High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk?

Shane Malone[1,2], Adam Owen2,3, Bruno Mendes[2], Brian Hughes[1], Kieran Collins[1], Tim J. Gabbett[4]

1. Human Performance Lab, Institute of Technology Tallaght, Tallaght, Dublin 24, Ireland.
2. BenficaLAB, S.L. Benfica, Lisbon, Portugal,
3. Claude Bernard University Lyon, Villeurbanne, Centre de Recherche et d'Innovation sur le Sport (CRIS), France
4. Gabbett Performance Solutions, Brisbane, Australia

Running Title: High-speed running, sprinting and injury risk in soccer

Corresponding author:
Mr Shane Malone
c/o Human Performance Lab, Institute of Technology Tallaght, Tallaght, Dublin 24, Ireland. Email: shane.malone@mymail.ittdublin.ie Tel: (+353) 87-4132808

Abstract word count: 250 words
Word count: 3015 words
Number of tables and figures: 4 Tables

Key Words: Odds Ratio, Injury Risk, Chronic Training Load, Soccer

ABSTRACT

Objectives: This study investigated the association between high-speed running (HSR) and sprint running (SR) and injuries within elite soccer players. The impact of intermittent aerobic fitness as measured by the end speed of the 30-15 intermittent fitness test (30-15V_{IFT}) and high chronic workloads (average 21-day) as potential mediators of injury risk were also investigated.

Design: Observational Cohort Study

Methods: 37 elite soccer players from one elite squad were involved in a one-season study. Training and game workloads (session-RPE x duration) were recorded in conjunction with external training loads (using global positioning system technology) to measure the HSR (>14.4 $km \cdot h^{-1}$) and SR (>19.8 $km \cdot h^{-1}$) distance covered across weekly periods during the season. Lower limb injuries were also recorded. Training load and GPS data were modelled against injury data using logistic regression. Odds ratios (OR) were calculated with 90% confidence intervals based on 21-day chronic training load status (sRPE), aerobic fitness, HSR and SR distance with these reported against a reference group.

Results: Players who completed moderate HSR (701 – 750-m: OR: 0.12, 90%CI: 0.08 – 0.94) and SR distances (201 – 350-m: OR: 0.54, 90%CI: 0.41 – 0.85) were at reduced injury risk compared to low HSR (≤674-m) and SR (≤165-m) reference groups. Injury risk was higher for players who experienced large weekly changes in HSR (351 – 455-m; OR: 3.02; 90%CI: 2.03 – 5.18) and SR distances (between 75 – 105-m; OR: 6.12, 90%CI: 4.66 – 8.29). Players who exerted higher chronic training loads (≥2584 AU) were at significantly reduced risk of injury when they covered 1-weekly HSR distances of 701 to 750 m compared to the reference group of <674 m (OR = 0.65, 90% CI 0.27 – 0.89). When intermittent aerobic fitness was considered based on 30-15V_{IFT} performance, players with poor aerobic fitness had a greater risk of injury than players with better-developed aerobic fitness.

Conclusions: Exposing players to large and rapid increases in HSR and SR distances increased the odds of injury. However, higher chronic training loads (≥2584 AU) and better intermittent aerobic fitness off-set lower limb injury risk associated with these running distances in elite soccer players.

INTRODUCTION

Training load has been reported as a modifiable risk factor for subsequent injury in soccer [1]. However, within professional soccer the frequency of competitive matches is high and players are frequently required to play consecutive matches with 3-days recovery [2]. Therefore, these players have an inherently high training load due to poor recovery periods between games and subsequent training sessions. These elite players are often exposed to year-long training and high match frequencies, with periods of a congested competition, which increases injury risk [1]. A high number of training days and matches lost due to injury has been shown to be detrimental to team success [3]. Recently, there has been a noted increase in the amount of high-speed running (HSR) performed during competitive soccer match-play [4]. Additionally, the ability to produce high speeds is considered an important quality for performance [5]. Well-developed high-speed and sprint running (SR) ability are required of players in order to gain advantages in attacking and defensive situations [6]. In order to optimally prepare players for these high speed elements of match-play, players require regular exposure to periods of HSR and SR during training environments [7,8]. Within a soccer specific context Djaoui et al [9] reported that small-sided games result in higher maximal speeds and greater HSR distances. However, there is currently no evidence within a soccer specific context that allows coaches to understand the dose-response of these exposures to higher speeds within training environments from an injury perspective.

Malone et al. [1] recently reported that elite soccer players were at increased risk of injury when they experienced high one-weekly cumulative training loads (≥1500 to ≤ 2120 AU). Increases in risk were also greater when one-weekly load was higher or large weekly changes in load, as represented by an acute:chronic workload ratio of ≥ 1.50 (OR: 2.33-3.03) were experienced. Within Australian rules football, larger 1-weekly, 2-weekly and previous to current week changes in workload were associated with increased risk of injury [10]. Owen et al. [11] recently reported that greater training time spent above 85% HR_{max} resulted in increased injury risk for players in subsequent match-play and training sessions. However, these results need to be contextualised given the known relationships between increased fitness and reduced injury risk for team sport players [1,12]. Clearly, there is a requirement for coaches to prescribe an appropriate training load to increase players' fitness to protect from subsequent risk [13].

Studies have found that rapid increases in training and game loads increase the risk of injury in Australian rules footballers [13,14] elite soccer players [1,15] elite Gaelic football players [12] and rugby union players [16]. Furthermore, GPS-derived data from elite rugby league demonstrate that greater volumes of HSR result in more soft tissue injuries [17]. Recent studies have reported a U-shaped relationship between exposure to maximal velocity and subsequent injury risk [7]. Within the same study, players with higher chronic training load (≥4750 AU) were able to tolerate greater distances at maximal velocity with reduced injury risk compared to a lower chronic load group (≤4750 AU). As such there appears to be a paradox whereby exposing players to HSR and SR within the training environment provides a ‘‘vaccine’’ for players, as long as they have been exposed to an appropriate chronic training load prior to performing these high-intensity activities. The aim of the current study was to determine whether HSR and SR distances were associated with an increased risk of lower limb non-contact injury in elite football players. Additionally we investigated if higher chronic training loads (average 21-day load) and aerobic fitness could off-set the injury risk associated with greater weekly volumes of HSR and SR.

METHODS

The current study was an observational prospective cohort design and was completed over 48 weeks spanning the 2015/2016 elite European soccer season (Liga Nos, Portugal). Data were collected for 37 players (Mean ± *SD*, age: 25 ± 3 years; height: 183 ± 7 cm; mass: 72 ± 7 kg) over one season. The study was approved by the local institute's research ethics committee and written informed consent was obtained from each participant. The study period involved all training and match play sessions during the 2015/2016 season. All participants had their running distances collected via GPS devices (STATSports Viper, Northern Ireland) and session rating of perceived exertion (sRPE) collected via a bespoke analysis system. Additionally, all injuries that prevented a player from taking full part in all training and match-play activities typically planned for that day, and prevented participation for a period greater than 24 h were recorded using a bespoke data base. The current definition of injury mirrors that employed by Brooks et al. [18] where an injury was defined as ‘‘any injury that prevents a player from taking a full part in all training and match play activities typically planned for that day for a period of greater than 24 hours from midnight at the end of the day the injury was sustained’’ and conforms to the consensus time-loss injury definitions proposed for team sport athletes [19]. All injuries were further classified as being low severity (1–3 missed training sessions); moderate severity (player was unavailable for 1–2 weeks); or high severity (player missed 3 or more weeks). Injuries were also categorised for injury type (description), body site (injury location) and mechanism in line with previous soccer investigations [1].

Global positioning system (GPS) measures of athlete movements have previously been reported to be accurate and reliable [20]. During the investigation period each player was fitted with a 10-Hz GPS unit (STATSports Viper, Northern Ireland). The unit was encased in a vest tightly fitted to each player, holding the unit between the scapulae. All devices were always activated 15 minutes before the data collection to allow acquisition of satellite signals in accordance with the manufacturer's instructions. High-speed (>14.4 $km \cdot h^{-1}$), and sprint (>19.8 $km \cdot h^{-1}$) running distances were calculated during each match and training session. After recording, the data were downloaded to a computer and analyzed using the software package Viper version 3.2 (STATSports, 2015). Any uploaded data containing 'signal dropout' errors or players not involved in the football drills were removed. The intensity of all training sessions (including gym based and rehabilitation gym and pitch sessions) and match-play were estimated using the modified Borg CR-10 rate of perceived exertion (RPE) scale, with ratings obtained from each individual player 30 mins after the end of each match and training session. Players were prompted for their RPE individually using a custom-designed application on a portable computer tablet (iPad, Apple Inc, California, USA). Each player selected his RPE rating by touching the respective score on the tablet which was represented as a visual image of the scale. The RPE provided was then automatically saved under the player's profile. Each individual RPE value was multiplied by the session duration (min) to generate an internal training load score (sRPE). Previously, work has demonstrated moderate associations between s-RPE and HSR (r =0.51) in team sport athletes [21]. The collection of weekly GPS and sRPE variables allowed for the calculation of chronic training loads (averaged 21-day load) [2], the absolute change in load from the previous week [3] and a specific soccer-based acute:chronic workload ratio comprised of a 3-day acute load period and a 21-day chronic load period. The structure of a professional soccer season means that 3-day acute periods include the main training sessions prior to matches and a specific times the previous match. With the 21-day chronic time windows may reflect these sessions and any previous matches in this specific time structure [1,22]. Given the number of matches that professional soccer players play within a condensed period of time a 3:21 day window would appear best to captures subtle and sudden increases in external and internal training load and the associated injury risk [22].

The aerobic fitness of players was assessed during each phase of the season. Players completed the 30-15 intermittent fitness test (30-15$_{IFT}$). The 30-15$_{IFT}$ consists of 34 stages of 30-s shuttle runs interspersed with 15-s periods of passive recovery. The initial running velocity was set at 8 km·h^{-1} for the first 30-s run and increased by 0.5 km·h^{-1} for every subsequent 45-s stage. Players ran back and forth between two lines set 40-m apart at a pace governed by a pre-recorded beep [(23)]. This pacing strategy allowed subjects to run at appropriate intervals and helped them adjust their running speed as they entered into 3-m zones at each end as well as the middle (20-m line) when a short beep sounds with players' final speed (30-15V$_{IFT}$) used for the analysis of aerobic fitness. Previously 30-15V$_{IFT}$ has been shown to be related to the aerobic fitness of team sport athletes [(23)]. Within this cohort, the maximal intermittent running velocity (30-15 V$_{IFT}$) demonstrated good reliability (ICC = 0.80). With the CV observed as 2.5% for between-test reliability for the 30-15$_{IFT}$ within this specific cohort of players. Aerobic fitness data (30-15V$_{IFT}$) were then split into quartiles (four even groups), with the highest speed range used as the reference group, this specific split was completed in order to best understand the impact of low through to high aerobic fitness on injury risk within soccer players.

SPSS Version 22.0 (IBM Corporation, New York, USA) was used to analyze the data. Descriptive statistics for HSR and SR during the season were expressed as means ± SD and 90% confidence intervals. Injury incidence was calculated by dividing the total number of injuries by the total number of training and match hours. The 90% confidence intervals (CIs) were calculated using the Poisson distribution, and the level of significance was set at $p \leq 0.05$. Weekly exposures to HSR, SR and injury data (injury vs. no injury) were then modelled using a logistic regression analysis with adjustment for intra-player cluster effects. Data were initially split into quartiles (four even groups), with the lowest training load range used as the reference group, this specific split was completed in order to best understand the impact of low through to high loading paradigms on injury risk within soccer players. This was completed for weekly HSR and SR distances, weekly change in HSR and SR distances, and HSR and SR distance acute:chronic workload ratio. Additionally, to better understand the impact of previous chronic training load on subsequent HSR and SR load, training load data was divided into low (≤ 2584 AU) and high (≥ 2584 AU) chronic training load groups using a dichotomous median split. Weekly HSR and SR distances, and injury data were summarised at the completion of each 21-day period. Acute (3-day) and chronic training load (average of 21-day) were calculated. Previous training load history was then associated with players' tolerance to HSR and SR distances and injuries sustained in the subsequent week. Players who sustained an injury were removed from analysis until they were medically cleared to return to full training. Based on a total of 75 injuries from 7,104 player-sessions (37 players participating in 192 training sessions), the calculated statistical power to establish the association between internal and external training loads and soft-tissue injuries was 85%. Odds ratios (OR) were calculated to determine the injury risk at a given HSR distance, SR distance, chronic training load, and fitness level. When an OR was greater than 1, an increased risk of injury was reported (i.e, OR = 1.50 is indicative of a 50% increased risk) and vice versa.

RESULTS

During the investigation 75 time-loss injuries were reported. The incidence proportion was 2.02 per player. Overall, match injury incidence was 10.9/1000 hours, (90% CI: 8.87 to 14.92) and training injury incidence was 4.9/1000 hours (90% CI: 3.95 to 5.14). Lower limb injuries resulted in the highest incidence across the year 16.2/1000 hours (90% CI: 11.35 to 17.14) with muscular injuries being the highest sub group of injury types (17.5/1000 hours; 90% CI: 9.84 to 18.95).

Independent of aerobic fitness and training load, players who completed moderate HSR (701 – 750-m: OR: 0.12, 90%CI: 0.08 – 0.94, p = 0.025) and SR distances (201 – 350-m: OR: 0.54: 90%CI: 0.41 – 0.85, p = 0.005) were at reduced injury risk compared to low HSR and SR groupings (HSR: ≤674-m; SR: ≤165-m) and high (HSR: Between 750 – 1025-m; SR: 350 – 525-m) reference groups (Table 1 and Figure 1). Injury risk was greater for player who experienced large weekly changes in HSR (351 – 455-m; OR: 3.02; 90%CI: 2.03 – 5.18, p = 0.011) and SR distances (75 – 105-m; OR: 6.12, 90%CI: 4.66 – 8.29; p = 0.001) compared to the reference HSR (≤100-m) and SR (≤50-m) group (Table 2). Players who had a HSR 3:21 day acute:chronic workload ratio of >1.25 and a 3:21 day SR distance acute:chronic workload ratio of >1.35 were at increased risk of subsequent injury (Table 2).

Players who exerted higher 21-day chronic training loads (≥2584 AU) were at reduced risk of injury when they covered 1-weekly HSR distances of 701 to 750 m compared to the reference group of <674 m (OR = 0.65, 90% CI 0.25–0.89, p = 0.024). Conversely, players who exerted low chronic training loads (≤2584 AU) and covered the same distance of 701 to 750 m were at greater risk of injury compared to the reference group of <674 m (OR = 3.12, 90% CI: 2.99–4.54, $p = 0.036$). Similar trends were observed for SR distance with higher 21-day chronic training loads allowing players to cover increased HSR and SR distances at reduced injury risk (Table 3)

Players with poor aerobic fitness as indicated by a lower 30-15 V_{IFT} had a greater risk of injury than players with better-developed aerobic fitness (OR = 2.15-3.19, p = 0.019-0.031). The risk of injury was greater in players with poor aerobic fitness at comparable absolute high speed workloads (>1025-m; OR: 3.15 90%CI: 2.98-5.50, $p = 0.033$), weekly change in HSR workloads (>300 to 600-m; OR: 2.99, 90%CI: 1.98-4.42, $p = 0.023$), and when the HSR acute:chronic workload ratio was >1.25 (Table 4). Similar trends were observed for SR distance with poor aerobic fitness increasing injury risk (Table 4)

DISCUSSION

The current study explored the association between training load, aerobic fitness, HSR and SR distances and subsequent injury risk in elite football players. Our data show that when HSR and SR distances are considered independently of aerobic fitness and previous training load history, a U-shaped association exists for distance completed at these speeds and subsequent injury risk, with moderate loading of these distances reducing subsequent injury risk. Interestingly, players with higher aerobic fitness as determined by a $30\text{-}15_{IFT}$, were able to complete increased weekly HSR and SR distances with a reduced injury risk compared to players with poorer aerobic fitness (OR: 2.15-3.19). Additionally, we have shown that higher 21-day chronic training loads (≥2584 AU) allow soccer players exposure to greater volumes of HSR and SR distances, which in turn offers a protective effect against injury (OR: 0.65). Interestingly, players with low chronic load (≤ 2584 AU) were observed to be at increased injury risk at similar HSR and SR distances (OR: 3.12). Our data highlight that the ability to expose players to HSR and SR distances within elite football is a function of their previous chronic training load history with moderate HSR and SR running protective for players. Furthermore, when combined with better aerobic fitness (higher 30-15 V_{IFT}) and higher chronic training loads, these distances can be completed at reduced risk. Practically, our data suggest that players should be exposed to consistent periods of training that best prepare them to attain higher speed movements.

Previous studies have reported relationships between high acute training loads and increased injury risk [10,15,17]. The results from our study add to previous workload-injury literature [12,16,17] by confirming that the injury risk associated with HSR and SR is increased when these distances were elevated [1,12]. However, the current investigation also found that higher chronic training loads can aid weekly HSR and SR workloads of soccer players, while also reducing the injury risk associated with these higher-speed movements [24]. Our model shows that training load has both positive and negative influences, with higher chronic loads (i.e. 21-days) associated with reduced injury risk for the same high-speed movements in contrast to lower chronic training loads. However, coaches should be cognisant that higher acute loads have previously been associated with an increase in fatigue status in players and resultant increase in injury risk [25]. A major finding of the current study, which is consistent with previous studies [7, 13], was that players exposed to large and rapid increases in HSR and SR distances were more likely to sustain a lower limb injury than players who were exposed to moderate distances, independent of previous training load and fitness characteristics [13, 17]. However, we found that players with higher 21 day chronic loads (≥2584 AU) completed increased HSR and SR distances with this increase in distance offering a protective effect against injury for these players. These findings can be explained by players being exposed to a chronic training load period that improved their ability to tolerate subsequent HSR and SR workload, ultimately reducing their risk of injury. In contrast, players with lower chronic loads were at greater risk of injury when exposed to the same HSR and SR distances, perhaps reflecting the consequences of inadequate exposure to a sufficient workload over the previous period. Our results are in line with previous investigations from other team-based field sports that have suggested that moderate and higher chronic training loads offer a protective effect against lower limb injury risk [7, 15, 16].

From a performance perspective, careful consideration should be taken when interpreting and applying the current findings to the high-performance environment. In alignment with earlier reports showing a positive relationship between greater training distance [7, 13] and intensity [11] and performance, a fine balance exists between reducing training loads to prevent injury, and increasing training loads to physically prepare players for competition [8, 13, 14]. Therefore, taking into account the need for an appropriate stimulus to improve performance, we used the current data to produce a model, based on a soccer-specific mesocycle of 21-days. Our model suggests that players will be exposed to greater risk of lower limb injury when HSR and SR distances are increased rapidly from week-to-week. The current findings are in agreement with previous investigations within Gaelic football [12] and Australian rules football [13] where rapid increases in workloads appear to be a precursor for lower limb injury.

Our results have shown that increased aerobic fitness allows players to better tolerate increased distances at high speed across weekly periods. Interestingly players with higher 30-15V_{IFT} were shown to be able to tolerate ‘spikes’ in HSR at reduced risk compared to players with a lower 30-15V_{IFT}. Aerobic fitness would appear to offer a protective effect for players who have a HSR acute:chronic workload ratio above 1.25, while players with lower aerobic fitness were at increased risk at the same HSR acute:chronic workload ratio. This could be related to increased intermittent aerobic fitness allowing players to recover quicker between repeated bouts of HSR [(26)]. The observations of the current investigation are in agreement with previous findings that increased aerobic fitness can reduce injury risk for team-sport players [(1,12)]. Indeed, the current findings have important practical implications as athletes who do not have the required physical qualities to tolerate the physical demands of competition are likely to have reduced playing performance and increased injury risk [(12)].

Factors in addition to weekly load, such as previous injury [(27)], perceived muscle soreness, fatigue, mood, sleep ratings [(28)] and psychological stressors [(28)], are likely to impact upon an individual’s injury risk, however these were not accounted for in the current analysis. Unfortunately, it was not possible to describe the external and subjective training loads of specific session types within the current study. Additionally, there is a need to assess the utility of external:internal load ratios as a potential metric for injury risk assessment given the known relationship between these ratios and fitness in team sport athletes [(29, 30)]. Finally, the model developed within the current investigation will be best suited to the population from which it is derived [(16, 19)]. Therefore, due to the fact that this study involves a single team over a single season, it is difficult to translate these findings to other teams across different leagues therefore we recommend cross-league and cross-team analysis of professional soccer teams training load data in order to better understand the injury-workload relationship within professional soccer.

CONCLUSION

The current study has shown an association between workload measures and injury risk in elite football players. Players were at an increased risk of injury if they had high cumulative HSR and SR workloads or large week-to-week changes in these workloads. Independent of previous training load and aerobic fitness, players exposed to large and rapid increases in HSR and SR distances were more likely to sustain a lower limb injury than players who were exposed to reduced distances. However, when previous training load and intermittent aerobic fitness were considered, players with higher chronic loads (≥2584 AU) completed greater HSR and SR distances at a lower risk of injury. Additionally, players with higher aerobic fitness were better able to tolerate 'spikes' in HSR and SR workloads at reduced risk compared to players with lower aerobic fitness. Therefore, higher chronic loads and better aerobic fitness appear to offer a protective effect against injury for elite soccer players and should be considered mediators of injury risk within this cohort.

PRACTICAL APPLICATION

- A U-Shaped curve exists between high-speed and sprint based running load and injury risk in soccer cohorts. The current study data suggests that a 3:21 day acute chronic workload ratio for both high speed and sprint based running has been shown to be related to injury risk in elite football players.

- These ratios should be applied within teams to better understand the associated risk with these variables, Coaches should aim to expose their players to periods of training that offer the ability for players to attain both high speed and sprint based speeds such as large small-sided games or linear running drills that offer the potential for athletes to achieve these speeds.

- Higher chronic training loads allow for players to the exposed to increased volumes of running at reduced risk. Higher intermittent aerobic fitness allows players to tolerate higher running volumes and changes in running volumes at reduced risk of injury.

ACKNOWLEDGEMENTS

The authors would like to declare no conflicts of interest and additionally we would like to thank all the players and staff who were involved in the current investigation.

REFERENCES

1. Malone S, Owen A, Newton M et al. The acute:chronic workload ratio in relation to injury risk in professional soccer. *J Sci Med Sport* 2016 Nov 8th doi:10.1016/j.jsams.10.014[Epub ahead of print]

2. Nedelec M, Halson SL, Abd-Elbasset A, et al. Stress, sleep and recovery in elite soccer: A critical review of the literature. *Sport Med*, 2015; 45(10):1387-1400.

3. Arnason A, Sigurdsson SB, Gudmundsson A, et al. Physical fitness, injuries, and team performance in soccer. *Med Sci Sports Exerc* 2004;36:278–85.

4. Barnes C, Archer DT, Hogg B et al. The evolution of physical and technical performance parameters in the English premier league. Int J Sports Med 2014, 35(13): 1095-1100.

5. Al Haddad , Simpson BM, Buchheit M, et al. Peak match speed and maximal sprinting speed in young soccer players: effect of age and playing position. *Int J Sports Physiol Perform* 2015;10:888–96.

6. Johnston RJ, Watsford ML, Pine MJ et al. Standardisation of acceleration zones in professional field sport athletes. *Int J Sports Sci Coaching* 2014; 9(6): 1161-1168.

7. Malone S, Roe M, Doran D et al. High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football . *J Sci Med Sport* 2016 Aug 10th pii: S1440-2440(16)30148-7. doi: 10.1016/j.jsams.2016.08.005. [Epub ahead of print]

8. Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? *Br J Sports Med*. 2016 Jan 12. pii: bjsports-2015-095788. doi: 10.1136/bjsports-2015-095788. [Epub ahead of print]

9. Djaoui L, Chamari K, Owen A et al. Maximal sprinting speed of elite soccer players during training and matches. *J Strength and Cond* Sept 23rd 2016: doi: 10.1519/JSC.0000000000001642 [Epub ahead of print]

10. Rogalski B, Dawson B, Heasman J, Gabbett TJ. Training and game loads and injury risk in elite Australian footballers. *J Sci Med Sport.* 2013;16(6):499-503.

11. Owen AL, Forsyth JJ, Wong DP et al. Heart-rate based training intensity and its impact on injury incidence among elite-level professional soccer players. *J Strength Cond Res* 2015; 29(6) 1705-1712.

12. Malone S, Roe M, Doran DA, et al. Aerobic fitness and playing experience protect against spikes in workload: The role of the acute:chronic workload ratio on injury risk in elite Gaelic football. *Int J Sports Physiol Perform* 2016. doi: 10.1123/ijspp.2016-0090 [Epub Ahead of Print]

13. Duhig S, Sheild AJ, Opar D et al. Effect of high speed running on hamstring strain injury risk. *Br J Sports Med*. 2016 Jun 10. pii: bjsports-2015-095679. doi: 10.1136/bjsports-2015-095679. [Epub ahead of print]

14. Colby MJ, Dawson B, Heasman J, Rogalski B, Gabbett TJ. Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *J Strength Cond Res* 2014;28(8):2244- 2252.

15. Bowen L, Gross AS, Gimple M, Li FX. Accumulated workloads and the acute:chronic workload ratio relate to injury risk in elite youth football players. *Br J Sports Med Open. July 22.* 10.1136/bjsports-2015-095820 [Epub ahead of print]

16. Cross MJ, Williams S, Trewartha G, Kemp SPT, Stokes KA. The influence of in-seaon training loads on injury risk in professional rugby union. *Int J Sports Physiol Perform.,* Aug 2015, DOI: 10.1123/ijspp.2015-0187

17. Gabbett TJ, Ullah S, Finch C. Identifying risk factors for contact injury in professional rugby league players—Application of a frailty model for recurrent injury. *J Sci Med Sport* 2012;15:496–504.

18. Brooks JH, Fuller CW, Kemp SP, Reddin DB. Epidemiology of injuries in English professional rugby union: part 1 match injuries. *Br J Sports Med* 2005;39:757–66.

19. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Clinical Journal of Sports Medicine,* 2006;16(2):97-106

20. Buchheit M, Allen A, Poon TK, Mondonutti M, Gregson W, Di Salvo V. Integrating different tracking systems in football: multiple camera semi-automatic system, local positioning measurement and GPS technologies. *J Sports Sci*, 2014; 32(20): 1844-1857

21. Gallo T, Cormack S, Gabbett T, et al. Characteristics impacting on session rating of perceived exertion training load in Australian footballers. J Sports Sci 2015;33:467–75.

22. Carey DL, Blanch P, Ong KL, et al. Training loads and injury risk in Australian football-differing acute: chronic workload ratios influence match injury risk. Br J Sports Med Published Online First: 27 Oct 2016 doi:10.1136/bjsports-2016-096309.

23. Buchheit, M. The 30-15 intermittent fitness test: accuracy for individualizing interval training of young intermittent sport players. *J Strength Cond Res* 22: 365- 374, 2008.

24. Hulin BT, Gabbett TJ, Blanch P, et al. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. Br J Sports Med 2013;48:708–12.

25. Hulin BT, Gabbett TJ, Lawson DW, et al. The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players.

Br J Sports Med Published Online First: 28 Oct 2015 doi:10.1136/bjsports-2015-094817.

26. Buchheit, M, Ufland, P. Effect of endurance training on performance and reoxygenation rate during repeated-sprint running. *Eur J Appl Physiol*, 111 (2): 293-301, 2011.

27. Hägglund 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.* Aug 2013;47(12):738-742.

28. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med*, 2014;44(2):139-147

29. Akubat I, Barrett S, Abt G. Integrating the internal and external training loads in soccer. *Int J Sports Physiol Perform*, 2014; 9(3): 457-462

30. Malone S, Doran D, Akubat I, Collins K. The integration of internal and external training load metrics in hurling. J Hum Kinet 2016 53:211-221

Table 1. Weekly high-speed running and sprint distances as a risk factor for lower limb injury in elite football players. Data presented as OR (90% CI) when compared to a reference group.

External Load Calculation	In-Season			
	Odds Risk (OR) of Lower Limb Injury	90% Confidence Interval		*p*-Value
		Lower	Upper	
Total 1-weekly high-speed distance (m)				
≤674-m	1.00			
Between 675-700-m	1.02	1.01	2.93	0.065
Between 701-750-m	0.12	0.08	0.94	0.025
Between 750-1025-m	5.02	1.33	6.19	0.006
Total 1-weekly sprint distance (m)				
≤165-m	1.00			
Between 165-200-m	1.12	1.01	2.87	0.345
Between 201-350-m	0.54	0.41	0.85	0.005
Between 350-525-m	3.44	2.98	4.84	0.004

Table 2. Absolute weekly change and acute:chronic workload ratio for high-speed running and sprint distances as a risk factor for injury in elite football players. Data presented as OR (90% CI) when compared to a reference group.

External Load Calculation	In-Season			
	Odds Risk (OR) of Lower Limb Injury	90% Confidence Interval		*p*-Value
		Lower	Upper	
Absolute weekly change in high-speed distance (m)				
≤100-m	1.00			
Between 101 - 205-m	1.20	1.05	3.93	0.034
Between 206 -350-m	2.27	1.93	4.44	0.002
Between 351-455-m	3.02	2.03	5.18	0.011
Absolute weekly change in sprint distance (m)				
≤50-m	1.00			
Between 51 - 64-m	3.12	2.86	6.13	0.033
Between 65 - 75-m	4.12	3.86	7.84	0.002
Between 75 -105-m	6.12	4.66	8.29	0.001
High speed distance acute:chronic workload ratio (AU)				
≤ 0.85	1.00			
Between 0.86 to 1.00	1.20	1.10	2.03	0.021
Between 1.00 to 1.25	2.27	2.13	3.04	0.001
≥ 1.25	3.02	2.53	4.98	0.001
Sprint distance acute:chronic workload ratio (AU)				
≤ 0.70	1.00			
Between 0.71 to 0.85	0.85	0.33	0.95	0.035
Between 0.86 to 1.35	1.15	1.11	2.14	0.012
≥ 1.35	5.00	3.01	7.38	0.021

Table 3. Combined effect of chronic (21-day) training load history and exposure to different high speed running and sprint distances as a risk factor for injury in elite football players. Data presented as OR (90% CI) when compared to a reference group.

External Load Calculation	In-Season			
		90% Confidence Interval		*p*-Value
	Odds Risk (OR) of Lower Limb Injury	Lower	Upper	
Total 1-weekly high-speed distance (m)				
Low chronic training load (≤2584 AU)				
≤674-m	1.00			
Between 675-700-m	2.12	2.08	3.93	0.044
Between 701-750-m	3.12	2.99	4.54	0.036
Between 750-1025-m	5.02	3.03	6.19	0.016
Total 1-weekly high-speed distance (m)				
High chronic training load (≥2584 AU)				
≤674-m	1.00			
Between 675-700-m	0.54	0.16	0.83	0.035
Between 701-750-m	0.65	0.27	0.89	0.024
Between 750-1025-m	1.22	1.03	2.99	0.016
Total 1-weekly sprint distance (m)				
Low chronic training load (≤2584 AU)				
≤165-m	1.00			
Between 165-200-m	1.12	1.08	2.87	0.455
Between 201-350-m	2.54	1.55	3.25	0.031
Between 350-525-m	3.44	1.98	4.84	0.004
Total 1-weekly sprint distance (m)				
High chronic training load (≥2584 AU)				
≤165-m	1.00			
Between 165-200-m	0.24	0.16	0.53	0.025
Between 201-350-m	0.65	0.25	0.93	0.035
Between 350-525-m	0.72	0.36	0.94	0.004

<u>Supplementary Material</u>

Figure 1. Weekly high-speed running (a) and sprint distance (b) as a risk factor for lower limb injury in elite football players independent of aerobic fitness and previous training load history. Data presented as Odds Risk (OR) with 90% CI

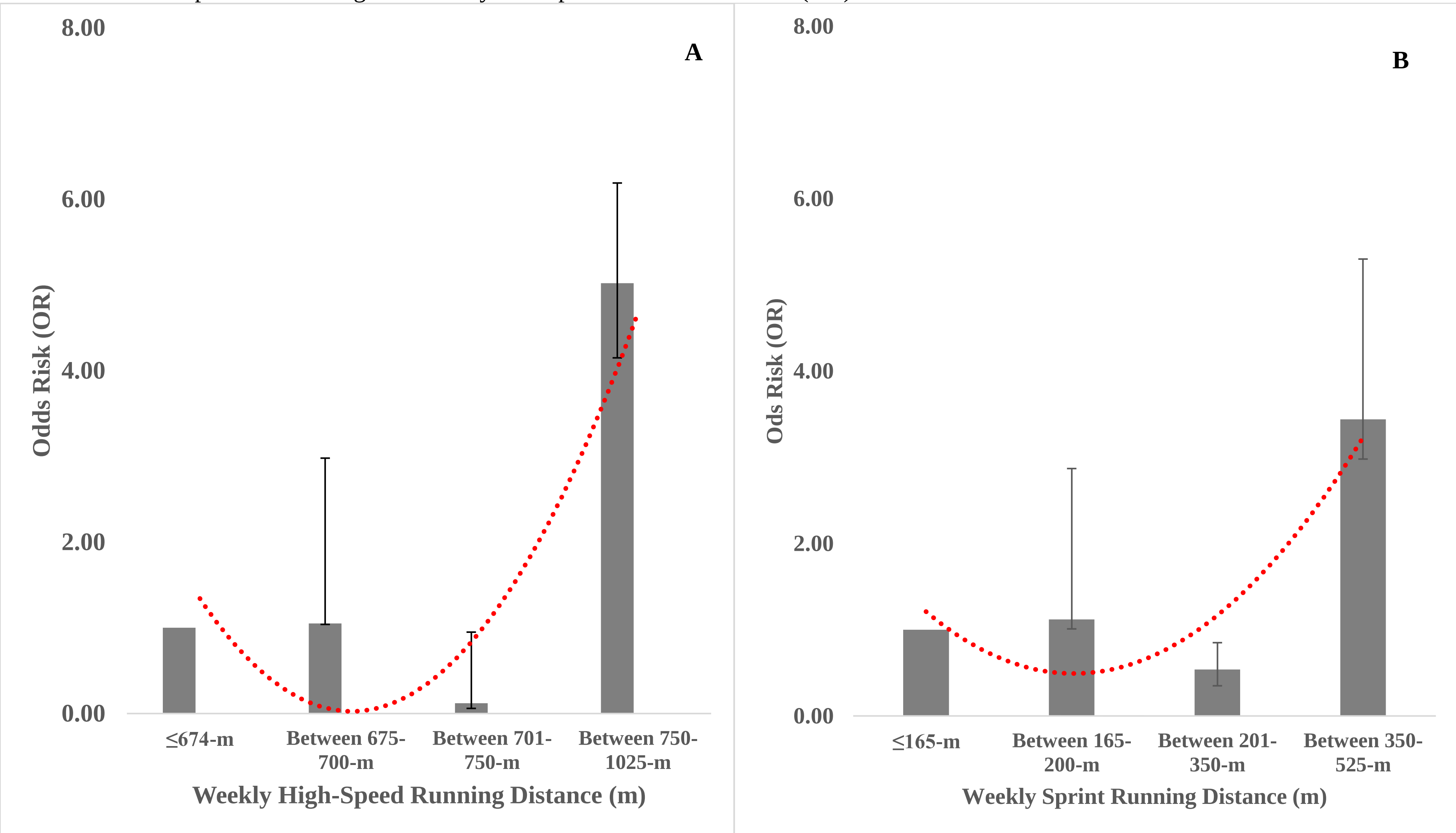

Table 4. Aerobic fitness as a risk factor for injury above certain high-speed running in elite football players. Data presented as OR (90% CI) when compared to a reference group.

Load Calculation	In-Season			
		90% Confidence Interval		*p*-Value
	Odds Risk (OR) of Lower Limb Injury	Lower	Upper	
Cumulative load (sum)				
1-week high speed distance				
>1025-m				
20 to 22.5 km·h^{-1}	1.00			
18 to 19.5 km·h^{-1}	1.51	1.39	2.99	0.009
16 to 17.5 km·h^{-1}	1.98	1.16	3.93	0.035
14 to 15.5 km·h^{-1}	3.15	2.98	5.30	0.033
1-week sprint distance				
>350-m				
20 to 22.5 km·h^{-1}	1.00			
18 to 19.5 km·h^{-1}	2.48	1.99	3.59	0.032
16 to 17.5 km·h^{-1}	3.45	2.88	4.13	0.011
14 to 15.5 km·h^{-1}	5.15	3.58	5.95	0.003
Absolute Change (±)				
Previous to Current Week high speed distance				
>300 to 600-m				
20 to 22.5 km·h^{-1}	1.00			
18 to 19.5 km·h^{-1}	1.54	1.38	2.99	0.009
16 to 17.5 km·h^{-1}	1.93	1.45	2.75	0.011
14 to 15.5 km·h^{-1}	2.99	2.18	3.52	0.023
High-speed distance acute:chronic workload ratio				
>1.25				
20 to 22.5 km·h^{-1}	1.00			
18 to 19.5 km·h^{-1}	2.04	1.48	3.76	0.009
16 to 17.5 km·h^{-1}	2.43	1.68	3.92	0.011
14 to 15.5 km·h^{-1}	3.99	3.08	4.92	0.023
Sprint distance acute:chronic workload ratio				
>1.35				
20 to 22.5 km·h^{-1}	1.00			
18 to 19.5 km·h^{-1}	1.14	1.05	1.39	0.115
16 to 17.5 km·h^{-1}	2.43	1.55	2.99	0.054
14 to 15.5 km·h^{-1}	3.98	3.44	5.05	0.045