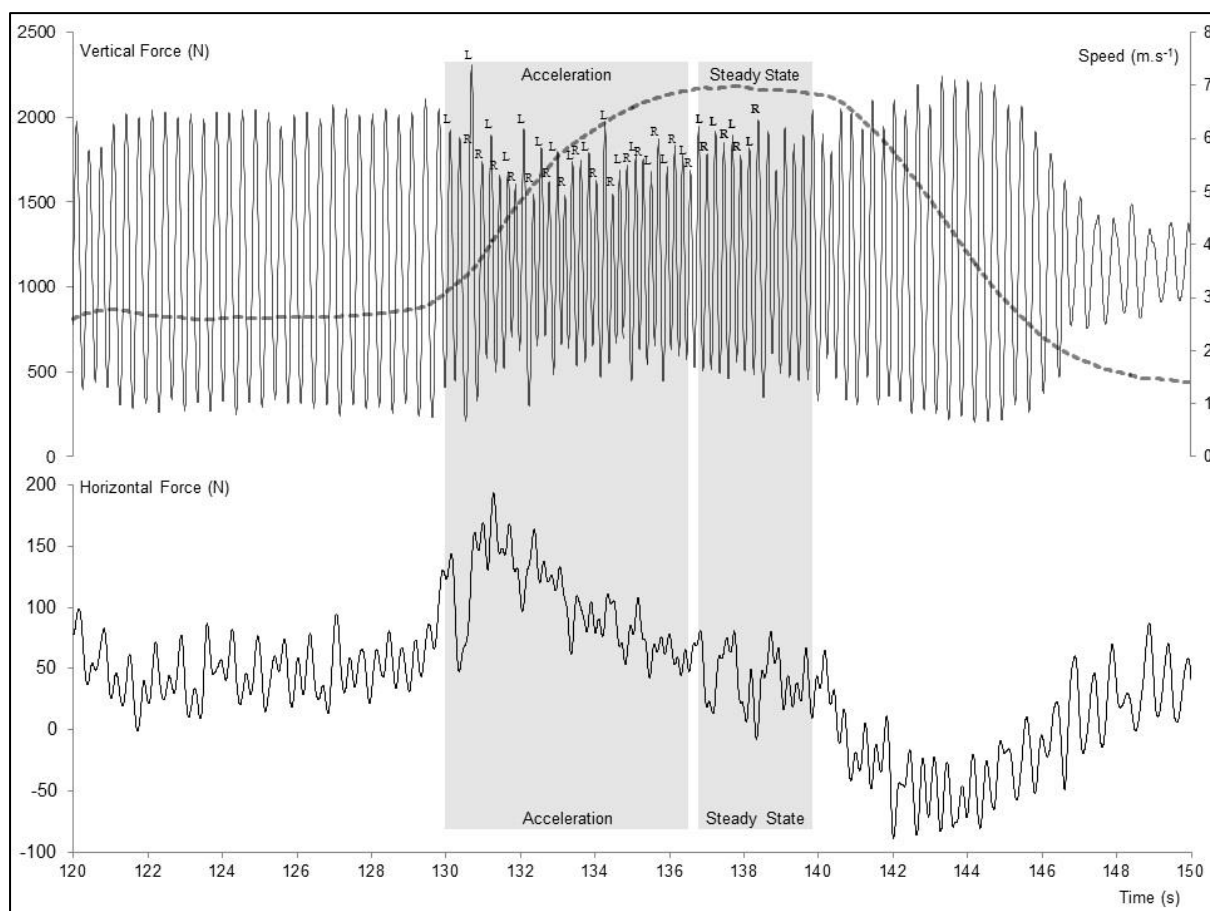


Figure 2: Force profile during acceleration and steady-state phases (shading) of a 10-s sprint on NMT. Sprint occurs from 130 to 140 s and identification of right (R) and left (L) is shown for the full acceleration phase and for 8 steps of maximum speed

Reliability protocol

A separate group of nine male participants performed the protocol three times on separate days (regular recreational athletes, age 29.6 ± 5.3 years; height 178.1 ± 8.3 cm; weight $76.2 \pm$

9.6 kg). Mauchly's test for sphericity was performed and one-way ANOVA for repeated measures was conducted for general differences among trials. Where a main trial effect was found, Tukey post-hoc comparisons were performed. Intra-class correlation was calculated for assessing reliability. Maximum speed values were only significantly lower in the first compared to consecutive two sessions, suggesting that one familiarisation session was sufficient to reach a consistent maximum speed on a NMT. Comparison of outcome measures revealed strong correlations between trial 2 and trial 3 ($r > 0.90$), except for a moderate correlation for Peak Horizontal Forces ($r = 0.62$). Overall, these results supported the use of a single familiarization session before data collection in the experimental protocol. Also, analysing averaged peak values for horizontal force as opposed to analysing only the highest peak value provides more reliable information. No other variables were collected from the subjects as all of them had been cleared to play according to criteria based on regular sports medicine examination but also physical parameters such as strength, flexibility, ability to run, sprint and perform football specific actions.

Participants

For the main study, 17 male professional football players from an English Premier League club were recruited to this study and allocated to two groups: hamstring injury group (HIG) ($n = 6$, age 24.5 ± 2.3 years, height 1.79 ± 0.03 m, mass 76.3 ± 2.5 kg) and non-hamstring injury group (control) ($n = 11$, age 21.27 ± 1.2 years, height 1.83 ± 0.03 m, mass 82.2 ± 2.8 kg). There were no significant statistical differences among groups for age, height or weight. Sample characteristics including playing position and foot dominance are expressed in Table 1, along with the severity of the hamstring injury and average absence time from training for the HIG. All subjects from HIG had sustained a sprint related hamstring injury. All participants provided prior written informed consent according to the guidelines of the local

ethical committee. This study meets the ethical standards of the International Journal of Sports Medicine [10].

For the purpose of this study, hamstring injury was defined as occurring during training or competition, which prevented participation in normal training and/or competition for more than 48 hours, not including the day of injury [11]. Club medical records were consulted to identify more detailed inclusion/exclusion criteria. Inclusion criteria for the HIG were a history of previous hamstring injury in one leg, and occurrence less than two years prior to the study, as in Brughelli et al.[5]. Exclusion criteria were the presence of lower limb or lumbar spine pathology at the time of study; chronic lumbar spine pathology; history of hamstring muscle or lumbar spine surgery [24, 25] and previous history of bilateral hamstring strain within two years of the study. Global Positioning System (GPS) data from a maximal sprint test in training were consulted to obtain records of overground maximum speed values for each player to compare maximum sprinting speeds achieved on the NMT versus overground, with the purpose of further understanding potential limitations in sprint speed performance on the NMT (GPSports[®], Dundalk, Ireland; Catapult Sports[®], South Melbourne, Australia).

Statistical analysis

Statistical procedures were conducted using SPSS (v.20.0, SPSS Inc., Chicago, IL, USA). Outcome variables were maximum speed, maximum peak force, and average of peak forces (horizontal and vertical, acceleration and steady state phase). Normality of data was checked using Shapiro-Wilk tests. Paired comparisons between previously injured versus uninjured leg in the HIG, and between dominant versus non dominant leg in the control group were made using paired student t-tests or Wilcoxon tests. Independent between-group comparisons for maximal and averaged peak force values in HIG versus control group were made using

independent student t-tests or Mann-Whitney U tests. Results are presented using mean and standard deviations. The level of significance was set as $p < 0.05$.

Table 1. Participants' playing position, foot dominance, and injury profile.

	n	Position			Foot Dominance		Grade of hamstring injury*			Days absent from training due to injury (Mean \pm SD)	Number of days since injury when tested (Min; Max)
		Defender	Midfielder	Striker	Right	Left	1	2	3		
HIG (n)	6	3	3	0	2	4	3	3	0	20.3 \pm 2.2	141; 518
Control (n)	11	4	6	1	8	3	-	-	-	-	-

*Injury grading system according to O'Donoghue (1962), Peetrans (2002) and Stoller (2007).

3.0 Results

No significant side-to-side differences were observed for any of the force-related variables studied during the acceleration phase of the sprint (table 2). For the steady state phase of the sprint maximum horizontal force development of dominant limb was significantly larger than the non-dominant limb in the control group ($p = 0.036$). No significant differences were found for any other variables.

No statistical differences were observed for force values between groups (table 3).

Across both groups the maximum speed on NMT was 25.2% lower than the maximum outdoor speed collected from GPS data.

Table 2. HIG and Control Group force related variables in the Acceleration and Steady State phases of the sprint.

Forces NMT (N)	Control Group (Mean ± SD)		<i>P</i> value	HIG Group (Mean ± SD)		P value
	Dominant side	Non dominant side		Previous injured side	Non-injured side	
Acceleration phase						
Max Horizontal Force (N)	211.0 ± 10.7	198.0 ± 14.4	0.27	198.0 ± 17.5	195.9 ± 17.2	0.75
Averaged Horizontal Force (N)	124.8 ± 9.4	124.8 ± 8.2	0.86	113.3 ± 7.9	115.5 ± 6.5	0.58
Max Vertical Force (N)	2312.7 ± 76.1	2158.0 ± 78.0	0.06	2116.1 ± 70.2	2076.4 ± 73.5	0.64
Averaged Vertical Force (N)	1875.6 ± 108.1	2025.5 ± 115.9	0.79	1866.8 ± 68.6	1802.0 ± 47.2	0.33
Steady State phase						
Max Horizontal Force (N)	67.1 ± 2.4	72.4 ± 3.8	0.036	70.2 ± 5.9	71.5 ± 6.5	0.81
Averaged Horizontal Force (N)	52.5 ± 4.4	54.3 ± 4.6	0.55	51.2 ± 4.5	51.7 ± 6.2	0.92
Max Vertical Force (N)	2101.9 ± 96.9	2140.4 ± 94.5	0.44	2048.6 ± 81.6	1985.1 ± 100.6	0.11
Averaged Vertical Force (N)	1984.1 ± 96.1	2047.8 ± 85.8	0.26	1888.5 ± 116.9	1791.5 ±100.1	0.80

Table 3. Group comparison of force related variables

	Acceleration Phase			Steady State Phase		
	HIG (Mean \pm SD)	Control (Mean \pm SD)		HIG (Mean \pm SD)	Control (Mean \pm SD)	
Max Speed NMT (m.s ⁻¹)	-	-		6.9 \pm 0.2	7.2 \pm 0.2	0.48
Max Speed Outdoor/GPS (m.s ⁻¹)	-	-		9.7 \pm 0.1	9.5 \pm 0.3	0.39
Horizontal Force Peak Right (N)	195.6 \pm 16.1	211.8 \pm 11.9	0.66	74.6 \pm 7.2	68.1 \pm 2.6	0.13
Horizontal Force Peak Left (N)	198.4 \pm 18.5	197.1 \pm 13.4	0.71	67 \pm 4.5	71.5 \pm 3.8	0.42
Horizontal Force Averaged Peaks Right (N)	115.4 \pm 5.8	124.6 \pm 7.8	0.59	52.3 \pm 6.9	52.0 \pm 3.6	0.25
Horizontal Force Averaged Peaks Left (N)	113.4 \pm 8.4	125.0 \pm 9.7	0.75	50.5 \pm 3.4	54.2 \pm 4.9	0.23
Vertical Force Peak Right (N)	2081.3 \pm 63.6	2229.8 \pm 72.5	0.09	2045.8 \pm 98.0	2097.1 \pm 93.3	0.52
Vertical Force Peak Left (N)	2111.2 \pm 79.7	2203.7 \pm 77.1	0.37	1987.9 \pm 94.5	2145.1 \pm 98.0	0.26
Vertical Force Averaged Peaks Right (N)	1832.6 \pm 56.8	1906.8 \pm 71.9	0.32	1834.6 \pm 131.6	2075.7 \pm 155.6	0.40
Vertical Force Averaged Peaks Left (N)	1836.2 \pm 64.2	1966.7 \pm 70.7	0.52	1845.4 \pm 85.4	2056.2 \pm 88.5	0.49

4.0 Discussion

The aim of this study was to quantify functional asymmetry in the magnitude of horizontal force development during a maximum sprint running on a NMT, in English Premier League football players with previous history of hamstring strain. Whilst Brughelli et al.[5] found that the previously injured limb presented 45.9% lower horizontal force generation than the non-injured limb, and that horizontal force generation in the injured group was significantly reduced compared to a control group, we found no differences in horizontal and vertical maximal force or averaged peak forces measured in the acceleration phase up to the maximum speed step in a 10 seconds sprint effort, as well as in the first eight steps of the steady state phase. We therefore rejected our a priori hypothesis that with the assessment we would reveal functional asymmetries in players with a previous hamstring injury. We will discuss possible explanations for this absence of differences, which may be associated with the population, the equipment, or the protocol.

A first possible explanation for our findings is that our participants had undergone an intensive rehabilitation program to increase chances of a successful return to football practice as well as to minimize the risk of re-injury occurring. Specifically, eccentric exercises were utilised as is now generally accepted in the therapeutic literature [1, 3, 21]. This rehabilitation routine might have better cancelled out any force deficits post-injury in our study. Also, the average time since injury may have been longer than that in Brughelli et al. [5], but this cannot be confirmed as this was not reported in their study.

Our rejection of the a priori hypothesis may also be related to the equipment. We used load cells embedded in a curved NMT for assessment of forces, whereas in Brughelli et al. [5] a Woodway® 3.0 with load cell in a non-elastic tether connected to the subject was used to

estimate forces. In our study low horizontal forces were observed during constant speed sprinting as opposed to high forces in the latter study (72.4 N and 324 N respectively). To our knowledge, no studies have been undertaken related to how reliable the measurement of forces is in either of the NMT models despite a few papers addressing reliability and validity in terms of power, speed, gait length and time to fatigue [12, 15, 18, 27]. Our pilot test evaluated test-retest reliability of the force related outcome measures for our NMT model, and identified peak horizontal force generation as a moderate outcome measure, but we currently have no means to compare this to other NMT models.

Rejection of the a priori hypothesis could be associated with the testing protocol. Horizontal force development is higher during the acceleration phase (figure 2) and has been correlated with performance variables related to acceleration, rather than those related to steady state sprinting [17]. For that reason it was hypothesised that any injury-related differences in horizontal force performance were more likely to be present in this phase. However results from our study presented no differences and in the study of Brughelli et al. [5] asymmetries were observed for force development during a steady state sprint. Whilst this may from a mechanical viewpoint be counterintuitive, there remains uncertainty over which phase may well be most meaningful. Sherry and Best [23] distinguish the moments of injury while running between sprinting and accelerating from a stationary position to full sprint. Whilst 13 of their 24 participants reported injury while sprinting, five reported injury during acceleration. Whilst we also evaluated force development during steady state sprinting, the steady state was a maximum speed effort, as opposed to an 80% effort adopted by Brughelli et al.[5]. Our decision to use a maximal effort was made under the assumption that replicating sport specific demands as involved in football play should consider a maximal and not sub-maximal effort. The maximal effort, in fact, was still considered to impose a limitation as it was found to allow the player to only achieve a progression speed of 75% of what is achieved

in an overground sprint, similar to what has been reported in previous work [16]. Equally the absence of an alternative strength assessment to confirm the absence of asymmetry in our study is a limitation to this study.

Overall, our study has challenged the robustness of functional asymmetry assessments in a club environment to identify risk of re-injury. This is an important finding for the practical field, as it in the first place highlights the need to rigorously test whether modifications to an assessment protocol annihilate its capacity to actually reveal deficiencies. We do not believe that our findings undermine the likely role of asymmetry as a re-injury mechanism, with considerable arguments existing that support the importance of horizontal force development in sprint performance. Rather, we hope that our findings can generate a critical attitude towards further development and validation of assessment protocols, including the ones that are ultimately implemented in a club setting. Furthermore, future translational research aiming at the validation of equipment in an actual club setting is suggested. This is a considerable challenge for practitioners in a club environment, dealing on the one hand with limitations of the elite environment context, and on the other hand with the continuous emergence of a broad variety of commodity technologies.

In conclusion, our results challenge the role of functional force deficits as a diagnostic measure of hamstring re-injury risk, and warrant further investigation to establish whether force development asymmetries can be indicative of re-injury risk. It remains uncertain whether horizontal force deficits in a NMT can represent a potential risk factor for hamstring injuries. More importantly though, it has highlighted the scientific challenges that practitioners are faced with in an elite club environment, and that there is a need to validate

assessment protocols, even if differences from lab based assessments may at first sight appear to be small.

References

1. Arnason A, Andersen TE, Holme I, Engebretsen L, Bahr R. Prevention of hamstring strains in elite soccer: an intervention study. *Scand J Med Sci Sports* 2008; 18: 40-48.
2. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med* 2004; 32: 5S.
3. Askling C, Karlsson J, Thorstensson A. Hamstring occurrence in elite soccer players after preseason strength with eccentric overload. *Scand J Med Sci Sports* 2003; 13: 244-250.
4. Brughelli M, Cronin J, Chaouachi, A. Effects of running velocity on running kinetics and kinematics. *J Strength Cond Res* 2011; 25: 933–939.
5. Brughelli M, Cronin, J, Mendiguchia J, Kinsella D, Nosaka K. Contralateral leg deficits in kinetic and kinematic variables during running in Australian Rules Football players with previous hamstring injuries. *J Strength Cond Res* 2010; 24: 2539-2544.
6. Cameron M, Adams R, Maher C. Motor control and strength as predictors of hamstring injury in elite players of Australian football. *Phys Ther Sport* 2003; 4: 159-166.
7. Ekstrand J, Häggglund M, Walden M. Injury incidence and injury patterns in professional football: the UEFA injury study. *Br J Sports Med* 2011; 45: 553–558.
8. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for hamstring injuries among male soccer players: a prospective cohort study. *Am J Sports Med* 2010; 38:1147-53.
9. Häggglund M, Walden M, Ekstrand J. Risk factors for lower extremity muscle injury in professional soccer. *Am J Sports Med* 2013; 41: 327-335.
10. Harriss DJ, Atkinson G. Ethical standards in sports and exercise science research: 2014 update. *Int J Sports Med* 2013; 34: 1025-1028.
11. Hawkins RD, Hulse MA, Wilkinson C. The association football medical research programme: an audit of injuries in professional football. *Br J Sports Med* 2001; 35: 43–47.
12. Highton, JM, Lamb KL, Twist C, Nicholas C. The reliability and validity of short distance sprint performance assessed on a nonmotorized treadmill. *J Strength Cond Res* 2012; 26, 458-465.
13. Hopker JG, Coleman DA, Jonathan DW, Calbraith A. Familiarisation and reliability of sprint test indices during laboratory and field assessment. *J Sports Sci Med* 2009; 8: 528-532.
14. Hughes MG, Doherty M, Tong RJ, Reilly, Cable NT. Reliability of repeated sprint exercise in non-motorised treadmill ergometry. *Int J Sports Med* 2006; 27: 900–904.
15. Lim JM, Chia MYH. Reliability of power output derived from the nonmotorized treadmill test. *J Strength Cond Res* 2007; 21: 993-996.

16. Morin JB, Sève P. Sprint running performance: comparison between treadmill and field conditions. *Eur J Appl Physiol* 2011; 111:1695-1703.
17. Mendiguchia J, Alerton-Geli E, Brughelli M. Hamstring strain injuries: are we heading in the right direction? *Br J Sports Med* 2011; 46: 81-85.
18. Oliver JL, Armstrong N, Williams CA. Reliability and validity of a soccer-specific test of prolonged repeated-sprint ability. *Int J Sports Physiol Perform* 2007; 2: 137-149.
19. Opar DA, Williams MD, Timmins RG, Dear NM, Shield AJ. Rate of torque and electromyographic development during anticipated eccentric contraction is lower in previously strained hamstrings. *Am J Sports Med* 2013; 41: 116-125.
20. Orchard JW. Hamstrings are most susceptible to injury during the early stance phase of sprinting. *Br J Sports Med* 2011; 46: 88-89.
21. Petersen J, Thorborg K. Preventive effect of eccentric training on acute hamstring injuries in men's soccer. *Am J Sports Med* 2011; 39: 2296-2303.
22. Prior M, Guerin M, Grimmer K. An evidence-approach to hamstring strain injury: a systematic review of the literature. *Sports Health* 2009; 1: 154-164.
23. Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strain. *J Orthop Sports Phys Ther* 2004; 34: 116-125.
24. Silder A, Reeder SB, Thelen DG. The influence of prior hamstring injury on lengthening muscle tissue mechanics. *J Biomech* 2010; 43, 2254-2260.
25. Sole G, Milosavljevic S, Nicholson H, Sullivan SJ. Altered muscle activation following hamstring injuries. *Br J Sports Med* 2011; 46: 118-123.
26. Sole G, Milosavljevic S, Nicholson H, Sullivan SJ. Selective strength loss and decreased muscle activity in hamstring injury. *J Orthop Sports Phys Ther* 2011; 4: 354-363.
27. Tong RJ, Bell W, Ball G, Winter EM. Reliability of power output measurements during repeated treadmill sprinting in rugby players. *J Sports Sci* 2001; 19: 289-297.
28. Woods C, Hawkins RD, Maltby S, Hulse M, Thomas A, Hodson A. The Football Association Medical Research Programme: an audit of injuries in professional football-analysis of hamstring injuries. *Br J Sports Med* 2004; 38: 36-41.