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High-speed running during match-play before and after return from hamstring injury in professional footballers

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Hamstring injuries constitute the single largest cause of lost playing time in professional football. While restoring high-speed running ability is paramount for rehabilitation from these injuries, little evidence exists regarding the extent of return to sport running performance after hamstring injury in football. We examined medical and match performance data available from a sample of 38 professional soccer players competing in the Qatar Stars League ($N = 1426$ observations) to describe high-speed running performance during match-play prior and subsequent to a hamstring strain injury. Multivariable-adjusted random-effects generalized additive models estimated post- versus pre-hamstring injury differences in maximal speed (km/h), high-speed running (>20 km/h), and sprinting (>25 km/h) distance. Mean effects and uncertainty (95% confidence interval, CI) were interpreted against the estimated random match-to-match variability in maximal sprinting speed, high-speed running distance, and sprinting running distance of ±1.67 km/h (95% CI, 1.62–1.72 km/h), ±102 m (95% CI, 99–105 m), and ±60 m (95% CI, 58–61 m), respectively. The estimated post- versus pre-hamstring injury mean differences in maximal sprinting speed, high-speed running distance, and sprinting running distance primary outcomes were −0.25 km/h (95% CI, −0.38 to −0.12 km/h), −43 m (95% CI, −56 to −30 m), and −22 m (95% CI, −29 to −16 m). Players returning to football match-play after hamstring strain injury experienced reductions in high-speed match physical performance that were well within normal match-to-match variation in performance.

KEYWORDS
hamstrings, injury, load management, match load

1 | INTRODUCTION

Comprising between 4% and 13% of all injuries in football, hamstring injuries are the single largest cause of lost playing time in the sport with one hamstring injury occurring somewhere between every 500–3333 h of football exposure.[1] This burden is increased as these injuries are seen to recur in 4%[2] to 68%[3] of those who suffer them. Rehabilitation from these injuries aimed to return players to training and matches as quickly as possible while

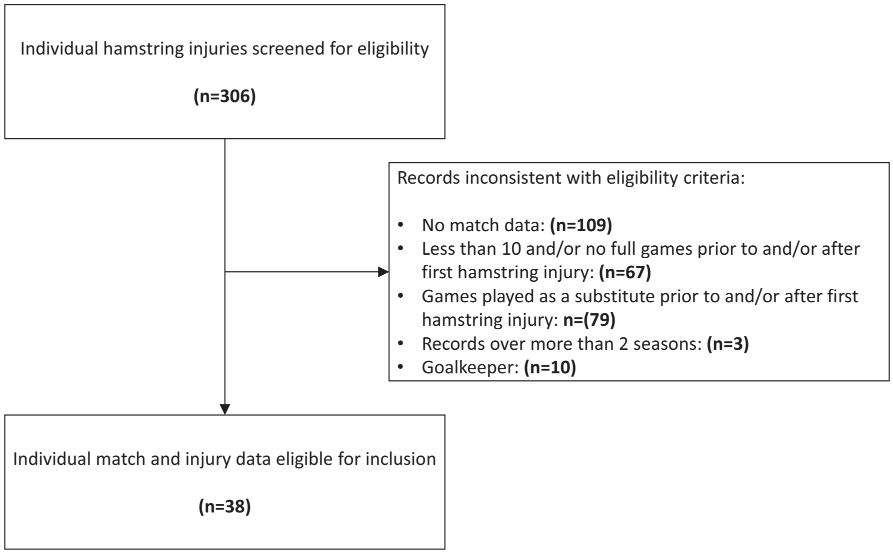

FIGURE 1 Flowchart of inclusion for the study

balancing the risk of re-injury.[4] The load placed through the hamstring muscles varies according to the task, and the methods used to quantify these loads; however, there is general agreement that high-speed running places significant stress on the hamstring muscles.[5–7] Restoring high-speed running ability is therefore one important aim for the rehabilitation and return to play process.[8] In balancing the risk–reward trade-off during rehabilitation, the performance of the athlete in terms of these higher load activities such as high-speed running needs to be considered.[9]

The decision to return to sport should include consideration of the potential for re-injury, as well as any impact on player performance.[9] A quicker return to sport may require a reduction in the amount of high-speed running required in order to avoid re-injury. Less attention has been paid to the subsequent on-field performance of players recovered from hamstring injury. A recent study suggested that nearly half of those professional football players who return from hamstring injury reduce their high-speed running distance after returning to match-play.[10] This study was limited by a relatively small sample that aggregated data from different sports (football, rugby union, and rugby league). A study in a group of 15 footballers from one organization suggested that the majority of players (83%) return to pre-injury maximum match running speed within two games, with maximum running speed taking, at most, five games to return to pre-injury levels[11] and other running metrics (relative total distance covered, relative distance covered at 17.5–22.5 km/h and relative distance covered at >22.5 km/h) normalizing sooner. Aside from this, there are no published data documenting return to sport running performance after hamstring injury. Furthermore, previous studies[10,11] failed to interpret changes in match physical performance variables against an established anchor in terms of match-to-match variability to better understand the practical relevance of any changes.[12,13] We therefore sought to describe the high-speed running performance of professional football players prior and subsequent to a hamstring strain injury to better understand whether there are any performance decrements after return to sport.

2 | MATERIALS AND METHODS

The present study examined medical and match performance data from a sample of 38 professional soccer players ($N = 1426$ observations) competing in the Qatar Stars League. Given the context of our investigation, we predefined eligibility criteria relevant to inform our sampling composition and methodological procedures. The final study sample included outfield players who played a minimum 45 min in at least 10 consecutive official matches as starters prior and subsequent to the first hamstring injury event (only) in the same calendar year. This study received ethics approval by the Aspire Zone Institutional Review Board, Doha, State of Qatar (protocol number: E202007004).

Hamstring injuries sustained during competitive matches were diagnosed and documented by the team's physician. Performance data were collected as a condition of employment in which player performance is routinely measured during match-play.[14] The methodologies and injury definitions applied in the present study adhered to guidelines presented in a previous consensus statement.[15,16] The type, location, and diagnosis of injury was recorded by the team physician. Thirty-eight hamstring injuries were identified for potential inclusion by manual search of the Aspetar Injury and Illness Surveillance Program[17] a league-wide injury surveillance database which uses a time-loss definition of injury (Figure 1). This represented 13% of all injuries in the observation period (2013–2014 to 2018–2019).

Match physical performance was evaluated using a multi-camera tracking system (Stats LLC, Chicago, IL) which has previously been shown to be a valid and reliable system for measuring match activity in soccer.[18] Maximal speed (km/h), high-speed running (>20 km/h), and sprinting (>25 km/h) distance (meters) were selected as the primary outcomes of interest.[7,18] Exploratory analyses were conducted to examine distributional patterns in the primary outcomes that may be similar between different center, left, and right outfield positions. Of the 21 software-based outfield positional bins, visual inspection of distribution curves informed a reduction of match performance data into eight positional bins as follow: central defender, wide defender, holding midfielder, central midfielder, wide midfielder, wide attacker, supporting attacker, attacker.

2.1 | Statistical analysis

We adopted a two-step approach with distinct random-effects generalized additive models with restricted maximum likelihood used for quantifying random within-subject match-to-match variability relevant to interpretations of post- versus pre-hamstring injury differences in match performance outcome measures. The primary outcomes of interest included in the models were maximal speed, high-speed running distance, and sprinting distance. In the absence of an established anchor to define a practically relevant increase or reduction in match-related performance variables and considering the evolution of contemporary soccer performance,[19] the estimated random within-subject match-to-match variability based on a full-season (2018–2019), league-wide data informed the definition of target difference values for each primary outcome of interest.[12,13] Distinct multivariable-adjusted models adopted for match-to-match variability estimation included each primary outcome as the response variable, with smooth terms specified for playing round as factor variable, played minutes, playing position, and a study subject-specific random-effect penalized by a ridge penalty.[20]

Separate multivariable-adjusted random-effects generalized additive models with restricted maximum likelihood estimated post- versus pre-hamstring injury differences in distinct primary outcomes measures relevant to match performance using the *mgcv* package.[20] Each model included the primary outcomes as response variables, condition (i.e., pre- vs. post-injury) as a categorical fixed effect, with smooth terms specified for the minutes played and playing position explanatory variables, plus study subject and playing position × study subject random-effects penalized by a ridge penalty.[20] An information-theoretic approach determined optimal smooth model selection.[20] Estimated marginal means described post- versus pre-hamstring injury differences in the primary outcomes measures presented with 95% confidence interval (CI) and interpreted against the estimated target difference values.[21] Post-estimation model diagnostics were conducted based on visual inspection of each model's raw residuals using the *mgcViz* package.[22] Random-effects variance decomposition was conducted to explore the proportion of variance explained by each random-effects term specified in the model.[23] Time-to-event and hamstring injury-related layoff days were summarized as median plus interquartile range (IQR). Effects were presented and interpreted as descriptive statistics.[24] Statistical analyses were conducted using R (version 3.6.3, R Foundation for Statistical Computing).

3 | RESULTS

Full-season, league-wide, match-to-match variability quantification involved 265 players with 2600 observations, and a median of nine games (IQR, 4–21 games) per player. The estimated random within-subject match-to-match variability in maximal sprinting speed, high-speed running distance, and sprinting running distance was ±1.67 km/h (95% CI, 1.62–1.72 km/h), ±102 m (95% CI, 99–105 m), and ±60 m (95% CI, 58–61 m), respectively.

The median layoff time was 14 days (IQR, 4–21 days). Pre- versus post-hamstring injury raw data for maximal sprinting speed, high-speed running distance, and sprinting running distance are presented in Figures 2, 3, and 4, respectively. Estimated marginal means by condition and random-effects variance decomposition statistic are illustrated in tables Tables 1 and 2. The estimated post- versus pre-hamstring injury mean differences in maximal sprinting speed, high-speed running distance, and sprinting running distance primary outcomes were −0.25 km/h (95% CI, −0.38 to −0.12 km/h), −43 m (95% CI, −56 to −30 m), and −22 m (95% CI, −29 to −16 m), respectively. Irrespective of the direction and width of the uncertainty for the observed differences in study condition, effects could not be distinguished from the within-subject match-to-match variability. Analysis of the random-effects variance components from each model suggested between-subject variability accounted for approximately a third to half (29%–47%) of the variance for the difference between pre- versus post-hamstring injury effects relevant to the primary outcomes of interest (Table 2). The median for the minutes played pre-(95 min [IQR, 94–97]) and post

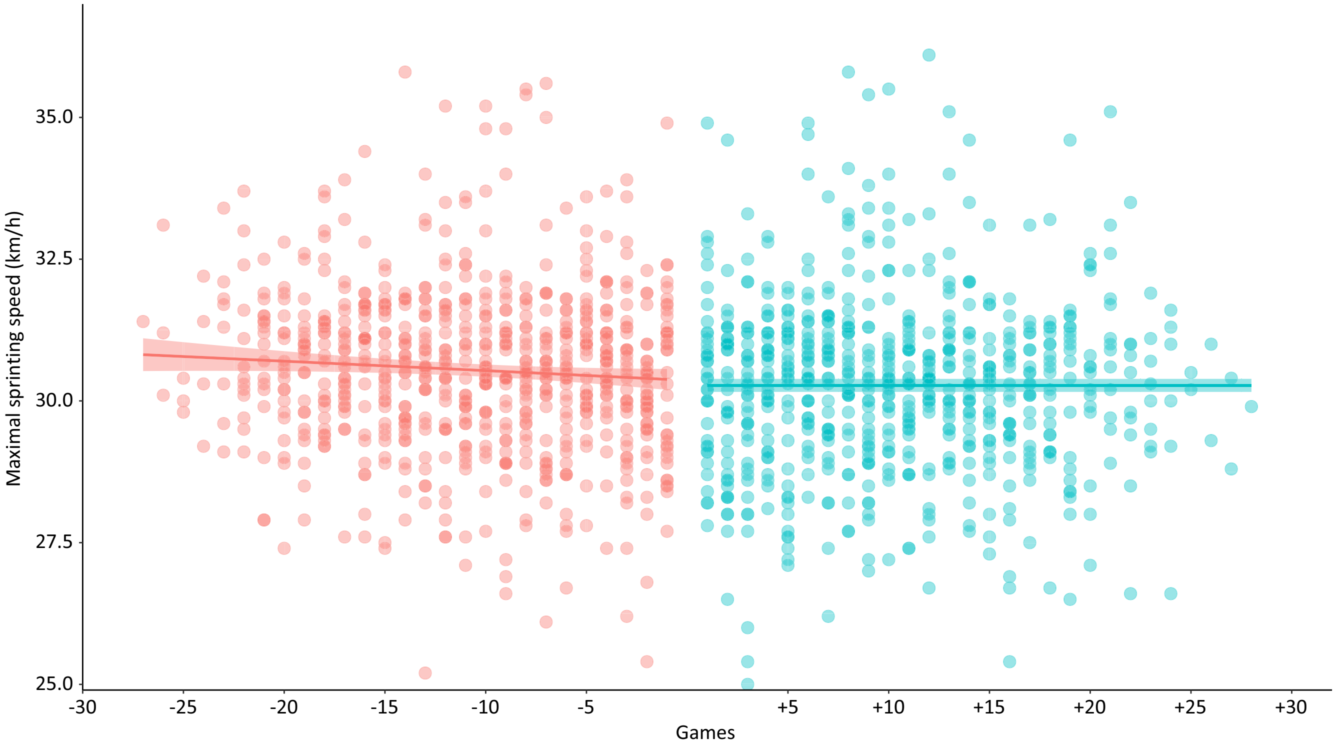

FIGURE 2 Individual data for maximal sprinting speed for players in the games prior and subsequent to hamstring strain injury along with lines of best fit and their associated 95% confidence intervals

(95 min [IQR, 94–97]) suggested differences between conditions were trivial.

4 | DISCUSSION

Restoring high-speed running ability following a hamstring injury represents an important aim for the rehabilitation and return to play process,[8] yet, as part of this process little attention has been paid to the subsequent on-field performance of professional football players recovered from hamstring injury.[10,11] We have demonstrated that players returning to match-play after hamstring injury experienced reductions in high-speed running distances and maximal sprinting speed that are not distinguishable from the within-subject match-to-match variability in the context of the present study.

Our study is the first to describe the effects of hamstring injury occurrence on subsequent match physical performance in a full cohort of professional soccer players. Likewise, for the first time, we described the degree of within-subject match-to-match variability in high-intensity activities and found this to be similar to data from the English Premier League[12] Our findings suggest reductions in our primary outcome measures of interest from pre- to post-hamstring injury. However, the width of the uncertainty surrounding our estimates compared against the typical match-to-match variability in this population of players suggest that the pre- to post-hamstring injury effect was minimal. In practical terms, the average reduction in maximum speed was small (−0.25 km/h, 95% CI: −0.38 to −0.12 km/h) compared to the normal within-subject match-to-match variability (±1.67 km/h, 95% CI: 1.62–1.72 km/h) although slightly greater for high-speed running [−43 m (95% CI, −56 to −30 m)] reduction versus [±102 m (95% CI, 99–105 m) variability] and sprint distances [−22 m (95% CI, −29 to −16 m) reduction vs. ±60 m (95% CI, 58–61 m) variability]. While we observed small decrements in running performance, the estimated differences for pre- versus post-hamstring injury comparisons could not be distinguished from the match-to-match variability given the context of our study.

Athletes may consider return to sport a success depending on the time it takes, whereas coaches may be more focused on the performance ability of the athlete upon return.[25] The shared decision-making model for return to sport also highlights the need for the coach to consider the ability to perform.[9] The present observations suggest performance goals are being met, and therefore, likely integrated in the shared decision-making process between the player, the medical team, and the coaching/preparation staff for any individual player returning from injury.[9] In the absence of an established anchor to define a practically relevant increase or reduction in match-related high-speed activity, the estimated random within-subject match-to-match variability informed the definition of

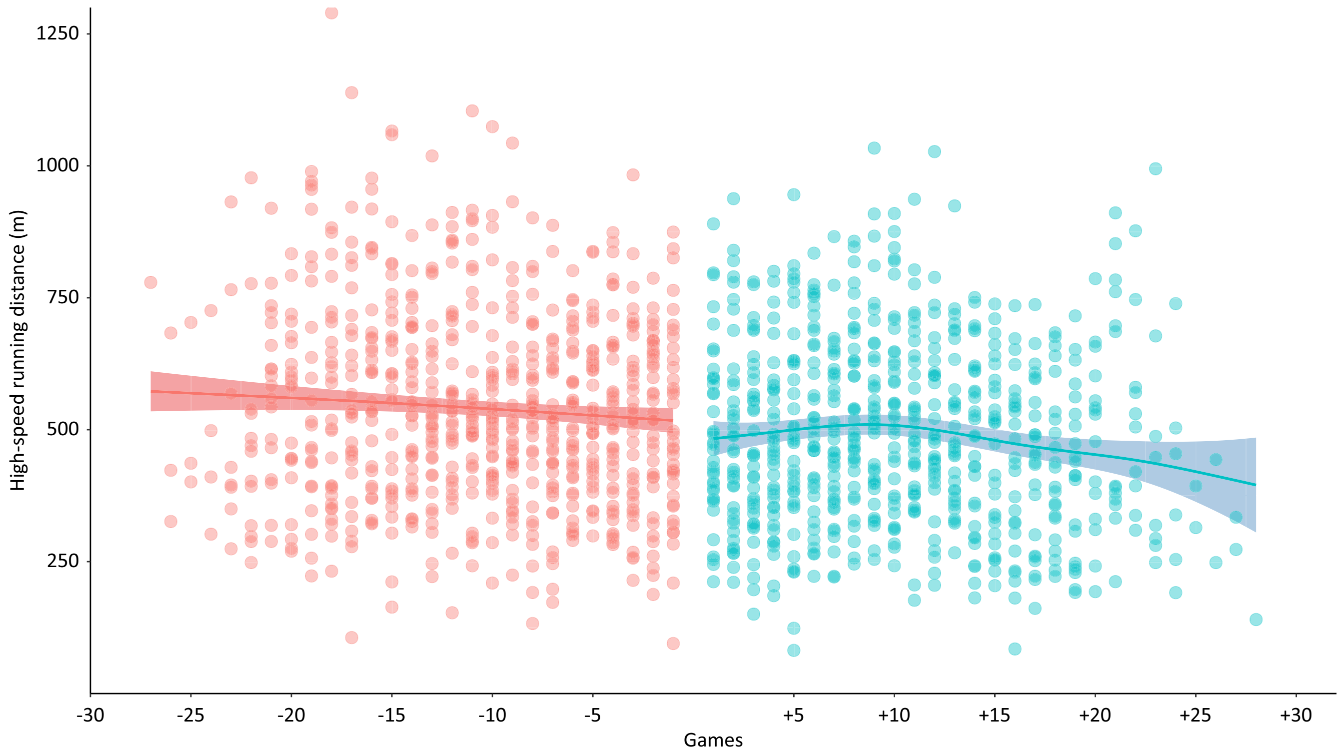

FIGURE 3 Individual data points for total high-speed running distance (meters covered at >20 km/h) in the game prior and subsequent to hamstring strain injury along with the lines of best fit and their 95% confidence intervals

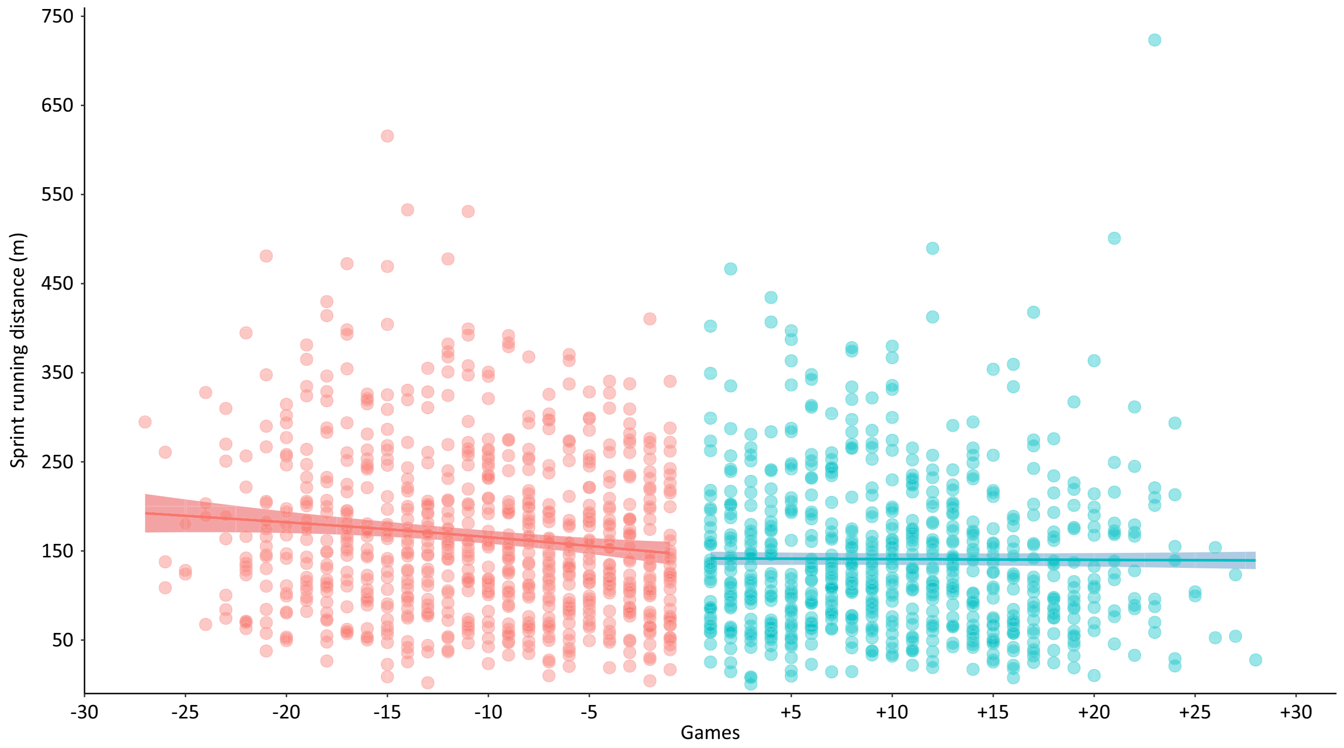

FIGURE 4 Individual data points for total sprint running distance (meters covered at >25 km/h) in the games prior and subsequent to hamstring strain injury along with the lines of best fit and their 95% confidence intervals

TABLE 1 Estimated marginal means by hamstring injury period ($n = 38$ players; $N = 1426$ observations; CI: confidence interval)

Variable	Pre-injury			Post-injury		
	Estimate	95% CI		Estimate	95% CI	
Maximal sprinting speed (km/h)	30.5	30.4	30.6	30.3	30.2	30.4
High-speed running distance (m)	557	543	571	514	500	528
Sprinting running distance (m)	164	158	169	141	136	147

TABLE 2 Model variance decomposition by primary outcome measure (SD: standard deviation)

Random-effect	SD	Explained variance (%)
Maximal sprinting speed (km/h)		
Played minutes	0.002	0
Playing position × Player	0.02	0
Playing position	0.1	0.4
Player	0.8	28.7
Residual	1.2	70.8
High-speed running distance (m)		
Played minutes	1.6	0
Playing position × Player	18	1.1
Playing position	21	1.6
Player	113	46.7
Residual	118	50.5
Sprinting running distance (m)		
Played minutes	0	0
Playing position × Player	15	3.2
Playing position	6	0.5
Player	55	42.8
Residual	62	53.6

target difference values for each high-speed activity of interest in the current study.[12,13] The small decrement in high-speed activity therefore suggests such changes are unlikely to have a meaningful impact on the physical performance of the individual player especially when compared with factors such as a change in playing position or tactical role of the player.[26]

Aside from variation mediated through the inherent demands of the game, an individual player's ability to regulate their own activity also contributes to the variability in high-speed activity in football.[27] The small reductions in high-speed activities presently observed may therefore to some extent reflect a change in the self-imposition of stress by the players themselves when returning from hamstring injury. The relative contribution of such pacing strategies cannot be directly quantified during match-play; to evaluate the player's true maximal performance capability it would be necessary to adopt more closed-loop performance assessment tasks which remove the complexities associated with the match performance construct.[28] It is noted that playing position was retained in the final model as being significantly associated with the running metrics examined. While none of the current data were affected by players changing position during the period of study, future research should consider this factor when examining running performance. We suggest standardized performance assessments may be adopted during rehabilitation to allow for better documentation of any reduction in post-injury high-speed running capacity. Access to such standardized assessment data pre- and post-injury was not available in the current cohort; however, integrating such information together with match performance data likely provides the most comprehensive approach to evaluate the players performance capability on return to sport.

The precision of our effects, based on repeated-measures data,[29] provides a meaningful contribution extending the current knowledge base in this field, yet not without limitations. To better account for match-to-match variability, the current paper had strict inclusion criteria wherein players had to have complete data for a minimum of 10 consecutive games prior and subsequent to the injury. This resulted in a sample size reduction of 88% for the final inclusion of 38 injuries (Figure 1). Accordingly, multiple imputation methods could be relevant in this context.[30] Nevertheless, any multiple imputation approach would be of limited empirical value since results should only be considered as hypothesis generating if more than 40% data are missing for primary variables.[30] While such approaches can be useful for addressing missingness, the fact that such approaches generally introduce extra random noise to the data render their consideration implausible given the nature of the within-subject match-to-match variability observed in this and other samples of soccer players.[31] With this in mind and despite reduction of individual records for analysis given our pre-defined eligibility criteria, sensitivity analyses based on a minimum of more than five consecutive games revealed that our original inference based on complete cases was robust, and not materially affected by reduction in our pool of available data. These points notwithstanding, it is important to note that this research documents the running performance of those who were able to perform 10 consecutive matches as a starting player upon return from hamstring injury and likely represents a "best case" survivorship bias. The running performance of those who did not meet these criteria may have been different and should not be inferred from these data.

Hamstring strain injury has been associated with unaccustomed increases in high-speed running distance.[32,33] It is conceivable that inadequate attention to high-speed running exposure during rehabilitation may contribute to the higher rates of re-injury than those seen for primary injury.[32,33] Future research may examine whether achieving pre-specified high-speed running targets helps reduce re-injury rates. In the present study, we observed substantial variation in the period of layoff experienced due to hamstring injury (IQR, 4–21 days). In future studies using larger cohorts, controlling for layoff period would establish whether or not extended periods of layoff influence on-field performance. Finally, the current data were extracted from a professional male league in the Arabian Gulf, and likely do not reflect other leagues, or the performance of females, or adolescents.

5 | PERSPECTIVE

Players returning to professional football match-play after hamstring strain injury experienced reductions in high-speed and sprint running distance, as well as maximum running speed, that were well within normal match-to-match variation in performance.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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REFERENCES

1. Diemer WM, Winters M, Tol JL, Pas H, Moen MH. Incidence of acute hamstring injuries in soccer: a systematic review of 13 studies involving more than 3800 athletes with 2 million sport exposure hours. *J Orthop Sports Phys Ther*. 2021;51(1):27-36.
2. Stubbe JH, van Beijsterveldt AM, van der Knaap S, et al. Injuries in professional male soccer players in The Netherlands: a prospective cohort study. *J Athl Train*. 2015;50(2):211-216.
3. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med*. 2004;32(1 Suppl):5S-16S.
4. Jacobsen P, Witvrouw E, Muxart P, Tol JL, Whiteley R. A combination of initial and follow-up physiotherapist examination predicts physician-determined time to return to play after hamstring injury, with no added value of MRI. *Br J Sports Med*. 2016;50(7):431-439.
5. Dorn TW, Schache AG, Pandy MG. Muscular strategy shift in human running: dependence of running speed on hip and ankle muscle performance. *J Exp Biol*. 2012;215(Pt 11):1944-1956.
6. Schache AG, Blanch PD, Dorn TW, Brown NA, Rosemond D, Pandy MG. Effect of running speed on lower limb joint kinetics. *Med Sci Sports Exerc*. 2011;43(7):1260-1271.
7. Gregson W, Di Salvo V, Varley MC, et al. Harmful association of sprinting with muscle injury occurrence in professional soccer match-play: a two-season, league wide exploratory investigation from the Qatar stars league. *J Sci Med Sport*. 2020;23(2):134-138.
8. Wangensteen A, Askling C, Hickey J, Purdam C, van der Made AD, Thorborg K. Rehabilitation of hamstring injuries. In: K Thorborg, D Opar, A Shield eds. *Prevention and Rehabilitation of Hamstring Injuries*. 1st ed Springer; 2020:225-270.
9. Dijkstra HP, Pollock N, Chakraverty R, Ardern CL. Return to play in elite sport: a shared decision-making process. *Br J Sports Med*. 2017;51(5):419-420.
10. Whiteley R, Massey A, Gabbett T, et al. Match high-speed running distances are often suppressed after return from hamstring strain injury in professional footballers. *Sports Health*. 2020;13(3):290-295.
11. Hoppen MI, Reurink G, de Boode VA, et al. Return to match running performance after a hamstring injury in elite football: a single-Centre retrospective cohort study. *BMJ Open Sport Exerc Med*. 2022;8(1):e001240.
12. Gregson W, Drust B, Atkinson G, Salvo VD. Match-to-match variability of high-speed activities in premier league soccer. *Int J Sports Med*. 2010;31(4):237-242.
13. Cook JA, Julious SA, Sones W, et al. DELTA(2) guidance on choosing the target difference and undertaking and reporting the sample size calculation for a randomised controlled trial. *BMJ (Clinical Research Ed)*. 2018;363:k3750.
14. Winter EM, Maughan RJ. Requirements for ethics approvals. *J Sports Sci*. 2009;27(10):985.
15. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med*. 2006;40(3):193-201.
16. Bahr R, Clarsen B, Derman W, et al. International Olympic Committee consensus statement: methods for recording and reporting of epidemiological data on injury and illness in sports 2020 (including the STROBE extension for sports injury and illness surveillance [STROBE-SIIS]). *Orthop J Sports Med*. 2020;8(2):2325967120902908.
17. Tabben M, Whiteley R, Wik EH, Bahr R, Chamari K. Methods may matter in injury surveillance: "how" may be more important than "what, when or why". *Biol Sport*. 2020;37(1):3-5.
18. Di Salvo V, Gregson W, Atkinson G, Tordoff P, Drust B. Analysis of high intensity activity in premier league soccer. *Int J Sports Med*. 2009;30(3):205-212.

19. Barnes C, Archer DT, Hogg B, Bush M, Bradley PS. The evolution of physical and technical performance parameters in the English premier league. *Int J Sports Med*. 2014;35(13):1095-1100.
20. Wood SN. *Generalized Additive Models: an Introduction with R*. 2nd ed. CRC Press; 2017.
21. Lenth RV, Buerkner P, Herve M, Love J, Riebl H, Singmann H. Emmeans: estimated marginal means, aka least-squares means. R Package Version 154 In: 2021.
22. Fasiolo M, Nedellec R, Goude Y, Wood SN. Scalable visualization methods for modern generalized additive models. *J Comput Graph Stat*. 2020;29(1):78-86.
23. Wood SN. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *J R Stat Soc Series B Stat Methodology*. 2011;73(1):3-36.
24. Amrhein V, Trafimow D, Greenland S. Inferential statistics as descriptive statistics: there is no replication crisis if we don't expect replication. *Am Stat*. 2019;73(sup1):262-270.
25. Ardern CL, Glasgow P, Schneiders A, et al. 2016 consensus statement on return to sport from the first world congress in sports physical therapy, Bern. *Br J Sports Med*. 2016;50(14):853-864.
26. Di Salvo V, Baron R, Tschan H, Calderon Montero FJ, Bachl N, Pigozzi F. Performance characteristics according to playing position in elite soccer. *Int J Sports Med*. 2007;28(3):222-227.
27. Drust B, Atkinson G, Reilly T. Future perspectives in the evaluation of the physiological demands of soccer. *Sports Med*. 2007;37(9):783-805.
28. Thorpe RT, Atkinson G, Drust B, Gregson W. Monitoring fatigue status in elite team-sport athletes: implications for practice. *Int J Sports Physiol Perform*. 2017;12(Suppl 2):S227-S234.
29. Cook NR, Ware JH. Design and analysis methods for longitudinal research. *Annu Rev Public Health*. 1983;4:1-23.
30. Lee KJ, Tilling KM, Cornish RP, et al. Framework for the treatment and reporting of missing data in observational studies: the treatment and reporting of missing data in observational studies framework. *J Clin Epidemiol*. 2021;134:79-88.
31. Rubin DB. Multiple imputation after 18+ years. *J Am Stat Assoc*. 1996;91(434):473-489.
32. Duhig S, Shield AJ, Opar D, Gabbett TJ, Ferguson C, Williams M. Effect of high-speed running on hamstring strain injury risk. *Br J Sports Med*. 2016;50(24):1536-1540.
33. Ruddy JD, Pollard CW, Timmins RG, Williams MD, Shield AJ, Opar DA. Running exposure is associated with the risk of hamstring strain injury in elite Australian footballers. *Br J Sports Med*. 2018;52(14):919-928.

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