

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

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43 **Abstract**

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

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

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92 Introduction

93 Hamstring injury is the most common type of non-contact muscle injury in elite football, with
94 one injury every 1000 h of play leading to 19 days lost from training and match-play.^{1,2} Until
95 2015, hamstring injury incidence increased annually by 2.3%, with an economic burden of
96 £74.4 million in elite European football.³⁻⁵ Also, the risk of re-injuries is substantial and non-
97 contact injuries can impact team performance negatively.⁶

98 Although many risk factors for hamstring injury have been investigated [i.e., strength,
99 flexibility, and previous injury],^{7,8} no work has evaluated the contribution of training and
100 competition loads on hamstring injury risk. This is somewhat surprising given the increasing
101 load demands⁹ and congested fixtures¹⁰ in elite football and a primary purpose of monitoring
102 training loads in elite football is injury reduction.¹⁰ From an applied standpoint, a clear
103 understanding of the association between load and non-contact hamstring injury is an
104 important, yet preliminary, step in the process for developing interventions to optimise
105 performance and maximise player availability.

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

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

132 Methods

133 Participants

134 Study participants included outfield professional football players competing in the Qatar Stars
135 League (QSL) over three seasons (May 2015 to February 2018). A complete overview of the

136 injury surveillance database assessment process and the final number of observations included
137 in the study is illustrated in Figure 1. The Anti-Doping Laboratory Institutional Review Board,
138 Qatar (protocol number: E2017000252) granted ethics approval.

139 **Aspetar Injury and Illness Surveillance Programme**

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

159 **Load monitoring**

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

164 **Calculation of load variables**

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

181 for illustrating how each variable was calculated, Figure 2 shows data for a player's 7-day
182 average s-RPE leading into an injury. Data for each variable were considered only for the
183 season in which an injury occurred.

184 **Statistical analysis**

185 The number of time-loss days for hamstring injury are summarised as median and interquartile
186 range (IQR). Conditional fixed-effects logistic regression analyses estimated the odds of
187 experiencing a hamstring injury based on the comparison of players' injury load data versus
188 control data in which an injury did not occur using the *survival* package. This procedure is
189 different from the conventional logistic regression modelling, whereby the calculation of the
190 conditional likelihood involved the analysis of load data with player identity as a cluster factor
191 in the model to account for the within-subject association between the examined
192 observations.²⁴ The relationship between each variable with hamstring injury was examined
193 for the first event only. To examine the association between training load and hamstring injury
194 occurrence, odds ratios (OR) were derived for a 2-within-player SD increment in each
195 variable,²⁵ representing the effect of a typically high versus a typically low value.²⁶ A within-
196 player SD of the variables was calculated as the square root of the residual mean square.²⁷
197 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
198 small, moderate, large, very large and extremely large beneficial and harmful effects,
199 respectively.²⁶ Retrospective design analyses assessed Type M error rates for the point
200 estimates and sampling uncertainty of the observed effects.²⁸ This approach provides an
201 objective quantification of the degree of overestimation of an observed effect estimate relative
202 to the magnitude of the true underlying population effect given the data.²⁸ Corrected ORs were
203 obtained by dividing the natural logarithm of the estimated OR by the respective magnitude of
204 exaggeration or Type M error relative to a targeted small increase or reduction in the odds of
205 injury of $\ln\text{OR} = \pm |0.105360515657826|$. In the absence of an established anchor defining a
206 practically important increase or reduction in the odds of sustaining a hamstring injury, we
207 considered a 10% lower (OR = 0.90) or a 11% higher (OR = 1.11) odds of clinical event as
208 substantially beneficial and substantially harmful effects, respectively.²⁶ Associations were
209 therefore declared practically important based on the location of the confidence interval for the
210 estimated true ORs to these thresholds.

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

219 **Results**

220 Overall, 30 outfield football players with valid physical load and hamstring injury data were
221 eligible for this study (Figure 1). A total of 145 injuries were excluded from the analysis; 3
222 were recurrent injuries, 18 due to reporting error and 124 due to insufficient exposure data. The
223 median time-loss days for hamstring injury was 18 (IQR, 13 to 25). Irrespective of different
224 approaches for the calculation of load data over predefined time periods, the corrected odds of
225 hamstring injury in the average RPE score, average s-RPE, cumulative duration in minutes,

226 and cumulative s-RPE for all the physical load periods were not practically important (Table
227 2).

228 **Discussion**

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

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

249 From applied and clinical perspectives, the present study advances our understanding of the
250 load-hamstring injury relationship in professional football. The notion of physical load
251 involves an understanding of the interplay between intensity, volume, and frequency to
252 determine training outcome,²³ yet this is underappreciated in the load-injury literature. While
253 technological advances now permit a detailed measurement of player external load,³³ when
254 compared with s-RPE measures, quantification of external load via global positioning system
255 (GPS) fails to represent the actual physiological stress imposed upon players.³³ Despite being
256 widely adopted in this context, s-RPE is not without limitation as a global measure of effort
257 perception. It might underrepresent the stochastic demands of football²³ and obfuscate the
258 separate effects and contribution of intensity and duration on the training process.²¹

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

270 The methodological flaws in the current field of research^{11-16,32} should be considered when
271 interpreting the available data. In particular, the conceptual and statistical flaws of
272 indiscriminate categorisation of continuous variables for prognostic model development are
273 well-established.¹⁹ Recently, the pitfalls of indiscriminate discretization were illustrated in the
274 case of regression modelling strategies involving measures of physical load entered as
275 categorical variables.¹⁹ With this in mind, using more appropriate conditional modelling
276 strategies³⁵ given the present study design, we estimated the effects per 2-within-player SD
277 increment in the exposure^{25,36} and therefore avoided inappropriate discrete approaches as
278 illustrated in a previous study.²⁰ Despite the available approaches for modelling training and
279 competition loads,^{19,20} estimation of the within-player variance may be a simpler and valid
280 approach to determine reference ranges for player load monitoring and guide
281 interpretations.^{27,36} Although variance is generally used to describe measurement error,
282 estimation of the within-player variability might represent a valuable alternative to facilitate
283 the longitudinal tracking of training and competition loads over time both for research and
284 applied purposes. The present study is the first to investigate the load-injury relationship in
285 football using a within-subject analysis. As illustrated in Figure 1, we lost over 80% of the
286 players eligible for this study to follow up and this was due to a lack of accurate data collection,
287 or insufficient data to perform the appropriate analysis. From applied and clinical perspectives,
288 this highlights the challenges in this type of data collection.

289 **Limitations**

290 Given the novelty of our study, a formal a priori sample size estimation informed by the
291 precision of coefficient estimates³⁷ or relevant model statistics³¹ from any existing study could
292 not be performed. Nevertheless, recent advances in the procedures for determining minimum
293 sample size now permit a robust appraisal of the sample size requirements based on pseudo-R²
294 statistics.³⁰ Therefore, we reported the recommended statistics³⁰ which can be used by
295 researchers and clinicians to inform sample size estimation for future investigations in this field
296 (Table 2). For example, in the case of the model with the 28-day cumulative session duration,
297 assuming a population outcome prevalence of 0.309⁷ and using the R²_{CS} value of 0.074 in the
298 equation indicate a minimum sample size requirement of 329, 583, 1166 players for the
299 development of new models with one, five, and ten load-related candidate predictor
300 parameters, respectively.

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

311 A clear distinction between match and training loads might also be necessary. For example, in-
312 season loads are substantially lower in training than during official match-play⁴⁰ and the
313 occurrence of hamstring injuries is higher during match-play than training.¹ Therefore,
314 competition load could determine higher risk for non-contact injuries, so investigating how
315 different physical efforts undertaken during match-play contribute to hamstring strains appears
316 warranted. Finally, the potential homogeneity of the present study cohort, representative of

317 mainly Middle East professional football players, training culture, and specific regional
318 climatic conditions are all factors limiting the generalisability of our study findings to other
319 contexts.

320 **Perspective**

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

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461 **Figure legends**

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

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

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471 **Table legends**

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

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

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

Session	Injury	RPE	Minutes	s-RPE	7-day average RPE	7-day cumulative minutes	7-day average s-RPE	7-day cumulative s-RPE
1	0	5	90	450	5	295	385	1540
2	0	3	80	240	5	310	380	1520
3	0	7	90	630	6	350	488	1950
4	0	3	85	255	5	345	394	1575
5	0	3	40	120	4	385	339	1695
6	0	7	97	679	5	482	396	2374
7	0	2	45	90	4	527	352	2464
8	0	2	60	120	4	497	305	2134
9	0	4	75	300	4	492	313	2194
10	1	4	30	120	4	432	241	1684

RPE, ratings of perceived exertion; s-RPE, session-RPE (session-duration × score).

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

Variable	Odds ratio (95% confidence interval)	Type M error	Cox-Snell R ²
Average RPE score (au)			
7-day (2-SD = 1.5)	1.07 (0.98 to 1.16)	8.62	0.071
14-day (2-SD = 1.1)	1.05 (0.96 to 1.14)	8.17	0.031
21-day (2-SD = 0.9)	0.98 (0.90 to 1.07)	8.90	0.004
28-day (2-SD = 0.8)	0.99 (0.91 to 1.08)	9.14	0.001
Cumulative duration (min)			
7-day (2-SD = 188)	1.01 (0.92 to 1.10)	8.18	0.001
14-day (2-SD = 333)	1.03 (0.94 to 1.12)	8.89	0.013
21-day (2-SD = 446)	1.04 (0.95 to 1.13)	9.36	0.022
28-day (2-SD = 566)	1.07 (0.98 to 1.16)	10.77	0.074
Week-to-week change (2-SD = 210)	0.99 (0.90 to 1.08)	8.23	0.004
Average s-RPE (au)			
7-day (2-SD = 149)	0.99 (0.90 to 1.08)	8.56	0.003
14-day (2-SD = 116)	1.02 (0.93 to 1.11)	8.15	0.004
21-day (2-SD = 93)	0.95 (0.87 to 1.03)	9.08	0.048
28-day (2-SD = 82)	0.95 (0.87 to 1.04)	9.36	0.042
Cumulative s-RPE (au)			
7-day (2-SD = 961)	1.01 (0.93 to 1.11)	8.30	0.004
14-day (2-SD = 1586)	1.04 (0.95 to 1.14)	8.89	0.028
21-day (2-SD = 2035)	1.03 (0.95 to 1.13)	9.14	0.017
28-day (2-SD = 2488)	1.06 (0.97 to 1.15)	10.09	0.054
Week-to-week change (2-SD = 1123)	0.98 (0.90 to 1.07)	8.35	0.007

*corrected point estimates for the odds ratios and sampling uncertainty were derived performing retrospective design calculations (Gelman and Carlin, 2014). Type M error indicates the factor by which the magnitude of the original effect differed from the true population effect to detect a small association of $\ln\text{OR} = \pm |0.105360515657826|$.

Hamstring injuries screened for eligibility
(n=175)

Records excluded with reasons (n=145):

- Recurrent injuries (n=3)
- Injury reporting error (n=18)
- Insufficient exposure data precluding time bins calculations for training load (n=124)

Events included in the analysis
(n=30)

