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No association between perceived exertion and session duration with hamstring injury occurrence in professional football

No association between measures of perceived exertion and session duration with hamstring injury occurrence in professional football

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Abstract

Training and competition loads have emerged as modifiable composite risk factors of non-contact injury. Hamstring strains are the most common injuries in football with substantial burden on the individual player and club. Nevertheless, robust evidence of a consistent load-hamstring injury relationship in professional football is lacking. Using available data from the Qatar Stars League over three competitive seasons, this study investigated the separate and combined effects of perceived exertion and session duration on hamstring injury occurrence in a sample of 30 outfield football players. Load variables were calculated into 7-day, 14-day, 21-day, 28-day periods of data, and week-to-week changes for average ratings of perceived exertion (RPE; au) score and session-RPE (s-RPE; session-duration × score), plus the cumulative training and match minutes and s-RPE, respectively. Conditional logistic regression models estimated load-injury relationships per 2-within-subject standard deviation increments in each candidate variable. Associations were declared practically important based on the location of the confidence interval in relation to thresholds of 0.90 and 1.11 defining small beneficial and harmful effects, respectively. The uncertainty for the corrected odds ratios show that typically high within-subject increments in each candidate variable were not practically important for training- and match-related hamstring injury (95% confidence intervals range: 0.85 to 1.16). We found limited exploratory evidence regarding the value of measures of perceived exertion and session duration as aetiological factors of hamstring injury in Middle-East professional football. Monitoring remains valuable to inform player load management strategies, but our exploratory findings suggest its role for type-specific injury risk determination appears empirically unsupported.

Keywords: hamstrings, load, perceived exertion, RPE, muscle injury, risk factors

Introduction

Hamstring injury is the most common type of non-contact muscle injury in elite football, with one injury every 1000 h of play leading to 19 days lost from training and match-play.[1,2] Until 2015, hamstring injury incidence increased annually by 2.3%, with an economic burden of £74.4 million in elite European football.[3-5] Also, the risk of re-injuries is substantial and non-contact injuries can impact team performance negatively.[6]

Although many risk factors for hamstring injury have been investigated [i.e., strength, flexibility, and previous injury],[7,8] no work has evaluated the contribution of training and competition loads on hamstring injury risk. This is somewhat surprising given the increasing load demands[9] and congested fixtures[10] in elite football and a primary purpose of monitoring training loads in elite football is injury reduction.[10] From an applied standpoint, a clear understanding of the association between load and non-contact hamstring injury is an important, yet preliminary, step in the process for developing interventions to optimise performance and maximise player availability.

Previous examinations of the load-injury relationship in elite football players have a number of limitations, including the injury groups used as outcome measures, the load metrics used as exposure measures and the study designs. First, studies have combined a range of different injury types as outcome measure and it is unlikely that the load-injury relationship is the same for different acute injury types (e.g., hamstring strains and ankle sprains) or overuse injuries (e.g., metatarsal stress fractures and patellar tendinopathy). No study has yet examined the relationship between a single injury type and load. Second, studies have calculated acute and chronic external and internal loads represented by prior 7-, 14-, 21-, and 28-day loads, week-to-week changes, and the acute:chronic workload ratio (ACWR), with inconsistent findings.[11-16] Despite inherent limitations of this ratio for applied and medical purposes,[17,18] recent studies in football have examined associations between typically high ACWR values and increased non-contact injury risk.[12,13,16] Furthermore, transforming continuous measures of load into categorical variables (e.g., high, moderate, low) involves a loss of statistical power, increased Type I error rates, and an underestimation of the variation in the outcome of interest.[19] Third, previous research has compared the load pattern of injured players to that of their uninjured teammates.[12-16,20] It seems more appropriate to compare injured players to themselves, i.e., whether the load pattern preceding injury differs from their usual load. Finally, previous investigations used a composite measure of internal load that combines training and competition duration with perceived exertion (session-RPE, s-RPE).[12,13,15,16] While this approach is useful for quantifying weekly and training phase load, a specific breakdown is unclear as the score neglects quantification of intensity and duration in isolation, both of which are important for effective training planning.[21]

We therefore designed the present study to examine the effect of load on acute hamstring injury occurrence, the most important type of injury in professional football, using continuous measures of perceived intensity and session duration and adopting the normal load pattern of injured players as our control comparison.

Methods

Participants

Study participants included outfield professional football players competing in the Qatar Stars League (QSL) over three seasons (May 2015 to February 2018). A complete overview of the injury surveillance database assessment process and the final number of observations included in the study is illustrated in Figure 1. The Anti-Doping Laboratory Institutional Review Board, Qatar (protocol number: E2017000252) granted ethics approval.

Aspetar Injury and Illness Surveillance Programme

Injury information was retrieved as part of the medical services provided to all participating QSL teams by the National Sports Medicine Programme within the Aspetar Orthopaedic and Sports Medicine Hospital. This centralized system with a focal point for the medical care of each club competing in the QSL allowed for standardization of the Aspetar Injury and Illness Surveillance Programme.[22] This programme includes prospective injury registration from all QSL teams. Injury data were collected prospectively, with monthly reporting and regular communication with the responsible team physician/physiotherapist to encourage timely and accurate reporting. As detailed previously,[7,8] a traumatic hamstring injury (i.e., sudden onset injury) was defined as acute pain in the posterior thigh that occurred during training or match play and resulted in immediate termination of all activity and a subsequent inability to participate in the next training session or match. These injuries were confirmed through a clinical examination (identifying pain on palpation, pain with isometric contraction, and pain with muscle lengthening) by the team physician. If indicated, the clinical diagnosis was supported by ultrasonography and magnetic resonance imaging at the study centre. Figure 1 depicts the inclusion methodology during the three study seasons. Only injuries that resulted in more than three days of absence were included in this study, calculated from the date of injury to the date of the player's return to full unrestricted participation in team training and availability for match selection. Recurrent hamstring injuries were excluded from the primary analysis.

Load monitoring

Training and match loads were quantified as session duration (minutes) and RPE. Players rated the global intensity of all sessions and matches using level-anchored semi-ratio CR-10 Borg scale (Borg CR10®).[23] Science and/or medicine staff collected RPE ~30 min after completion of the session/match.

Calculation of load variables

The study sample included only players with a minimum of two-months of complete measurements after the first official match of the season, and players with insufficient in-season data precluding the calculation of the predefined time periods free from the influence of the pre-season data were excluded from the analyses (Figure 1). Where available, given the retrospective nature of the present study, the injury load day value was included in the calculation. If not recorded, the load calculation considered the observation of the day prior to hamstring injury occurrence. In the case of missing values for the load variable with complete outcome data information, the sample-based session-specific median value for either training or match-play was assigned for missing load observations in the available data set (9.6%). Table 1 provides a detailed illustration of an example dataset of one player showing the data structure for performance and injury data required for this study. We calculated the following exposure variables: i) average RPE score, ii) average s-RPE (session duration × score), iii) cumulative exposure in minutes, and iv) cumulative s-RPE calculated over 7-day, 14-day, 21-day, and 28-day periods. In addition to this, week-to-changes for cumulative duration in minutes and s-RPE were derived.[16] These data were, therefore, calculated into the predefined load periods in which the injury (i) occurred and (ii) did not occur (Table 1). As an example, for illustrating how each variable was calculated, Figure 2 shows data for a player's 7-day average s-RPE leading into an injury. Data for each variable were considered only for the season in which an injury occurred.

Statistical analysis

The number of time-loss days for hamstring injury are summarised as median and interquartile range (IQR). Conditional fixed-effects logistic regression analyses estimated the odds of experiencing a hamstring injury based on the comparison of players' injury load data versus control data in which an injury did not occur using the *survival* package. This procedure is different from the conventional logistic regression modelling, whereby the calculation of the conditional likelihood involved the analysis of load data with player identity as a cluster factor in the model to account for the within-subject association between the examined observations.[24] The relationship between each variable with hamstring injury was examined for the first event only. To examine the association between training load and hamstring injury occurrence, odds ratios (OR) were derived for a 2-within-player SD increment in each variable,[25] representing the effect of a typically high versus a typically low value.[26] A within-player SD of the variables was calculated as the square root of the residual mean square.[27] Thresholds of 0.9, 0.7, 0.5, 0.3 and 0.1 and their reciprocals 1.11, 1.43, 2.0, 3.3 and 10 defined small, moderate, large, very large and extremely large beneficial and harmful effects, respectively.[26] Retrospective design analyses assessed Type M error rates for the point estimates and sampling uncertainty of the observed effects.[28] This approach provides an objective quantification of the degree of overestimation of an observed effect estimate relative to the magnitude of the true underlying population effect given the data.[28] Corrected ORs were obtained by dividing the natural logarithm of the estimated OR by the respective magnitude of exaggeration or Type M error relative to a targeted small increase or reduction in the odds of injury of $\ln OR = \pm |0.105360515657826|$. In the absence of an established anchor defining a practically important increase or reduction in the odds of sustaining a hamstring injury, we considered a 10% lower (OR = 0.90) or a 11% higher (OR = 1.11) odds of clinical event as substantially beneficial and substantially harmful effects, respectively.[26] Associations were therefore declared practically important based on the location of the confidence interval for the estimated true ORs to these thresholds.

Since this is the first study to examine the relationship between load and hamstring injury in football, a formal a priori sample size estimation was not possible using existing studies as per the TRIPOD (Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis) statement 22-item checklist.[29] Accordingly, to inform the design of future studies,[30] Cox-Snell pseudo-R^2 (R^2_{CS}) statistics were reported as measures of model overall performance.[31] Outcome statistics are reported as point estimates and 95% confidence intervals (CI). Statistical analyses were performed using R (version 3.5.1, R Foundation for Statistical Computing, Vienna, Austria).

Results

Overall, 30 outfield football players with valid physical load and hamstring injury data were eligible for this study (Figure 1). A total of 145 injuries were excluded from the analysis; 3 were recurrent injuries, 18 due to reporting error and 124 due to insufficient exposure data. The median time-loss days for hamstring injury was 18 (IQR, 13 to 25). Irrespective of different approaches for the calculation of load data over predefined time periods, the corrected odds of hamstring injury in the average RPE score, average s-RPE, cumulative duration in minutes, and cumulative s-RPE for all the physical load periods were not practically important (Table 2).

Discussion

This is the first study examining the relationship of match and training load with acute hamstring injuries in professional football. Using a research design and methodological framework addressing common shortcomings in the current literature, we did not find any practically relevant association between measures of perceived exertion and session duration with hamstring injury occurrence in professional football players.

Load monitoring is critical to inform medical and performance staff strategies.[32] Previous investigations into associations of load with non-contact injury occurrence in football examined the prognostic value of composite measures of external and internal load as potential risk factors yielding unclear and inconsistent findings.[11-16] However, these studies were not without methodological shortcomings, most notably the use of ratio indices, multiple load time bins analysed as categorical variables, and a composite score.[18,19,21] Additionally, the failure of researchers to distinguish the specific nature of an event within the spectrum of acute or overuse injuries represents and additional limitation substantiating the limited practical utility of load-injury studies in the available literature.[11-16] The lack of a clear differentiation between injury types as outcome measures implies that the load-injury relationship is assumed to be same within the spectrum of acute or overuse injuries, which appears implausible on clinical grounds. Therefore, also depending on which external or internal load measure is selected as exposure variable, we maintain that a precise definition of the injury type is fundamental to provide information about the odds or risk of type-specific injury to inform medical and performance staff meaningfully.

From applied and clinical perspectives, the present study advances our understanding of the load-hamstring injury relationship in professional football. The notion of physical load involves an understanding of the interplay between intensity, volume, and frequency to determine training outcome,[23] yet this is underappreciated in the load-injury literature. While technological advances now permit a detailed measurement of player external load,[33] when compared with s-RPE measures, quantification of external load via global positioning system (GPS) fails to represent the actual physiological stress imposed upon players.[33] Despite being widely adopted in this context, s-RPE is not without limitation as a global measure of effort perception. It might underrepresent the stochastic demands of football[23] and obfuscate the separate effects and contribution of intensity and duration on the training process.[21]

Previous examinations of the load-injury relationship in elite football players have reported inconsistent findings regarding the association with loading derived from various time windows .[13,15,16] Irrespective of the use of different time windows and alternative approaches for the calculation of training and competition loads in the present study, we did not find any effect of separate and combined measures of intensity and duration on hamstring injury occurrence were not practically important (Table 2). From a real-world perspective, current match schedule informs the training plan and weekly schedules (i.e., 7-day) are designed to ensure players are match ready.[10,34] In this context, 7-day and 28-day periods would represent logical and practical units to define short- and long-term physical loads.[10] The use of multiple time periods to determine physical loads likely adds a further layer of unnecessary complexity, and it might have contributed to the inconsistency of studies in football.

The methodological flaws in the current field of research[11-16,32] should be considered when interpreting the available data. In particular, the conceptual and statistical flaws of indiscriminate categorisation of continuous variables for prognostic model development are well-established.[19] Recently, the pitfalls of indiscriminate discretization were illustrated in the case of regression modelling strategies involving measures of physical load entered as categorical variables.[19]. With this in mind, using more appropriate conditional modelling strategies[35] given the present study design, we estimated the effects per 2-within-player SD increment in the exposure[25,36] and therefore avoided inappropriate discrete approaches as illustrated in a previous study.[20] Despite the available approaches for modelling training and competition loads,[19,20] estimation of the within-player variance may be a simpler and valid approach to determine reference ranges for player load monitoring and guide interpretations.[27,36] Although variance is generally used to describe measurement error, estimation of the within-player variability might represent a valuable alternative to facilitate the longitudinal tracking of training and competition loads over time both for research and applied purposes. The present study is the first to investigate the load-injury relationship in football using a within-subject analysis. As illustrated in Figure 1, we lost over 80% of the players eligible for this study to follow up and this was due to a lack of accurate data collection, or insufficient data to perform the appropriate analysis. From applied and clinical perspectives, this highlights the challenges in this type of data collection.

Limitations

Given the novelty of our study, a formal a priori sample size estimation informed by the precision of coefficient estimates[37] or relevant model statistics[31] from any existing study could not be performed. Nevertheless, recent advances in the procedures for determining minimum sample size now permit a robust appraisal of the sample size requirements based on pseudo-R^2 statistics.[30] Therefore, we reported the recommended statistics[30] which can be used by researchers and clinicians to inform sample size estimation for future investigations in this field (Table 2). For example, in the case of the model with the 28-day cumulative session duration, assuming a population outcome prevalence of 0.309[7] and using the R^2_{CS} value of 0.074 in the equation indicate a minimum sample size requirement of 329, 583, 1166 players for the development of new models with one, five, and ten load-related candidate predictor parameters, respectively.

In the present study, internal load was quantified using RPE, which represents a global measure of session intensity. While this measure is practical, it fails to capture the whole range of football-related perceptual sensations.[38] Similar to the quantification of the physical performance demands based on relevant measures of external load,[39] the use of differential RPE would represent a valuable alternative here as it provides greater precision in scaling psychophysiological signals during training and match-play and therefore enhances understanding of how different dimensions of exertion contribute to overall physical exertion.[38] From a medical perspective, differential RPE may also be of particular relevance for the study of type-specific soft-tissue injuries aetiology (e.g., peripherally dominated ratings on the Borg scale).[38]

A clear distinction between match and training loads might also be necessary. For example, in-season loads are substantially lower in training than during official match-play[40] and the occurrence of hamstring injuries is higher during match-play than training.[1] Therefore, competition load could determine higher risk for non-contact injuries, so investigating how different physical efforts undertaken during match-play contribute to hamstring strains appears warranted. Finally, the potential homogeneity of the present study cohort, representative of mainly Middle East professional football players, training culture, and specific regional climatic conditions are all factors limiting the generalisability of our study findings to other contexts.

Perspective

We found no preliminary evidence of associations between hamstring injuries and measures of perceived exertion intensity or session duration that may suggest a role in the aetiology of this type of injury. While longitudinal tracking of changes in training and competition loads remains important for informing the player management process, our exploratory study suggests that the use of separate or combined measures of perceived exertion and session duration in examining the load-hamstring injury relationship is not empirically supported. For the first time, given the novelty of our investigation, we also provide distinct R^2_{CS} estimates which are anticipated to serve as a guide to inform sample size calculations in future studies on load and hamstring injury occurrence in professional football.

References

1. 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(12):731-737.
2. Bahr R, Clarsen B, Ekstrand J. Why we should focus on the burden of injuries and illnesses, not just their incidence. *Br J Sports Med.* 2018;52(16):1018-1021.
3. Ekstrand J. Keeping your top players on the pitch: the key to football medicine at a professional level. *Br J Sports Med.* 2013(47):723-724.
4. de Visser HM, Reijman M, Heijboer MP, Bos PK. Risk factors of recurrent hamstring injuries: a systematic review. *Br J Sports Med.* 2012;46(2):124-130.
5. Wangensteen A, Tol JL, Witvrouw E, et al. Hamstring reinjuries occur at the same location and early after return to sport: a descriptive study of MRI-confirmed reinjuries. *Am J Sports Med.* 2016;44(8):2112-2121.
6. Hagglund M, Walden M, Magnusson H, Kristenson K, Bengtsson H, Ekstrand J. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med.* 2013;47(12):738-742.
7. van Dyk N, Bahr R, Whiteley R, et al. Hamstring and quadriceps isokinetic strength deficits are weak risk factors for hamstring strain injuries: a 4-year cohort study. *Am J Sports Med.* 2016;44(7):1789-1795.
8. van Dyk N, Farooq A, Bahr R, Witvrouw E. Hamstring and ankle flexibility deficits are weak risk factors for hamstring Injury in professional soccer players: a prospective cohort study of 438 players including 78 injuries. *Am J Sports Med.* 2018;46(9):2203-2210.
9. 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.
10. Weston M. Training load monitoring in elite English soccer: a comparison of practices and perceptions between coaches and practitioners. *Sci Med Footb.* 2018.
11. Bowen L, Gross AS, Gimpel M, Bruce-Low S, Li FX. Spikes in acute:chronic workload ratio (ACWR) associated with a 5-7 times greater injury rate in English Premier League football players: a comprehensive 3-year study. *Br J Sports Med.* 2019.

12. Delecroix B, McCall A, Dawson B, Berthoin S, Dupont G. Workload and non-contact injury incidence in elite football players competing in European leagues. *Eur J Sport Sci.* 2018;18(9):1280-1287.
13. Fanchini M, Rampinini E, Riggio M, Coutts AJ, Pecci C, McCall A. Despite association, the acute:chronic work load ratio does not predict non-contact injury in elite footballers. *Sci Med Footb.* 2018:108-114.
14. Jaspers A, Kuyvenhoven JP, Staes F, Frencken WGP, Helsen WF, Brink MS. Examination of the external and internal load indicators' association with overuse injuries in professional soccer players. *J Sci Med Sport.* 2018;21(6):579-585.
15. Malone S, Owen A, Newton M, Mendes B, Collins KD, Gabbett TJ. The acute:chonic workload ratio in relation to injury risk in professional soccer. *J Sci Med Sport.* 2016.
16. McCall A, Dupont G, Ekstrand J. Internal workload and non-contact injury: a one-season study of five teams from the UEFA Elite Club Injury Study. *Br J Sports Med.* 2018.
17. Lolli L, Batterham AM, Hawkins R, et al. Mathematical coupling causes spurious correlation within the conventional acute-to-chronic workload ratio calculations. *Br J Sports Med.* 2017.
18. Lolli L, Batterham AM, Hawkins R, et al. The acute-to-chronic workload ratio: an inaccurate scaling index for an unnecessary normalisation process? *Br J Sports Med.* 2018.
19. Carey DL, Crossley KM, Whiteley R, et al. Modelling training loads and injuries: the dangers of discretization. *Med Sci Sports Exerc.* 2018.
20. Windt J, Ardern CL, Gabbett TJ, et al. Getting the most out of intensive longitudinal data: a methodological review of workload-injury studies. *BMJ Open.* 2018;8(10):e022626.
21. Juhari F, Ritchie D, O'Connor F, et al. The quantification of within-week session intensity, duration, and intensity distribution across a season in Australian football using the session rating of perceived exertion method. *Int J Sports Physiol Perform.* 2018;13(7):940-946.
22. Bakken A, Targett S, Bere T, et al. Health conditions detected in a comprehensive periodic health evaluation of 558 professional football players. *Br J Sports Med.* 2016;50(18):1142-1150.
23. McLaren SJ, Macpherson TW, Coutts AJ, Hurst C, Spears IR, Weston M. The relationships between internal and external measures of training load and intensity in team sports: a meta-analysis. *Sports Med.* 2018;48(3):641-658.
24. Connolly MA, Liang KY. Conditional logistic regression models for correlated binary data. *Biometrika.* 1988;75(3):501-506.
25. Gelman A. Scaling regression inputs by dividing by two standard deviations. *Stat Med.* 2008;27(15):2865-2873.
26. Sharma J, Weston M, Batterham AM, Spears IR. Gait retraining and incidence of medial tibial stress syndrome in army recruits. *Med Sci Sports Exerc.* 2014;46(9):1684-1692.
27. Bland JM, Altman DG. Measurement error. *BMJ.* 1996;313(7059):744.
28. Gelman A, Carlin J. Beyond power calculations: assessing type S (sign) and type M (magnitude) errors. *Perspect Psychol Sci.* 2014;9(6):641-651.
29. Moons KG, Altman DG, Reitsma JB, et al. Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis (TRIPOD): explanation and elaboration. *Ann Intern Med.* 2015;162(1):W1-73.

30. Riley RD, Snell KI, Ensor J, et al. Minimum sample size for developing a multivariable prediction model: PART II - binary and time-to-event outcomes. *Stat Med.* 2018.
31. Steyerberg EW, Vickers AJ, Cook NR, et al. Assessing the performance of prediction models: a framework for traditional and novel measures. *Epidemiology.* 2010;21(1):128-138.
32. Bourdon PC, Cardinale M, Murray A, et al. Monitoring athlete training loads: consensus statement. *Int J Sports Physiol Perform.* 2017;12(Suppl 2):S2161-S2170.
33. Weston M. Difficulties in determining the dose-response nature of competitive soccer matches. *J Athl Enhancement.* 2013;2(1).
34. 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.
35. Hu FB, Goldberg J, Hedeker D, Flay BR, Pentz MA. Comparison of population-averaged and subject-specific approaches for analyzing repeated binary outcomes. *Am J Epidemiol.* 1998;147(7):694-703.
36. Carroll RJ. Variances are not always nuisance parameters. *Biometrics.* 2003;59(2):211-220.
37. Borenstein M. Planning for precision in survival studies. *J Clin Epidemiol.* 1994;47(11):1277-1285.
38. Weston M, Siegler J, Bahnert A, McBrien J, Lovell R. The application of differential ratings of perceived exertion to Australian Football League matches. *J Sci Med Sport.* 2015;18(6):704-708.
39. Gregson W, Di Salvo V, Varley M, 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.* 2019.
40. Stevens TGA, de Ruiter CJ, Twisk JWR, Savelsbergh GJP, Beek PJ. Quantification of in-season training load relative to match load in professional Dutch Eredivisie football players. *Sci Med Footb.* 2017;1(2):117-125.

Figure legends

Figure 1. Flow diagram of the hamstring injury eligibility assessment process.

Figure 2. Descriptive characteristics a player's 7-day average s-RPE leading into an injury as an illustrative example of variable calculation. Black dots identify the observed values and the grey-shaded area defines the 95% confidence interval for the conditional-smoothed mean over the player's observational period.

Table legends

Table 1. Structure of a fictive data set from one player illustrated in long format.

Table 2. Estimated effects for the candidate variables from the univariable conditional logistic regression models.