



Original research

Greater loss of horizontal force after a repeated-sprint test in footballers with a previous hamstring injury

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ABSTRACT

Objectives: To quantify changes in running kinetics and kinematics during a repeated-sprint test in football players, and explore the sensitivity and specificity with which these variables can identify previous hamstring injury.

Design: 20 Western Australia State League footballers with previous unilateral hamstring injury and 20 players without completed a 10 × 6-s repeated-sprint test on a non-motorised treadmill dynamometer. **Methods:** Changes in horizontal force, vertical force, contact time and flight time were compared between previously injured and uninjured legs of participants.

Results: Mean horizontal force production of the previously injured leg in the injured group was 13% lower ($p = 0.001$), and this magnitude of change was used to identify the injured legs within the cohort with 77% specificity and 85% sensitivity. Furthermore, the area under the Receiver Operating Characteristics curve (0.846) demonstrated that the between-leg difference in mean horizontal force was a good instrument for identifying previous hamstring injury.

Conclusions: There is a greater fatigued-induced change in mean horizontal force during a repeated-sprint test in legs with previous hamstring injury than the non-injured legs of the injured players or the legs of uninjured players. Such asymmetry may contribute to impaired performance in football players returning from hamstring injury and also to the high rate of hamstring re-injury. Rehabilitation and return-to-play strategies should emphasise a reduction in asymmetry, particularly during repeated high-intensity efforts. Furthermore, binary regression and Receiver Operating Characteristic analyses suggest that changes in mean horizontal force could be used to assess risk of hamstring injury, re-injury and/or return to play.

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1. Introduction

Hamstring injuries are the most common football-related muscle injury, accounting for 13–17% of all injuries in football.¹ These injuries require extensive treatment and rehabilitation periods, necessitating an individual to be absent from training and competition for up to 90 days.¹ Alarming, hamstring injuries have been reported to have a high recurrence rate, varying from 12 to 33%,¹ and have increased by 4% annually since 2001 in male elite football.² Certainly, the most commonly cited cause of hamstring injury is previous injury³ so preventing an initial injury and limiting risk factors for re-injury are both important.

While one specific explanation as to the cause of hamstring injuries does not exist, one current theory is that excessive knee flexor muscle fatigue may increase hamstring injury risk.⁴ There is general agreement that football requires bouts of repeated sprinting, and that such activity is highly fatiguing,⁵ and the number of hamstring injuries is known to increase as the number of sprints in a game increases.² Considering that half of all hamstring injuries during competitive football matches occur within the last 15 min of each half,¹ hamstring fatigue has been suggested to be a factor strongly influencing hamstring injuries.² It is therefore unsurprising that the isokinetic measurement of knee flexor torque changes through repeated maximal contractions has been shown to identify previous hamstring injury in footballers.⁴ The effect of hamstring fatigue on injury risk may be explained by the weaker, fatigued muscle being susceptible to force-induced injury, but fatigue has also been shown to alter running mechanics in a way that may

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increase the risk of hamstring injury, possibly due to the altered muscular proprioception that occurs during fatigue.⁶

Preferential lateralisation in the lower limbs has previously been demonstrated in actions such as jumping, cycling, running⁷ and kicking.⁸ Dominance with the lower limbs is also associated with mechanical asymmetries which can affect hamstring bilateral asymmetry.⁸ Indeed, a strength difference greater than 15% has been shown to be related to hamstring injuries in football players.⁹ Much like asymmetries in strength, asymmetries in running mechanics are also common.¹⁰ Both strength asymmetries and sprint-related fatigue have been cited as risk factors for hamstring injuries, thus the assessment of asymmetries, particularly during or after fatiguing repeated-sprint runs, may prove a useful test for hamstring injury risk in football players.

Whilst hamstring injuries most commonly occur in the latter half of the recovery phase of the gait cycle as the knee begins extension towards the stance phase,¹¹ assessment of knee flexor function requires complex inverse dynamics analyses during running, which is not easily achievable outside of a purpose-built laboratory. Such assessment also requires several assumptions to be made regarding the contributions of the hamstrings to the knee extensor moment, which is problematic when trying to assess individuals with potentially affected neuromechanical function. Thus, examination of knee flexor function during sprint running may not provide accessible, relevant information relating to hamstring injury risk.

The horizontal ground reaction force (F_H), which may be easily measured during overground running using force platforms or on instrumented treadmills, has been identified as a key mechanical feature of sprint acceleration performance.^{12–14} In producing the ground reaction force, the hip extensor and knee flexor muscles have been shown to play a prominent role as running speed increases to maximal sprint speeds.¹⁵ Interestingly, previous research has documented alterations in F_H production in athletes recovering, or having recovered, from a recent hamstring injury.^{10,16} These results were interpreted as hamstring muscle weakness inducing weaker hip extension and knee flexion functions,¹⁷ and reduced F_H production as a result.¹⁶ Subsequent studies showed preferential declines in myoelectrical activity of biceps femoris, and thus declines in eccentric knee flexor strength, following repeated-sprint running.¹⁸ Moreover, previously injured hamstrings have shown to exhibit substantial weakness in eccentric strength despite players being cleared to return to full training and competition.^{11,17} Based on these findings, not only is it possible that previous hamstring injury might reduce the ability to generate forward propulsion in the acceleration phase of a sprint run,¹⁶ but fatiguing exercise could further exacerbate declines in strength and force production (i.e. bilateral hamstring asymmetry) thus increasing injury risk. Nonetheless, the potential exacerbation of lateralisation may provide a unique marker for potential injury in players, and it is of interest to explore the use of F_H production in sprinting in this regard.

The purpose of the present study, therefore, was twofold: (1) to compare kinetic and kinematic parameters obtained during sprints between semi-professional football players with and without recent hamstring injury, and (2) to examine the fatigue-induced changes in inter-limb asymmetry, particularly with respect to F_H production, across repeated-sprint repetitions. Furthermore, determining whether a football-relevant repeated-sprint (i.e. fatiguing) protocol could identify previous hamstring injured legs was of interest, thus the sensitivity and specificity with which kinetic and kinematic variables obtained during repeated sprints could correctly classify previously injured and uninjured legs was assessed using binary logistic regression and Receiver Operating Characteristics (ROC) curve analyses.

2. Methods

Forty semi-professional footballers currently playing in the Western Australia State League volunteered for the study; data describing sprint-induced changes in knee flexor strength measured by isokinetic dynamometry and their relation to hamstring injury have been published previously.⁴ All footballers had 5 years playing experience in football, and at least 2 years of playing experience in the State League. Players were assigned to either an injured (IG; 23.8 ± 2.7 years, 73.9 ± 4.7 kg) or uninjured group (UG; 20.1 ± 3.2 years, 71.4 ± 3.6 kg) determined by the following criteria: (a) injury history of one or multiple hamstring injuries to one leg only (a unilateral hamstring injury) as reported by a clinical physiotherapist; (b) the injury caused the athlete to miss at least one week of training (6 ± 2 weeks; the injury was significant); (c) the injury occurred less than 2 years prior to testing (13 ± 4 months; the injury was recent enough for some deficiencies to potentially remain). All participants in the injured group experienced their unilateral hamstring injury in the kicking leg. All participants provided written informed consent prior to data collection. The Ethical approval for the study was granted by the university's Human Research Ethics Committee (ID9302).

After two familiarisation sessions during which the repeated-sprint test (RST) was practised (described below), testing was performed over two sessions separated by one week and completed at the same time of day. The participants were asked to maintain a normal diet and refrain from participating in any strenuous exercise for 48 h prior to testing. A 5-min jogging (2 m s^{-1}) warm-up was completed on a non-motorised treadmill (Curve Treadmill Dynamometer, Woodway, Waukesha, Winconsin, USA; supplied by Fitness Technology, Adelaide, Australia) before the commencement of testing with the participants given the opportunity to perform dynamic stretches after the warm-up for a total of 2 min. This warm-up was repeated in the subsequent sessions. Once the warm-up and dynamic stretching were completed the participants followed the testing protocol.

As repeated sprints initiated from a slow movement speed (rather than from a stationary start) are prominent in football,¹⁹ the RST was used to elicit a fatigue response over 10 repeated sprints with the ten 6-s running bouts performed at maximum velocity with 24-s of active recovery (jog at 2 m s^{-1}) between each sprint. Feedback of running speed and time were provided by the Pacer Performance System software (Innervations Solutions, Joondalup, Australia). The participants were instructed to build to their maximum velocity as quickly as possible, and the acceleration phase of the sprint was included in the 6-s sprint data collection period. Data collection variables included mean horizontal force production, mean vertical force production, mean contact time and mean flight time. Participants were given verbal encouragement to perform maximally throughout the RST.

The Woodway Curve non-motorised treadmill contains four load cells (on the left and right side, at the front and rear of the treadmill belt) that measure vertical ground reaction force at 200 Hz.²⁰ According to our contact time data (e.g. see Table 1), this would provide >20 sample points in the propulsive phase (i.e. for ~30 sample points per ground contact.²¹ F_H is calculated within the Pacer Performance System software using the formula: $F_H = \text{acceleration} \times (\text{body mass} \times \text{belt friction})$. Calibration of the non-motorised treadmill was conducted before each testing session using a range of known loads, according to the manufacturer's guidelines. Previously, the curved non-motorised treadmill has shown good reliability during short duration sprints.¹³ Flight time was differentiated by the time of the end of foot contact to the start of foot contact of the same leg.

Data were analysed using SPSS statistical software (SPSS 23, Chicago, Ill). Means and standard deviations were calculated as

Table 1

Mean (\pm SD) and percent changes in mean horizontal force, vertical force, contact time and flight time of kicking and non-kicking legs in injured (IG) and uninjured groups (UG) during the first and tenth sprint of the repeated-sprint test (RST).

| | Sprint 1 | Sprint 10 | % Change | Effect size (<i>d</i>) |
|----------------------|--------------------|--------------------|------------------------------|--------------------------|
| Horizontal force (N) | | | | |
| Injured group | | | | |
| Kicking leg | 156.3 \pm 12.4 | 135.3 \pm 10.1 | -13 \pm 8 ^{a,b,c} | 1.69 |
| Non-kicking leg | 159.7 \pm 11.3 | 154.5 \pm 10.9 | -3 \pm 6 | 0.45 |
| Uninjured group | | | | |
| Kicking leg | 144.9 \pm 13.6 | 141.1 \pm 12.6 | -3 \pm 1 | 0.28 |
| Non-kicking leg | 148.5 \pm 15.0 | 143.2 \pm 12.3 | -3 \pm 5 | 0.35 |
| Vertical force (N) | | | | |
| Injured group | | | | |
| Kicking leg | 2015.5 \pm 210.0 | 1938.2 \pm 132.1 | -1 \pm 8 | 0.15 |
| Non-kicking leg | 2034.8 \pm 156.1 | 2002.5 \pm 106.1 | -1 \pm 8 | 0.21 |
| Uninjured group | | | | |
| Kicking leg | 1905.9 \pm 109.6 | 1872.8 \pm 80.7 | -1 \pm 8 | 0.30 |
| Non-kicking leg | 1932.5 \pm 100.9 | 1904.4 \pm 78.2 | -1 \pm 6 | 0.28 |
| Contact time (s) | | | | |
| Injured group | | | | |
| Kicking leg | 0.150 \pm 0.004 | 0.152 \pm 0.003 | -1 \pm 3 | -0.49 |
| Non-kicking leg | 0.148 \pm 0.002 | 0.149 \pm 0.003 | -1 \pm 2 | -0.34 |
| Uninjured group | | | | |
| Kicking leg | 0.155 \pm 0.004 | 0.157 \pm 0.004 | -1 \pm 3 | -0.30 |
| Non-kicking leg | 0.156 \pm 0.005 | 0.157 \pm 0.004 | -1 \pm 4 | -0.31 |
| Flight time (s) | | | | |
| Injured group | | | | |
| Kicking leg | 0.180 \pm 0.004 | 0.176 \pm 0.003 | -3 \pm 3 | 1.23 |
| Non-kicking leg | 0.182 \pm 0.002 | 0.179 \pm 0.004 | -1 \pm 3 | 0.99 |
| Uninjured group | | | | |
| Kicking leg | 0.174 \pm 0.003 | 0.173 \pm 0.004 | -1 \pm 2 | 0.41 |
| Non-kicking leg | 0.174 \pm 0.003 | 0.173 \pm 0.004 | -1 \pm 3 | 0.39 |

^a Significant difference ($p < 0.05$) before and after RST.

^b Significant difference ($p < 0.05$) between kicking and non-kicking legs in injured group.

^c Significant difference ($p < 0.05$) between kicking legs of injured and uninjured groups.

measures of centrality and spread of data for all dependent variables. Outcome measures were analysed using a repeated measures ANOVA, with 'leg' (injured and non-injured leg) and 'sprint' (sprint number during the repeated-sprint test) as between-participant variables with the between-group factor of 'group' (with two levels; injured and uninjured). Independent t-tests were performed between groups to assess whether significant differences were detectable between the injured and uninjured groups. Effect sizes (ES) were calculated as the ratio of the mean difference to the control group (before RST) standard deviation.²² Binary logistic regression analysis was performed to determine the probability of the legs of participants falling into 'injured' or 'uninjured' leg categories. From this analysis, sensitivity (true positive/(true positive + false negative) \times 100) and specificity (true negative/(true negative + false positive) \times 100) were calculated. Receiver operating characteristics (ROC) were computed and the area under the curve (AUC) calculated in order to indicate how well the variables under consideration discriminated between previously injured and uninjured legs. An AUC of 1 (100%) represents perfect discrimination for a binary outcome. The point at which the AUC was maximised, and is reflective of the optimal discrimination potential, was considered the value at which a "cut-off" might identify previous injury. Statistical significance was accepted at an alpha level of 0.05.

3. Results

Changes in mean horizontal force (F_H ; propulsive), vertical force (F_V), contact time (CT) and flight time (FT) of the injured (i.e. kicking leg in all cases) and non-injured (non-kicking) legs in both injured and uninjured groups during the RST are shown in Table 1. A significantly greater decrease in mean F_H occurred in the kicking

(injured) leg in the injured group (-13%; $p = 0.001$; ES = 1.69) than in the kicking leg in the uninjured group (-3%; $p = 0.058$; ES = 0.28; see Fig. 1). However, there were no statistically significant difference in the decrease in mean F_V between the kicking leg of the injured group (-1%; $p = 0.571$; ES = 0.15) and the kicking leg in the uninjured group (-1%; $p = 0.518$; ES = 0.30) ($p = 0.642$).

There were also no significant differences in the decrease in CT between the kicking leg in the injured group (-1%; $p = 0.704$; ES = -0.49) and the kicking leg in the uninjured group (-1%; $p = 0.992$; ES = -0.30) ($p = 0.862$), or the decrease in FT between the kicking leg in the injured group (-3%; $p = 0.081$; ES = 1.23) and the kicking leg in the uninjured group (-1%; $p = 0.862$; ES = 0.41) ($p = 0.484$).

Binary logistic regression analysis was performed to identify the previously injured legs (i.e. from 80 total legs) from running kinetics during RST (Table 2). The difference in F_H from RST repetition 1 to repetition 10 ($p < 0.001$) explained 39.8% of the variance (Nagelkerke R^2) and correctly classified 77% of previously injured legs and 85% of uninjured legs (i.e. 77% sensitivity and 85% specificity), and was the best identifier of previous hamstring injury. Thus, a ROC curve was built for this variable, with the AUC (0.846) maximised at a mean F_H of 11.5 N (Table 2 and Fig. 1).

4. Discussion

In the current study, the inter-limb asymmetry of the mean horizontal ground reaction force (F_H) measured during 10 repeated sprint runs increased to a very large (12%) extent and was significantly larger than the small change (1%) in the legs of previously uninjured players. This was attributable to a 13% change in F_H in previously injured legs, which did not notably change (3%) in uninjured legs of previously injured legs, since the uninjured leg did not notably change (3%) (see Table 1). We conclude that, since all of our previously injured participants had injured their kicking leg, the increasing between-leg difference in our hamstring-injured group was associated with previous hamstring injury. Importantly, this suggests that an association between previous injury and the rate of fatigue exists, which may potentially increase the risk of re-injury in this group. While fatigability before injury was not determined in the current study, the current data provide support for a prospective investigation on inter-limb asymmetry fatigue before and after injury.

The existence of kinetic and kinematic asymmetries between legs is well documented in running.⁷ For example, running asymmetries observed in youth athletes demonstrated a 15–20% difference between legs.²³ Similarly, running asymmetries have also been reported in uninjured rugby union athletes during an 8-s maximal effort sprint.^{24,25} While recent research has shown that bilateral asymmetry is not exacerbated by fatigue (i.e. legs fatigue at an equal rate)²⁶ in otherwise healthy participants, the present study is the first to document a significant increase in changes in mean F_H during 10 repeated sprint runs and, as a result, increases in between-leg asymmetry in previously hamstring-injured footballers. While minimal changes in F_H were observed from sprint 1 to sprint 2 (-2%) in the previously injured leg, the magnitude of change after the completion of sprint 10 suggests that an association between previous injury and fatigue exists. Additionally, the injured and uninjured groups shared similar playing levels of football and training history, and body mass and peak running velocities during testing (IG; $7.9 \pm 1.7 \text{ m s}^{-1}$, UG; $7.4 \pm 1.3 \text{ m s}^{-1}$) were not different between groups. We therefore conclude that it was most likely the effect of previous hamstring injury rather than participant characteristics that underpinned the fatigue-related decrement in F_H propulsive force.

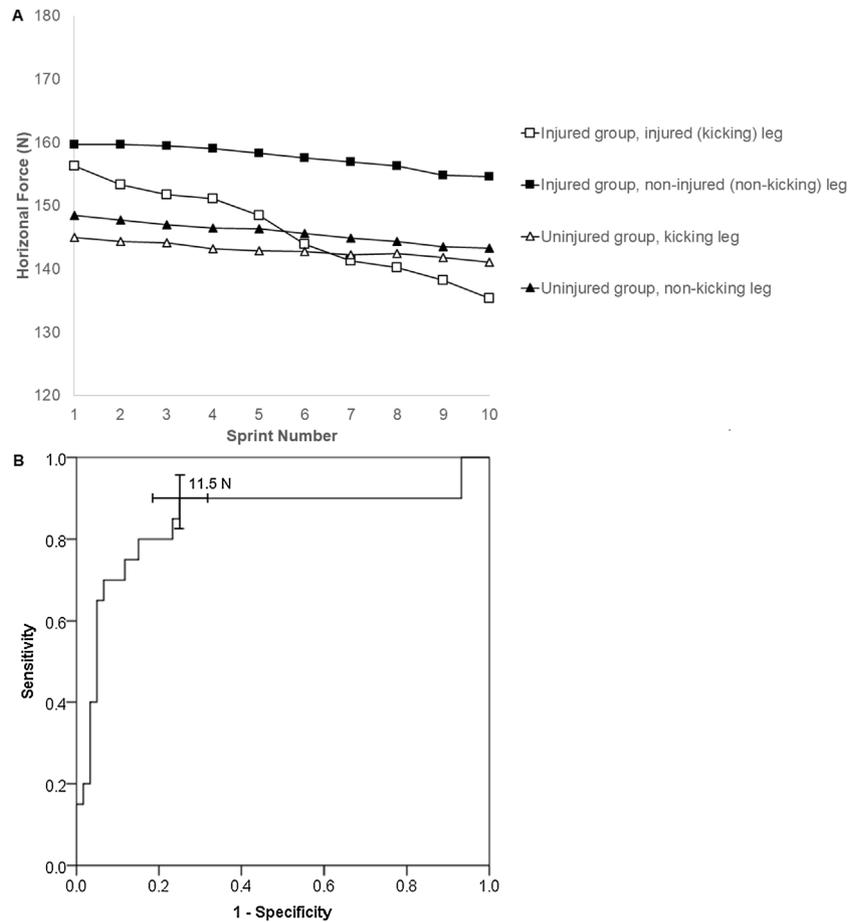


Fig. 1. Mean repeated-sprint test (RST) data (1A) from injured (IG; square symbols) and uninjured (UG; triangle symbols) groups, showing changes in mean horizontal force in injured (kicking; light symbols) and uninjured (non-kicking; dark symbols) legs during each of the 10 sprints and (1B) the receiver operating characteristics (ROC) curve for the difference in mean horizontal force (F_H) from the first repeated-sprint test (RST) repetition to the tenth, displaying the optimal discrimination potential of the area under the curve (AUC).

Table 2

P values (P), sensitivity and specificity for the binary logistic regression analysis for all subjects (injured and uninjured), and area under the curve (AUC), P values (P), 95% confidence interval (95% CI) and the cut-off point for the receiver operating characteristics (ROC) analysis for all subjects (injured and uninjured).

| | Nagelkerke R^2 | P | Sensitivity (%) | Specificity (%) |
|--|------------------|---------|-----------------|-----------------|
| Difference in F_H RST ¹ -to-RST ¹⁰ | 0.398 | <0.001* | 77 | 85 |
| Difference in FT RST ¹ -to-RST ¹⁰ | 0.152 | 0.028* | 50 | 76 |
| Mean CT RST ¹ -to-RST ¹⁰ | 0.293 | <0.001* | 15 | 73 |
| Mean F_V RST ¹ -to-RST ¹⁰ | 0.083 | 0.033* | 1 | 76 |
| Mean FT RST ¹ -to-RST ¹⁰ | 0.044 | 0.241 | 0 | 75 |
| Mean F_H RST ¹ -to-RST ¹⁰ | 0.008 | 0.508 | 0 | 75 |
| Difference in CT RST ¹ -to-RST ¹⁰ | 0.003 | 0.678 | 0 | 75 |
| Difference in F_V RST ¹ -to-RST ¹⁰ | 0.003 | 0.675 | 0 | 100 |
| | AUC | P | 95% CI | Cut-off point |
| Difference in F_H RST ¹ -to-RST ¹⁰ | 0.846 | <0.001* | 0.721–0.970 | 11.5 N |
| Difference in FT RST ¹ -to-RST ¹⁰ | 0.678 | 0.018* | 0.539–0.817 | 0.009 s |
| Mean CT RST ¹ -to-RST ¹⁰ | 0.249 | 0.001* | 0.145–0.352 | 0.158 s |
| Mean F_V RST ¹ -to-RST ¹⁰ | 0.662 | 0.03* | 0.518–0.807 | 2145.2 N |
| Mean FT RST ¹ -to-RST ¹⁰ | 0.636 | 0.070 | 0.519–0.752 | 0.182 s |
| Mean F_H RST ¹ -to-RST ¹⁰ | 0.473 | 0.722 | 0.329–0.618 | 160.3 N |
| Difference in CT RST ¹ -to-RST ¹⁰ | 0.624 | 0.098 | 0.489–0.760 | 0.007 s |
| Difference in F_V RST ¹ -to-RST ¹⁰ | 0.561 | 0.414 | 0.416–0.706 | 405.8 N |

F_H = horizontal force.

RST¹-to-RST¹⁰ = first repetition of RST (repeated-sprint test) to the tenth repetition.

FT = flight time.

CT = contact time.

F_V = vertical force.

* Significant predictors ($p < 0.05$).

Voluntary muscle force production characteristics such as peak force and power can be impaired for months or years after a hamstring injury.^{11,27} In addition to changes in the neural control of the muscles, these changes also occur at least partially from persistent changes in the muscle, such as scar tissue,²⁷ which are observable in magnetic resonance imaging scans²⁷ and may persist indefinitely²⁸ even after successful completion of a rehabilitation program.²⁷ Therefore, alterations in the neuromuscular system such as scar tissue formation may reduce muscular endurance and may have speculatively contributed to the greater loss of F_H in the previously injured leg (–13%) compared to the uninjured leg (–2%) of the previously injured players in the current study; this difference appeared to be consistent within the injured subjects despite them likely having completed different rehabilitation programs and having different recovery times since injury. The potential contribution of neuromuscular alterations to the reduction in F_H in previously hamstring-injured football players is exemplified by the minimal change in F_H in uninjured participants in both the kicking (–3%) and non-kicking (–3%) legs. Similarly, a greater loss in peak knee flexor torque production (–16%) in previously injured legs was recently documented when compared to the reduction in the uninjured leg (less than 6% loss) of either injured or uninjured groups.⁴ This suggests that hamstring injury affects muscle function during sport-specific performances (i.e. repeated sprints) as well as hamstring-specific tasks (e.g. knee flexion tests), although it was not observed to influence other tasks such as vertical jumping.⁴ While these reductions further indicate an injury-induced maladaptation of hamstring function, the ability to identify previous hamstring injury due to these reductions is seldom examined.

In order to examine whether repeated-sprint kinetics may be a useful injury (or re-injury) prediction tool, logistic regression analysis was performed to assess the specificity and sensitivity with which previously injured legs ($N=20$ legs) could be identified from the test data ($N=80$ legs). In this analysis, 77% of previously injured legs and 85% of uninjured legs could be correctly classified using the difference in F_H from sprint 1 to sprint 10 (see Table 2 and Fig. 1). Additionally, ROC analysis demonstrated that this test may be a good instrument (AUC=0.846) for identifying previous injury (see Table 2). These results indicate that bilateral F_H production may be used to identify ongoing decrements in hamstring function after return to play and that maladaptation in F_H production due to previous hamstring injury may allow repeated-sprint protocols to be implemented as a sport-specific injury prediction tool. Based on these findings, the use of a repeated-sprint test to prospectively predict hamstring injury in competitive football players might also be explored in future studies.²⁹

While logistic regression and ROC analyses revealed the difference in F_H over the course of a repeated-sprint test to be a good instrument for identifying recent injury, our previous data obtained in the same participant cohort⁴ showed that decreases in peak knee flexor torque as well as knee flexor torque during an isokinetic endurance test (on an isokinetic dynamometer) were able to perfectly (AUC = 1) identify previously-injured legs. The perfect identification of previously-injured legs could be attributed to the isokinetic endurance test specifically testing knee flexion capacity, however the less-than-perfect identification of injury observed using the sprint running test might be explained by the fact that other factors, in addition to hamstring force production, contribute to changes in (horizontal) force production during sprint running.¹² Together, these studies indicate that the fatiguing knee extensor/flexor tests may have better discriminative ability than repeated-sprint running tests. It should be noted that while the present mean F_H propulsive forces appear to be slightly lower than previously published data,^{14,30} this is largely attributable to the participants accelerating from a jogging start (2 m s^{-1}) which reduces the peak F_H magnitude.²¹

Regardless, from a practical perspective, a repeated-sprint test may be preferred in some environments as it is easier to implement in running-based athletes, can be performed as an element within a larger training session, and would not need to be performed at a separate venue. Furthermore, non-motorised treadmills or force platform units may be less expensive alternatives to isokinetic dynamometers. For these reasons, testing of F_H during a repeated-sprint test may be a cost-effective alternative for not only potentially identifying previous injury, despite having a slightly lesser scope for injury risk assessment than knee flexion endurance tests, but also as an assessment for risk of hamstring injury, re-injury and/or return to play.

5. Conclusion

The current research has demonstrated that horizontal force production decreases at a greater rate in previously injured than uninjured hamstrings during a repeated-sprint test in football players. Since repeated-sprint endurance is a key component of football fitness, such asymmetry likely contributes to impaired football and global athletic performance by reducing the football player's ability to complete game-specific movement tasks. Additionally, the continued performance of sprints as hamstrings fatigue accumulates may also contribute to the high rate of hamstring re-injury. Rehabilitation and return-to-play management practices should emphasise the reduction of asymmetry, particularly when reconditioning for repeated high-intensity efforts.

Practical implications

- The reported accuracy of identification of previous hamstring injury from the decrement in mean horizontal force suggests that the sport-specific test procedure (repeated-sprint test) is a useful instrument for identifying persistent deficits in previous hamstring injuries.
- Identifying persistent deficits will allow rehabilitation management practices to reduce the athlete's deficits.
- The current study results indicate that the repeated-sprint test's usefulness in identifying persistent deficits may be a useful tool for assessing the athlete's readiness for return-to-play.

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