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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

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1 **Harmful association of sprinting with muscle injury occurrence in professional soccer**
2 **match-play: a two-season, league wide exploratory investigation from the Qatar Stars**
3 **League**

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33

34 **Abstract**

35 **Objective:** To investigate the impact of physical efforts performed in the period preceding
36 activity as a potential risk factor of muscle injury during match-play within a sample of
37 professional soccer players.

38 **Design:** Observational cohort study.

39 **Methods:** Match load (running [>14.4 - 19.8 km/h], high-speed running [>19.8 km/h to 25.2
40 km/h], sprinting [> 25.2 km/], leading and explosive sprint type) averaged in 1-minute and 5-
41 minute periods prior to an event or non event for 29 professional outfield soccer players.
42 Conditional logistic and Poisson regression models estimated the risk of injury for a 2 within-
43 subject standard deviation in match load or 1-action increment in the number of sprinting
44 activities, respectively. Associations were deemed beneficial or harmful based on non-overlap
45 of the 95% confidence intervals against thresholds of 0.90 and 1.11, respectively.

46 **Results:** An increment in sprinting distance [$+ 2$ -SDs = 11 meters] covered over a 1-minute
47 period (odds ratio [OR]: 1.22, 95%CI, 1.12 to 1.33) increased the odds of muscle injury.

48 **Conclusions:** Our study provides novel exploratory evidence that the volume of sprinting
49 during competitive soccer match-play has a harmful association with muscle injury occurrence.

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67 Introduction

68 In elite soccer, lower injury incidence and higher match availability is positively associated
69 with points gained per league match.¹ Strategies focused on enhancing playing availability are
70 therefore fundamental to the work of players' support teams; routine modifications in training
71 load help prepare players for the demands of competition as well as for reducing susceptibility
72 to non-functional over-reaching, injury, and illness.² Increasingly, attention has focused on the
73 influence of training load as a modifiable injury risk factor. Players can be at increased injury
74 risk when exposed to high (i.e. "spikes") absolute (1-3 week) training loads, large week-to-
75 week changes in load,² and greater training times spent above 85% of maximal heart rate.³
76 Paradoxically, players are better able to tolerate higher loads and high-intensity activities with
77 reduced injury risk following exposure to appropriate chronic (e.g. 3-4 week) training loads
78 prior to performing these high-intensity activities.⁴ Thus, completion of high-intensity activity
79 as part of correctly prescribed training load, culminating in enhanced aerobic fitness may serve
80 to reduce the injury risk associated with high-intensity activity.⁴

81 While useful for understanding associations between training load and injury risk, the
82 aforementioned studies did not isolate match loads which represent the highest load
83 experienced by players during the microcycle. Predictably, overall injury incidence is greater
84 in matches (27.5 injuries per 1000 h) than in training (4.1 injuries per 1000 h),⁵ with muscle
85 injury incidence also greater during matches than training and influenced by fixture
86 congestion.⁶ Of further relevance to help our understanding of soccer match injuries and in turn
87 the support provided to players, is that precise descriptions of the inciting event are needed to
88 help understand injury cause.⁷ In the context of soccer match-play, increases in critical
89 incidents and injury risk observed during the early and latter stages of match-play were
90 postulated to reflect both the higher exercise intensities when players are fresh and lower
91 intensities when players experience fatigue, although player activity was not recorded.⁸ In other
92 studies, movement intensities were recorded subjectively but no comprehensive data were
93 provided on running characteristics (e.g., speed) preceding injury.^{9, 10} Using match data
94 recorded via a computerised motion-analysis system, high-speed running and recovery
95 between high-speed bouts was generally higher and lower in the 5-minute period immediately
96 preceding injury, respectively.¹¹ However, this investigation did not examine the association
97 between physical match load and injury occurrence. Therefore, further research on the role of
98 prior activity on match injury occurrence is needed.¹¹ Using motion analysis data derived from
99 an entire professional soccer league and adopting a novel design analysis approach to provide
100 realistic associations,¹² we aimed to examine the influence of players' physical efforts during
101 1-minute and 5-minute periods immediately preceding a muscle injury sustained during match-
102 play.

103 Methods

104 Study participants were 29 outfield professional soccer players competing in the Qatar Stars
105 League (2013-2014 and 2014-2015). Muscle injuries sustained during 276 competitive
106 matches were diagnosed and documented by the team's physician. Performance data were
107 collected as a condition of employment in which player performance is routinely measured
108 during match-play.¹³ The Aspire Zone Research Committee and the Anti-Doping Laboratory
109 Institutional Review Board, Qatar (protocol number: E2017000252) granted ethics approval.

110 The methodologies and definitions of injury used in the present study closely follow those of
111 a previous consensus statement.¹⁴ Information including the type, location, and diagnosis of
112 injury, alongside the occasion (training/match) and minute of the injury were recorded by the

113 team physician on a injury card. Descriptive information on the final action at the time the
114 injury was sustained and whether contact had occurred between players was recorded. Each
115 match injury incident was cross-referenced to determine whether the match had been recorded
116 and analysed by the multiple-camera player tracking system (Prozone®, Leeds, England) used
117 by the clubs to evaluate physical performance in competition as described previously.¹⁵ This
118 system has previously been shown to be a valid and reliable system for measuring match
119 activity in soccer.¹⁵ Where information from the system was available, physical performance
120 data were used to measure the players' efforts over 1-minute and 5-minute periods leading up
121 to the injury.

122 To investigate the effects of physical efforts prior to injury, distances covered in the following
123 activity categories were measured over the 1-minute and 5-minute period preceding the time
124 of injury: walking (<7.2 km/h), jogging (>7.2-14.4 km/h), running (>14.4-19.8 km/h), high-
125 speed running distance (>19.8 km/h to 25.2 km/h), and sprinting distance (> 25.2 km/h).¹⁵
126 Further analysis of sprint activity (> 25.2 km/h) included the total number of leading and
127 explosive sprints undertaken. An explosive sprint (i.e., rapid acceleration), was defined as the
128 attainment of sprint speed from either walking, jogging or running with time spent in the high-
129 speed running category less than 0.5 seconds.¹⁶ A leading sprint (i.e., gradual acceleration),
130 was defined as the attainment of sprint speed from either walking, jogging or running with time
131 spent in the high-speed running category for a minimum of 0.5 seconds.¹⁶ To determine
132 whether performance over these 1-minute and 5-minute periods influenced muscle injury
133 occurrence, data across the completed matches were used in an attempt to establish a normative
134 physical performance profile for each player.¹¹ For this profile, the total high-intensity distance
135 (>14.4 km/h) covered was calculated for entire games. For example, to calculate the distance
136 covered over a 5-minute period, the total high-intensity distance covered was divided by the
137 match duration expressed in minutes and then multiplied by 5. This figure was considered to
138 be the player's habitual match-play high-intensity activity level over a 5-minute period. The
139 physical performance data used for the normative profile were based on information during the
140 same season in which injury occurred. The normative profile was subsequently compared to
141 physical efforts over the 5-minute period prior to injury. The characteristics of physical efforts
142 undertaken during the final 5-seconds preceding each injury occurrence were also investigated.
143 Where the exact time of injury was not discernible from video observation, the injury was not
144 included in the analysis (N=4).

145 Distances were averaged into 1-minute and 5-minute periods for the three primary exposures
146 (running distance, high-speed running distance and sprint distance). These data were stratified
147 into (i) the 1-minute and 5-minute time periods immediately preceding an in-match muscle
148 injury, (ii) the 1-minute and 5-minute periods for the same players as in (i) but for all other
149 within-match time periods (those periods that did not immediately precede the injury), and (iii)
150 normative data of 1-minute and 5-minute data bins where an injury did not occur.

151 Conditional fixed-effects logistic regression analyses estimated the odds of muscle injury
152 occurrence (0, no; 1, yes) based on the comparison of players' pre-injury match load data versus
153 normative data in which an injury did not occur using the *survival* package. This procedure is
154 conceptually different from the conventional logistic regression modelling, whereby the
155 calculation of the conditional likelihood involved the analysis of load data with player identity
156 as a cluster factor in the model to account for the within-subject association between the
157 examined observations.¹⁷ The association between distances covered at running, high-speed
158 running, or sprint intensities with injury occurrence was examined for the first event only. Odds
159 ratios (OR) to determine the association between physical match load and muscle injury

160 occurrence were derived for a 2-within-player SD increment in each primary exposure variable,
161 representing the effect of a typically high versus a typically low value of the exposure.¹⁸ A
162 within-player SD of the exposure was calculated as the square root of the residual mean
163 square.¹⁹ Separate conditional Poisson regression models estimated rate ratios (RR) describing
164 the association of a 1-action increment in leading and explosive sprint activities, entered as
165 primary exposure variables in the model, and muscle injury occurrence.²⁰ In the absence of an
166 established anchor to inform on the smallest meaningful association between physical match
167 load and muscle injury, thresholds of 0.90 and 1.11 represented beneficial and harmful
168 associations, respectively.¹⁸ Retrospective design analyses assessed Type M error rates and,
169 corrected the point estimates and respective sampling uncertainty for the observed effects.²¹
170 This approach provides an objective quantification of the Type M error indicating the degree
171 of overestimation of an observed effect estimate relative to the magnitude of the true underlying
172 population effect given the data.²¹ Corrected ORs were obtained by dividing the logarithm of
173 the estimated OR by the respective magnitude of exaggeration or Type M error relative to a
174 targeted increase or reduction in the odds of muscle injury of $\ln OR = \pm |0.105360515657826|$.
175 Associations were deemed beneficial or harmful based on non-overlap of the respective 95%
176 confidence intervals for the estimated ratio statistic with the aforementioned thresholds (i.e.,
177 0.90 and 1.11). Overlap of the confidence interval with these thresholds represented a trivial
178 association. Outcome statistics are reported as point estimates and 95% confidence intervals
179 (CI). Statistical analyses were performed using R (version 3.6.1, R Foundation for Statistical
180 Computing, Vienna, Austria).

181 **Results**

182 A complete overview of the number and type of muscle injuries examined in the study is
183 illustrated in Figure 1. Twenty injuries occurred in the second half of which eight events during
184 the final 15 minutes.

185 Analysis of the 1-minute data periods revealed a harmful association only between sprinting
186 distance and muscle injury (Figure 2a). Type M error rates for the observed point estimates for
187 running (7.20), high-speed running (6.29), and sprinting distances (3.65) indicated the original
188 injury odds to be overestimated by approximately 4-to-7 times. Conditional Poisson regression
189 analyses revealed a trivial association between a 1-action increment in the number of leading
190 (RR = 1.16; 95%CI, 1.06 to 1.26) and explosive (RR = 1.09; 95%CI, 1.00 to 1.19) sprints
191 undertaken by a player 1-minute prior to the event.

192 For the analysis of the 5-minute data periods, running, high-speed running, and sprinting
193 distance were all trivially associated with muscle injury occurrence (Figure 2b). The
194 corresponding Type M error rates were 8.57, 8.87, and 7.10 suggesting the original injury
195 effects to be exaggerated by approximately 7-to-8 times. A 1-action increment in the number
196 of leading (RR = 1.01; 95%CI, 0.92 to 1.10) or explosive (RR = 0.99; 95%CI, 0.91 to 1.08)
197 sprints undertaken by a player 5-minute prior to an injury resulted in trivial associations.
198 Additional sensitivity analyses comparing the 1-minute or 5-minute periods immediately
199 preceding an in-match muscle injury with the 1-minute and 5-minute periods within the same
200 match time periods or the available normative data in which an injury did not occur revealed
201 our results to be unaffected.

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203

204 **Discussion**

205 Competition load is deemed a critical element contributing to greater muscle injury risk,² yet
206 our understanding of the activity preceding injury during professional soccer match-play is not
207 well understood. Therefore, we investigated the influence of player match physical activity
208 during time periods immediately prior to muscle injury. Of the match load variables commonly
209 investigated, we found only match sprinting to be harmfully associated with muscle injury
210 occurrence in professional soccer players.

211 Match injuries have previously been reported to be preceded by players moving at relatively
212 moderate speeds during the prior 5-minute period.¹¹ In the present study though, the
213 associations between a 2 within-subject SD increment in sprinting, high-speed running or
214 running distances and muscle injury were all trivial. However, when using the 1-minute period
215 prior to injury, a typically high increment sprinting distance had a harmful association. As short
216 sprints (≤ 10 m) represent the dominant type of sprint activity during elite soccer match-play,¹⁵
217 the risk associated with the increment in pre-injury 1-minute sprinting distance is likely
218 equivalent to 1-2 sprints. Taken together, while the use of 5-minute periods is a widely adopted
219 match analysis criterion,²² our findings highlight the importance of quantifying and examining
220 physical match loads in shorter time periods.

221 In the context of load-injury research, our study provides novel applied and methodological
222 insights. First, the present investigation advances current knowledge regarding pre-injury
223 running activities. An early study examining players' exposure to injury risk reported
224 contesting possession as a determining factor for experiencing injury,⁸ yet subsequent work
225 showed most injuries occurred during breakdown attacks and tackling duels.¹⁰ However, no
226 exact detail about pre-injury running activities was provided.¹⁰ More recently, Carling et al.,¹¹
227 reported that eight of ten final running actions immediately preceding injury involved a high-
228 intensity running effort. In the present study the same analysis was not possible due to the
229 nature of the data available. Therefore, it remains to be determined whether the activity
230 immediately prior or the cumulative (i.e., 1-minute) activity serves as the likely risk factor in
231 these instances. Second, the design analyses revealed studies in this field were conducted with
232 inadequate sample sizes and incorrect statistical analyses. Furthermore, when using advances
233 in methodological procedures established on pseudo-R² statistics²³ and informed by existing
234 studies⁶ a minimum sample size of 369 players would be needed in our 1-minute sprinting
235 distance model (Cox-Snell pseudo-R² = 0.362). Taken together, in this field of research, the
236 use of design analysis demonstrated how associations from small-scale studies are anticipated
237 to be exaggerated in future similar investigations of equal size leading to erroneous and
238 misleading conclusions.^{12, 24}

239 Published investigations on load and injury have also failed to demonstrate how any estimated
240 association could inform the player management and training process meaningfully in applied
241 terms.²⁵ In practice, the presence of any association indicating the higher the load, the higher
242 the in-match injury risk would suggest coaches and practitioners pay particular attention to
243 prepare players adequately to cope with the demands characterising soccer match-play. In
244 general, physical demands are assumed to be greater in competition than during training.²
245 Accordingly, repeated-sprint training has the potential to elicit clear beneficial effect for the
246 development of speed, explosive leg power, and high-intensity running performance.²⁶
247 Therefore, adoption of training strategies impacting on physical determinants of soccer
248 performance, with a particular reference to a player's ability to repeat and tolerate very high-
249 intensity efforts during match-play, would appear relevant to the context of our study.²⁶

250 Our study is not without its limitations. Given the underlying nature of our research question,
251 our study analyses might not have accounted for potentially relevant unmeasured intrinsic and
252 extrinsic factors of injury risk. Specifically, with a larger sample size, inclusion of other
253 independent predictors could have potentially mitigated the extent of the main effects of the
254 selected primary exposures in a multivariable-adjusted model. For example, even though
255 players' in-match load distances for non-event outcome were treated as control data in our
256 investigation, a lack of information about training load over the examined period might
257 represent a limitation. Likewise, as observed in other team-sport contexts, cumulative match
258 involvement could have been deemed an additional variable relevant to our study.²⁷ The
259 analysis of in-match loads expressed in terms of distances covered in predefined speed zones
260 may also represent another limitation of our study. In practical terms, the use of arbitrary speed
261 thresholds likely fails to provide coaches and sports scientists with an accurate quantification
262 of the relative physical demands during a soccer match.²⁸ As our data were collected across an
263 entire professional league, individualisation of speeds zones was not, however, logistically
264 possible. Also, information regarding prior clinical history to the selected observational period
265 for players involved in this study were not available. Finally, it is necessary to point out that
266 ratio outcome statistics substantiating information about odds or hazards of event provide
267 clinicians and practitioners with estimates regarding the average effect describing the
268 probability of clinical outcome, but this may not necessarily translate to meaningful impact in
269 the real-world. We, therefore, maintain that caution is necessary to generalise our findings to
270 other populations of professional soccer players or to consider the estimated odds of injury as
271 real effects since our results provided small-scale empirical evidence which ultimately rendered
272 the present investigation exploratory in nature.

273 **Conclusions**

274 Our study provides novel evidence that the volume of sprinting during competitive soccer
275 match-play has a harmful association with muscle injury occurrence. Therefore, we
276 recommend careful attention be paid to preparing players to sustain and repeat sprint type
277 activity during match-play. Collectively, our findings provide an important contribution that
278 may be valuable to inform decisions of coaches and practitioners relating to the optimal player
279 management throughout a season.

280

281 **Practical implications**

- 282 • The volume of match sprinting activity is a risk factor of muscle injury occurrence in
283 elite soccer players.
- 284 • There is greater sensitivity in quantifying the relationship between physical
285 performance and assessing injury risk using shorter (e.g., 1-minute) time periods than
286 those traditionally used (e.g., 5-minute).
- 287 • Our exploratory findings place emphasis on the physical preparation of players to
288 withstand high isolated and repeated sprint activities during competitive match-play.

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- 294 1. Hagglund M, Walden M, Magnusson H, Kristenson K, Bengtsson H, Ekstrand J.
295 Injuries affect team performance negatively in professional football: an 11-year
296 follow-up of the UEFA Champions League injury study. *Br. J. Sports Med.* 2013;
297 47(12):738-742.
- 298 2. Windt J, Gabbett TJ. How do training and competition workloads relate to injury?
299 The workload-injury aetiology model. *Br. J. Sports Med.* 2017; 51(5):428-435.
- 300 3. Owen AL, Forsyth JJ, Wong del P, Dellal A, Connelly SP, Chamari K. Heart rate-
301 based training intensity and its impact on injury incidence among elite-level
302 professional soccer players. *J. Strength Cond. Res.* 2015; 29(6):1705-1712.
- 303 4. Gabbett TJ, Hulin BT, Blanch P, Whiteley R. High training workloads alone do not
304 cause sports injuries: how you get there is the real issue. *Br. J. Sports Med.* 2016;
305 50(8):444-445.
- 306 5. Ekstrand J, Hagglund M, Walden M. Injury incidence and injury patterns in
307 professional football: the UEFA injury study. *Br. J. Sports Med.* 2011; 45(7):553-558.
- 308 6. Bengtsson H, Ekstrand J, Walden M, Hagglund M. Muscle injury rate in professional
309 football is higher in matches played within 5 days since the previous match: a 14-year
310 prospective study with more than 130 000 match observations. *Br. J. Sports Med.*
311 2018; 52(17):1116-1122.
- 312 7. Bahr R, Krosshaug T. Understanding injury mechanisms: a key component of
313 preventing injuries in sport. *Br. J. Sports Med.* 2005; 39(6):324-329.
- 314 8. Rahnama N, Reilly T, Lees A. Injury risk associated with playing actions during
315 competitive soccer. *Br. J. Sports Med.* 2002; 36(5):354-359.
- 316 9. Andersen TE, Larsen O, Tenga A, Engebretsen L, Bahr R. Football incident analysis:
317 a new video based method to describe injury mechanisms in professional football. *Br.*
318 *J. Sports Med.* 2003; 37(3):226-232.
- 319 10. Arnason A, Tenga A, Engebretsen L, Bahr R. A prospective video-based analysis of
320 injury situations in elite male football: football incident analysis. *Am. J. Sports Med.*
321 2004; 32(6):1459-1465.
- 322 11. Carling C, Gall FL, Reilly TP. Effects of physical efforts on injury in elite soccer. *Int.*
323 *J. Sports Med.* 2010; 31(3):180-185.
- 324 12. Lord EM, Weir IR, Trinquart L. Design analysis indicates Potential overestimation of
325 treatment effects in randomized controlled trials supporting Food and Drug
326 Administration cancer drug approvals. *J Clin Epidemiol.* 2018; 103:1-9.
- 327 13. Winter EM, Maughan RJ. Requirements for ethics approvals. *J Sports Sci.* 2009;
328 27(10):985.
- 329 14. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and
330 data collection procedures in studies of football (soccer) injuries. *Clin. J. Sport Med.*
331 2006; 16(2):97-106.
- 332 15. Di Salvo V, Gregson W, Atkinson G, Tordoff P, Drust B. Analysis of high intensity
333 activity in Premier League soccer. *Int. J. Sports Med.* 2009; 30(3):205-212.
- 334 16. Di Salvo V, Baron R, Gonzalez-Haro C, Gormasz C, Pigozzi F, Bachl N. Sprinting
335 analysis of elite soccer players during European Champions League and UEFA Cup
336 matches. *J Sports Sci.* 2010; 28(14):1489-1494.
- 337 17. Connolly MA, Liang KY. Conditional logistic regression models for correlated binary
338 data. *Biometrika.* 1988; 75(3):501-506.
- 339 18. Sharma J, Weston M, Batterham AM, Spears IR. Gait retraining and incidence of
340 medial tibial stress syndrome in army recruits. *Med. Sci. Sports Exerc.* 2014;
341 46(9):1684-1692.

- 342 19. Bland JM, Altman DG. Measurement error. *BMJ*. 1996; 313(7059):744.
- 343 20. Armstrong BG, Gasparrini A, Tobias A. Conditional Poisson models: a flexible
344 alternative to conditional logistic case cross-over analysis. *BMC Med. Res. Methodol.*
345 2014; 14:122.
- 346 21. Gelman A, Carlin J. Beyond power calculations: assessing type S (sign) and type M
347 (magnitude) errors. *Perspect. Psychol. Sci.* 2014; 9(6):641-651.
- 348 22. Mohr M, Krstrup P, Bangsbo J. Match performance of high-standard soccer players
349 with special reference to development of fatigue. *J Sports Sci.* 2003; 21(7):519-528.
- 350 23. Riley RD, Snell KI, Ensor J, et al. Minimum sample size for developing a
351 multivariable prediction model: PART II - binary and time-to-event outcomes. *Stat*
352 *Med.* 2019; 38(7):1276-1296.
- 353 24. Gelman A, Skardhamar T, Aaltonen M. Type M error might explain Weisburd's
354 paradox. *J Quant Criminol.* 2017.
- 355 25. Bourdon PC, Cardinale M, Murray A, et al. Monitoring athlete training loads:
356 consensus statement. *Int. J. Sports Physiol. Perform.* 2017; 12(Suppl 2):S2161-S2170.
- 357 26. Taylor J, Macpherson T, Spears I, Weston M. The effects of repeated-sprint training
358 on field-based fitness measures: a meta-analysis of controlled and non-controlled
359 trials. *Sports Med.* 2015; 45(6):881-891.
- 360 27. Williams S, Trewartha G, Kemp SPT, et al. How much rugby is too much? a seven-
361 season prospective cohort study of match exposure and injury risk in professional
362 rugby union players. *Sports Med.* 2017; 47(11):2395-2402.
- 363 28. Weston M. Difficulties in determining the dose-response nature of competitive soccer
364 matches. *J Athl Enhancement.* 2013; 2(1).

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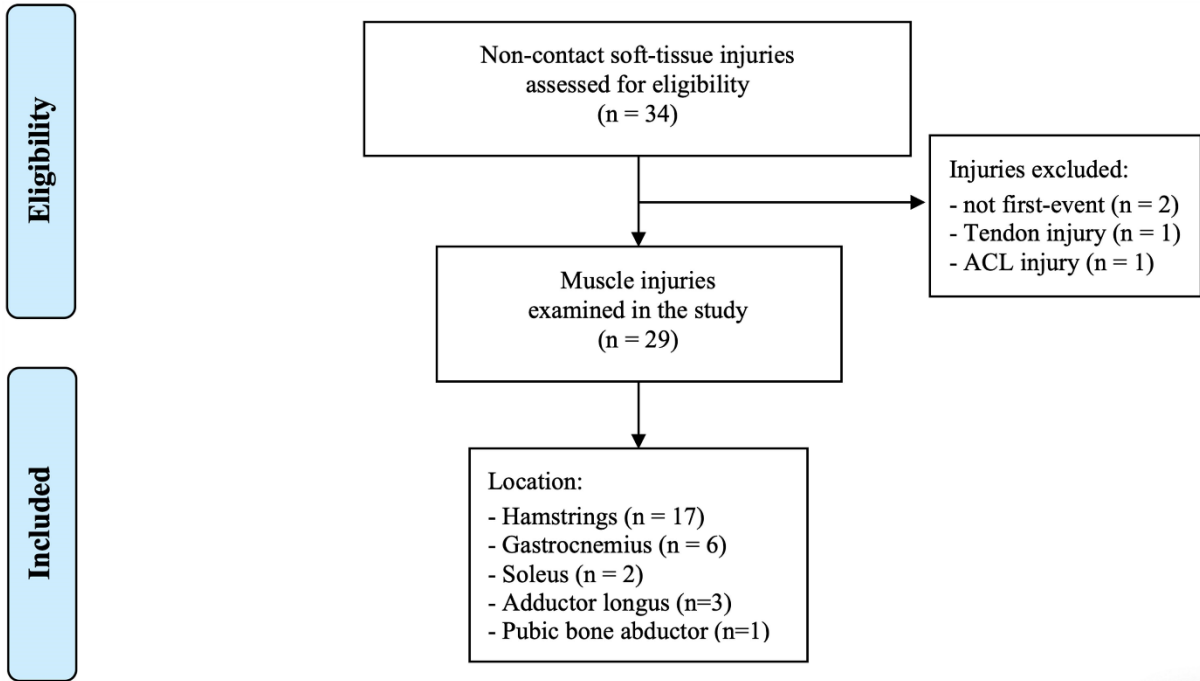
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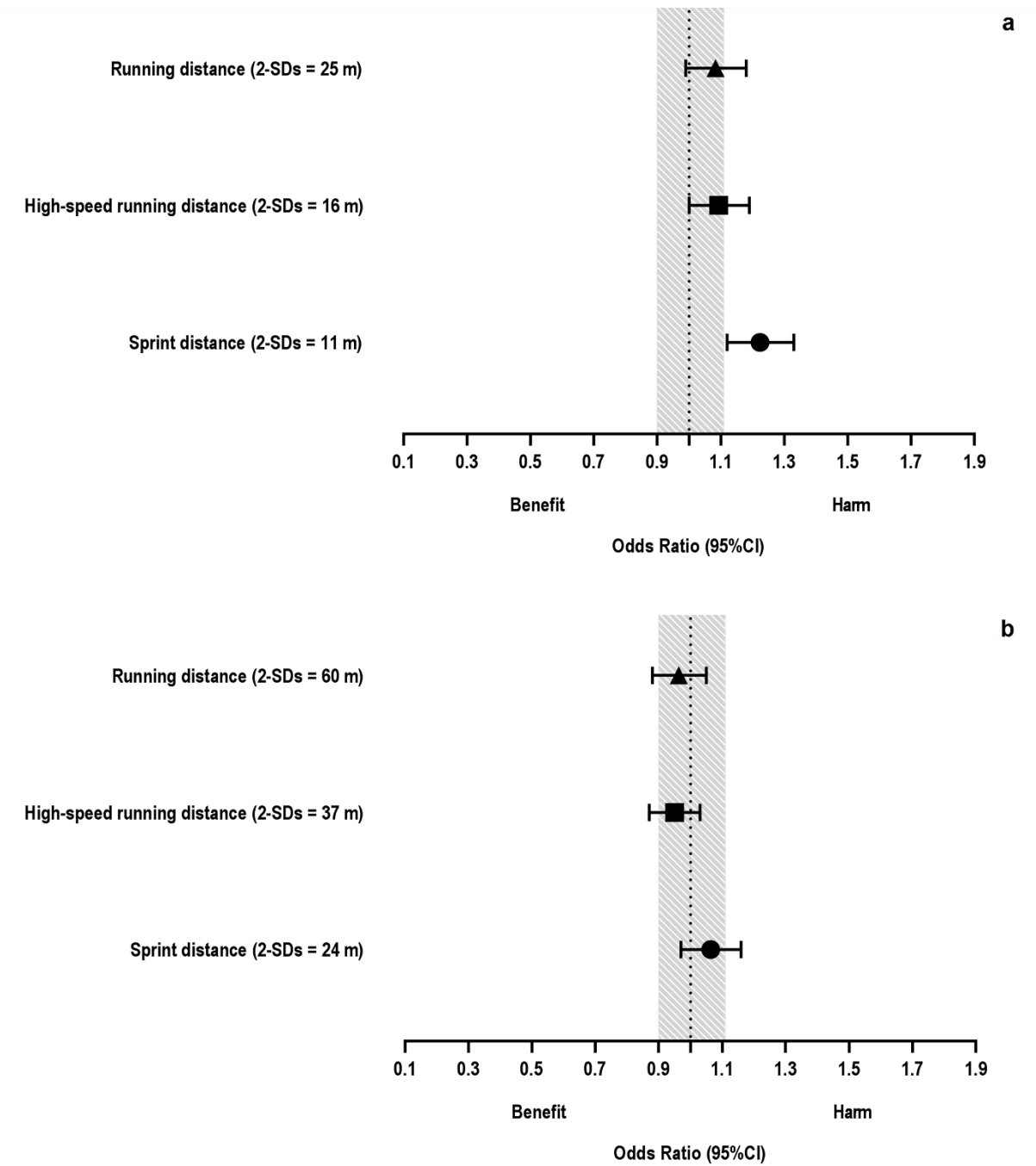
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383 **Figure 1.** Flowchart illustrating the number and type of muscle injury examined in the study.



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385 **Figure 2.** Outcome statistics for the association between 1-minute match load (a), 5-minute
 386 match load (b), and muscle injury occurrence. The grey shaded area identifies the bounds for a
 387 small reduction (OR =0.9) or increase (OR = 1.11) in the risk of injury, respectively.