Exposures to near-to-maximal speed running bouts during different turnarounds in elite football: association with match hamstring injuries

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ABSTRACT

Purpose: To examine the association between the occurrence of near-to-maximal sprinting speed (MSS) running bouts during training and hamstring injury rate during the consecutive match of the same turnaround in elite soccer.

Methods : Retrospective data from 36 team-seasons (16 elite teams performing in top European leagues) were analysed (627 players, 152 non-contact time loss hamstring injuries).

We looked at 1) match hamstring injury rate within each turnaround in relation to >85%, >90% or >95% MSS exposures or not during training and 2) match hamstring injuries in relation to the day(s) within the turnarounds when these exposures occurred.

Results: There were negative correlations between the proportion of players reaching near-to-MSS speeds during training and turnaround length (0.95 < *r* < 0.99). For some turnarounds, there were no match hamstring injuries when players were exposed to running bouts >95% MSS during training vs. when there were no exposures. Finally, there were no hamstring injuries when >95% MSS exposures occurred at D-2, while in contrast, injuries still happened when players were not exposed at all, or when these exposures occurred at D-3 and/or earlier within the turnaround.

Conclusion: Programming >95% MSS exposures at D-2 may be a relevant strategy to decrease the incidence of match hamstring injuries in elite football.

INTRODUCTION

Hamstring strain injuries remain the most prevalent time loss injuries in professional soccer.[1] While their relative occurrence may have slightly decreased in relation to the likely increased match demands over the past decade,[2] practitioners are still seeking mitigation strategies both in the gym and on the pitch.[3] Among the different recommended strategies, the use of eccentric-based exercises[4] and exposures to near-to-maximal sprinting speed (MSS) running bouts (either with or without the ball) are now the most recommended.[5,6] Sprinting is indeed both complex and unique at many levels (e.g., legs interaction, elastic energy transfer, reflexes, kinematics, kinetics)[5] and a similar recruitment intensity of the hamstring muscles (i.e., electromyographic activity) can't be reached with isolated gym exercises.[7]

In practice, recent studies have shown relationships between hamstring strain injuries and near-to-MSS exposures both in Australian Rules Football[8,9] and Gaelic Football[10] players. More precisely, both under- and over near-to-MSS exposures were associated with the higher injury rates, suggesting the existence of an optimal chronic "dose" (i.e., number of weekly exposure[8,10] and/or monthly cumulative distance.[9] This optimal chronic dose is likely specific to each population and context, and it is therefore difficult to provide guidelines for all practitioners on the back of those two studies. More importantly, those studies do not provide clear guidelines on how and when to program these near-to-MSS exposures during turnarounds of different lengths. How fast soccer players should run is also still unclear, since large variations in relative velocities have been reported, ranging from ≥80,[9] to 85[8] or even 95% of MSS.[10]

In fact, the question of the optimal intensity (i.e., >85% vs >90% or 95% MSS) and on which day to program these near-to-MSS exposures is something that has not been examined scientifically despite its immense importance in terms of match performance and hamstring injury management.[11] The only (yet partial) answer to this question that is available to us today comes from the 100 elite soccer practitioners that we surveyed in 2021.[12] While the large majority of the responders confirmed the need to regularly expose players to these high-speed running bouts, there was a lack of agreement as to when MSS work should be programmed, especially between D-3 vs D-2 (i.e., (3 vs 2 days before the match). This was likely due to the lack of robust evidence, and this programming practice was rather based on experience and/or adherence to typical periodization paradigms and models (e.g., tactical periodization, R. Verheijen, or el modelo estructurado of FC Barcelona).

In order to shed light into this important topic, we examined the association between near-to-MSS exposures and match hamstring injury rate, using retrospective data from 19 elite teams performing in top football leagues across the globe. We more precisely also looked at the timing of these exposures within turnarounds of varying length. We believe that the information provided will help performance staff support managers to optimise the programming of their microcycles, within their own context.

METHODS

Data collection

For this study, player characteristics, participation data and injury details were extracted from an online database (i.e., Kitman Labs platform, Dublin, Ireland) commonly used by all the football teams involved in the study. Each player and club is provided with an ID number on the platform. The researchers in charge of the analysis could only pull and analyze data associated with their IDs - no names included. Then, data was transformed and coded for injury occurrence (dates only used for assessing occurrences, such as during a match vs during training and when in relation from/to the previous match) and type (contact or non-contact injury, without any more details), to provide a final dataset.

The medical staff of each team registers injury details in the platform as a part of their daily player care management, including variables such as date of injury, type of injury and injury severity (days lost). Similarly, player game and training session participation are recorded as part of the team staff's daily monitoring. Additionally, the measures of training and competitive load are also added to the platform. The fact that all clubs used the same platform ensured the standardisation and the reliability of all types of entries, from medical information to exposure measures (e.g., session duration and GPS data attached to the system calendar). We nevertheless ran a thorough data health check to ensure that all data retained for analysis met the same standard. Permission was granted by the teams for their inclusion in this study, therefore ethics committee clearance was not required. The study conforms nevertheless to the recommendations of the Declaration of Helsinki.

Data were extracted from 18 teams belonging to EPL, the Italian Serie A, the Bundesliga, the Scottish Premiership, the MLS and the Dutch Eredivisie from January 2018 to December 2021. This represented 82 team-seasons.

Since preliminary analysis didn't show any trends suggestive of differences between the different leagues or continents, all data were pooled together to increase sample size.

Team-seasons for which injury information was not accessible were not used for analysis. Likewise, when there was not enough information about players on the platform (e.g. no exposure for less than 15 players over the entire season), the team season was not included. The final data set included 36 team-seasons, including a total of 667 players, 1581 injuries including 229 non-contact time loss (> 3 days missed) hamstring injuries, 1495 non-international matches and 6698 training session days. Since preliminary analysis didn't show any trends suggestive of differences between the different leagues or continents, all data were pooled together to increase sample size.

Data preparation

A *n*-d turnaround was defined as a microcycle with *n* days between the first and second match, where *n* is the count of days from the first day after a match up to and including the following match day. The shortest observed turnaround was 3 days (3-d) e.g. playing a match on Sunday and again the following Wednesday, while the longest was 8 days (8-d) e.g. playing on Saturday and again the following Sunday. The longer and less common turnarounds were excluded from analysis. In total, 1358 turnarounds (at the team level) were extracted and were grouped by their respective length.

Injuries

Injury is often defined as an occurrence sustained during either training or match-play which prevents a player from taking part in training or match-play for 1 or more days following the occurrence.[13] In this study we wanted to focus on non-contact injuries that substantially impact training and match participation and so only considered injuries that caused a minimum of 3 days of training/playing interruption i.e. ≥3-day time loss.

Near-to-maximal sprinting speed exposures

Maximal sprinting speed was defined by two means, depending on available data. The ideal scenario was when a club was actually testing for MSS; in this case the provided data was used for analysis. In the situation when proper testing data wasn't available, we used the average of the three highest speeds reached in the entire data set of each player (after having manually removed all possible erroneous data >37 km/h).[11] Individual speed thresholds were then applied, using >85%, >90% and >95% of players' individual MSS.[11]

Sequence and turnaround participation

A player was considered as 'active' during a turnaround if he had an injury at any point during the microcycle, played the match that ended the current turnaround or if he had participated to at least one (3- to 5-d turnarounds) or two (6- and 8-d turnarounds) field (pitch, based on GPS readings) training sessions within that turnaround. Each individual player observation was considered as a player-turnaround. Player-turnarounds in which any injuries occurred, other than non-contact time loss hamstring injuries, were removed from the analysis.

For a first high-level type of analysis (i.e., "does it matter to touch near-to-MSS speed during training?"), we coded the entire individual player training sequences leading to the match (as a block of 2 to 7 days for 3- to 8-d turnarounds) as including (true) and not (false) one or more near-to-MSS exposure. Second, to dive further into the actual programming of the exposures, individual player near-to-MSS exposures distribution patterns were examined within each microcycle. Each day was coded as 'x' for a day without and as 'o' for a day with exposure (irrespective of the number of occurence per a given day); all possible combinations (e.g. x/x/x, o/x/x, x/o/x, x/x/o, o/o/x, o/x/o, x/o/o, o/o/o for 4-d turnarounds) were then created for each turnaround. We decided to group together the first training days of each turnaround up to D-3 included (i.e., D-6 to D-3 grouped as D-3 for a 7-d turnaround, and then D-2 and D-1 considered as unique typical days) for two main reasons: 1) there was a very large variability of combinations, especially for the longest turnarounds (e.g., 56 combinations within the 8-d turnaround, including from 1 to 233 player-sequences per combination) and 2) coaches generally split the between-match training cycle into two phases (recovery/compensation from D+1 until D-3, and match preparation D-2 and D-1). This grouping allowed for a standard 3-day combination for all turnarounds that could then be averaged all together. Since 3-d turnarounds don't include a D-3, this microcycle was only included in a part of this second analytical step. Finally, only the final 3-day combinations including ≥200 player-sequences, i.e. 10 turnarounds of 20 players, were retained for the analysis.

Considering all the above, the final analysis was run on a total of 627 players participating in 5052 training session days and 1358 non-international matches for a total of 24486 player-turnarounds (3 to 8 days), and 152 hamstring injuries, with 96 of those occurring during matches, as part of the 36 team-seasons.

Data analysis

We first looked at match hamstring injury rate within each turnaround in relation to >85%, >90% or >95% MSS running bout exposures during the overall block of training sessions leading to those matches.

Afterwards, we looked at match hamstring injuries in relation to the day when these exposures occurred (e.g., near-to-MSS exposure at D-2 vs D-1, respectively).

Statistical analysis

Results are presented as a mean and 95% confidence intervals. Substantial differences were assumed when the CIs did not overlap.[14] Cohen'd were then calculated to provide a magnitude of the differences, with thresholds of 0.2, 0.8, 1.2 and 2 considered as small, moderate large and very large effects/differences.

RESULTS

The number of player-sequences within each turnaround examined where >85%, >90% and >95% MSS exposures occurred (true) or not (false) during the training session days leading to the match are shown in Table 1, 2 and 3, respectively. The number and rate of hamstring injuries during matches are also shown in these 3 tables.

	Occurrence of >85% MSS running bouts	Number of player-sequences	Number of hamstring match injuries	Injury rate/1000 sequences (95% CL)

	during the training session days leading to the match			
3 d	False	7389	33	4.5 (2.9-6)
	True	1626	9	5.5 (1.9-9.1)
4 d	False	5663	17	3.0 (1.6-4.4)
	True	2750	9	3.3 (1.1-5.4)
5 d	False	1461	2	1.4 (0-3.3)
	True	1177	2	1.7 (0-4.1)
6 d	False	1037	1	1.0 (0-2.9)
	True	1580	4	2.5 (0.1-5)
7 d	False	1430	4	2.8 (0.1-5.5)
	True	3677	11	3.0 (1.2-4.8)
8 d	False	439	0	0.0 (0-8.4)
	True	1207	4	3.3 (0.1-6.6)
Total	False	17419	57	3.3 (2.4-4.1)
	True	12017	39	3.2 (2.2-4.3)

Table 1. Number of player-sequences within each turnaround examined where >85% MSS exposures occurred (true) or not (false) during the training session days leading to the match,

number and rate (95% confidence limits, CL) of hamstring injuries during matches.

	Occurrence of >90% MSS running bouts during the training session days leading to the match	Number of player-sequences	Number of hamstring match injuries	Injury rate/1000 sequences (95% CL)
3 d	False	8259	38	4.6 (3.1-6.1)
	True	756	4	5.3 (0.1-10.5)
4 d	False	6933	22	3.2 (1.8-4.5)
	True	1480	4	2.7 (0.1-5.3)
5 d	False	1992	4	2 (0-4)
	True	646	0	0 (0-5.7)
6 d	False	1724	4	2.3 (0-4.6)
	True	893	1	1.1 (0-3.3)
7 d	False	2564	7	2.7 (0.7-4.7)
	True	2543	8	3.1 (1-5.3)
8 d	False	843	2	2.4 (0-5.7)
	True	803	2	2.5 (0-5.9)

Total	False	22315	77	3.5 (2.7-4.2)
	True	7121	19	2.7 (1.5-3.9)

Table 2. Number of player-sequences within each turnaround examined where >90% MSS exposures occurred (true) or not (false) during the training session days leading to the match, number and rate (95% confidence limits, CL) of hamstring injuries during matches.

	Occurrence of >95% MSS running bouts during the training session days leading to the match	Number of player-sequences	Number of hamstring match injuries	Injury rate/1000 sequences (95% CL)
3 d	False	8774	42	4.8 (3.3-6.2)
	True	241	0	0 (0.0-15.2)
4 d	False	7837	23	2.9 (1.7-4.1)
	True	576	3	5.2 (0-11.1)
5 d	False	2416	4	1.7 (0-3.3)
	True	222	0	0 (0.0-16.2)
6 d	False	2254	5	2.2 (0.3-4.2)
	True	363	0	0 (0.0-10.1)

7 d	False	3902	12	3.1 (1.3-4.8)
	True	1205	3	2.5 (0-5.3)
8 d	False	1310	2	1.5 (0-3.6)
	True	336	2	6 (0-14.2)
Total	False	26493	88	3.3 (2.6-4)
	True	2943	8	2.7 (0.8-4.6)

Table 3. Number of player-sequences within each turnaround examined where >95% MSS exposures occurred (true) or not (false) during the training session days leading to the match, number and rate (95% confidence limits, CL) of hamstring injuries during matches.

Overall, the proportion of training sequences with at least one near-to-MSS exposure was clearly lower than without, i.e., 40%, 24%, 10% for >85, >90 and >90% MSS, respectively.

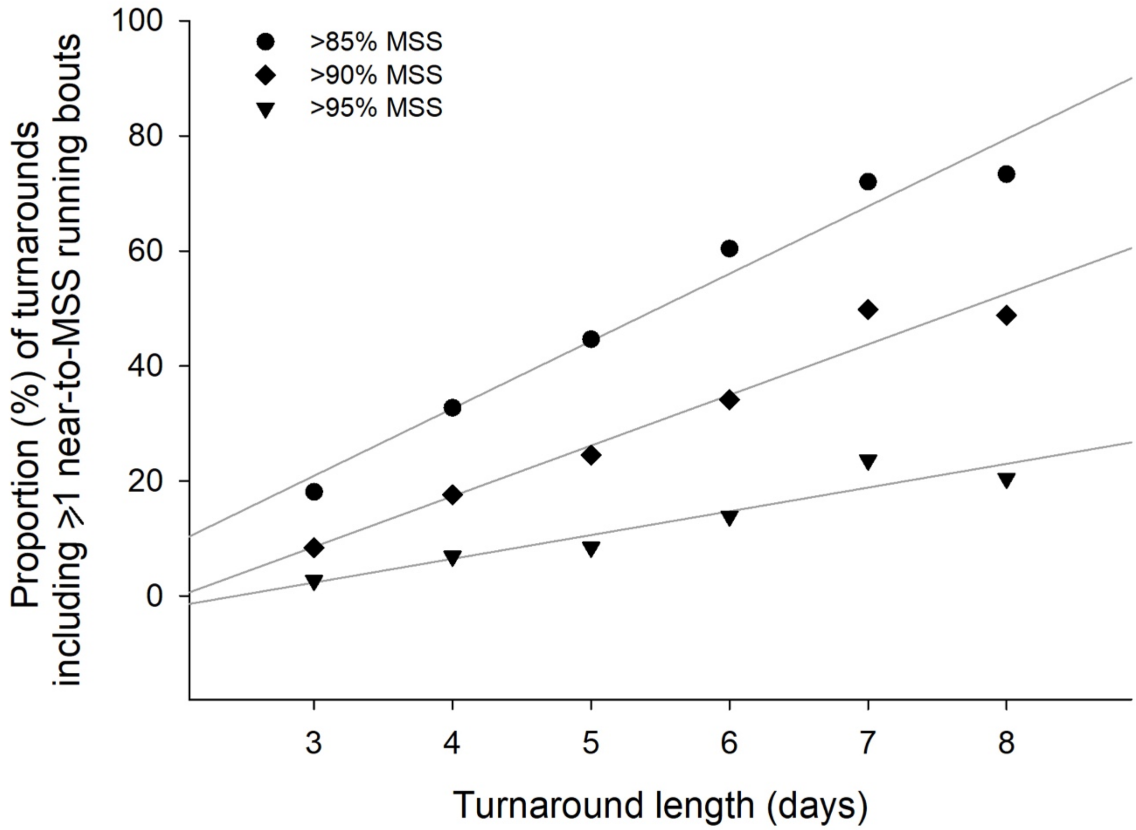

Figure 1. Association between the proportion of (training) player-sequences including at least one >85%, >90% and >95% MSS running bouts occurrence, and the length of the turnaround. Correlations coefficients were 0.98 (0.82;1.00), 0.98 (0.82;1.00) and 0.95 (0.60;0.99) for >85%, >90% and >95% MSS running bouts occurrences, respectively.

When looking at the turnaround level, there were linear correlations between the number of training sequences with near-to-MSS exposures and the length of the turnarounds - with the lower the speed thresholds, the greater the number (and proportion) of near-to-MSS exposures (Figure 1 and Tables 1-3). For example, when considering >85% MSS exposures, there were 2 (5-d turnarounds) to 5 x (3-d turnarounds) more sequences without exposures than with. For the longest turnarounds however, sequences with near-to-MSS exposures were 2 (7-d turnaround) to 3 x (8-d turnaround) greater than those without.

When looking at all turnarounds pooled, there was no difference in injury rate between training sequences including vs. not including near-to-MSS running exposures, irrespective of the speed threshold considered (Table 1-3). However, when looking within each turnaround, there were no match hamstring injuries when players were exposed to running bouts >90% MSS (i.e., 5-d turnaround) and >95% MSS (i.e., 3-, 5- and 6-d turnaround) during the training sessions days leading to matches (Table 3 and Figure 2 lower panel).

In contrast, injury rate was still substantial when considering running bouts >85%, and when looking at the majority of turnarounds with >90% MSS exposures (Table 1 and 2, Figure 2 upper and middle panel).

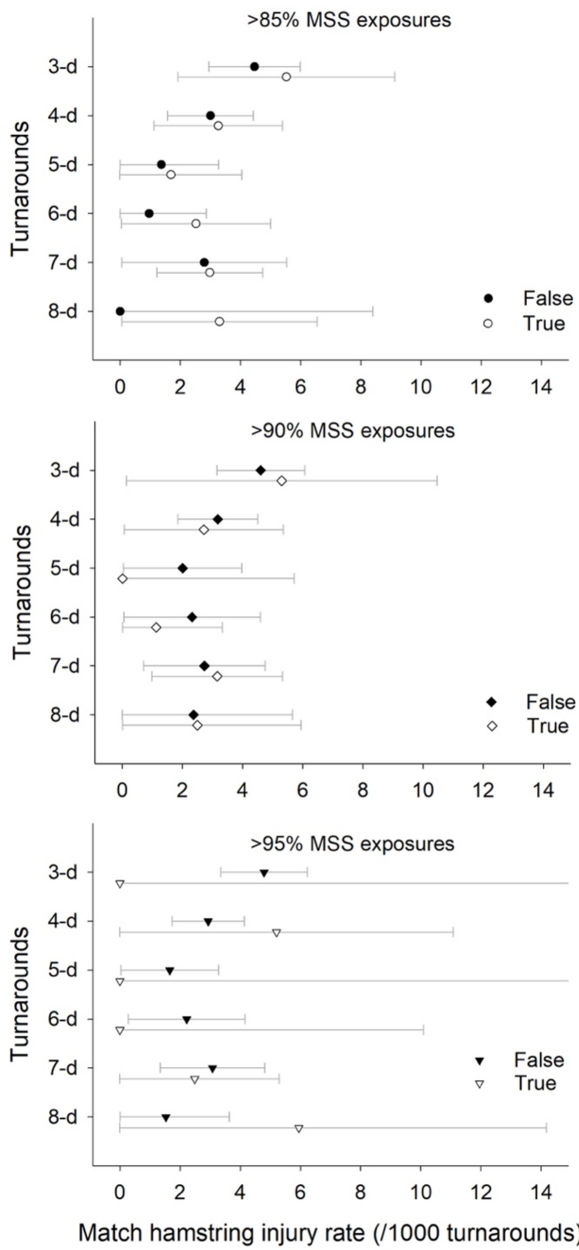

Figure 2. Match hamstring injury rate (with 95% confidence intervals, and per 1000 turnarounds participation) in players achieving (true) or not (false) >85% (upper panel), >90% (middle panel) or >95% (lower panel) of their maximal sprinting speed (MSS) during the training session days leading to the match, for the different turnarounds examined.

When looking specifically at the day(s) when >95% MSS was reached within an average turnaround (i.e., 4- to 8-d turnarounds pooled), there were four main patterns with large sample sizes (n >200): near-to-MSS occurrence at D-3 and before, n = 990 player-turnarounds and 6 injuries; at D-2, n= 480 and 0 injuries; at D-1, n = 215 and 2 injuries, and no exposure throughout the turnaround, n = 11168 and 46 injuries. The other day-combinations (e.g., occurrences both at D-2 and D-1) had all very low sample sizes (n < 50), for a total of 126 player-turnarounds in total and no injuries; these later combinations weren't used for analysis.

During 3-d turnarounds (excluded from the above analysis since not including D-3 data), 97% of the player-sequences (n = 5854 player-turnarounds and 42 injuries) didn't include 95% MSS exposures, with an hamstring injury rate of 7.1 (6.1-8.3). The number of other player-sequences were all below 80, with no injury when >95%MSS exposures occurred at D-2 or D-1.

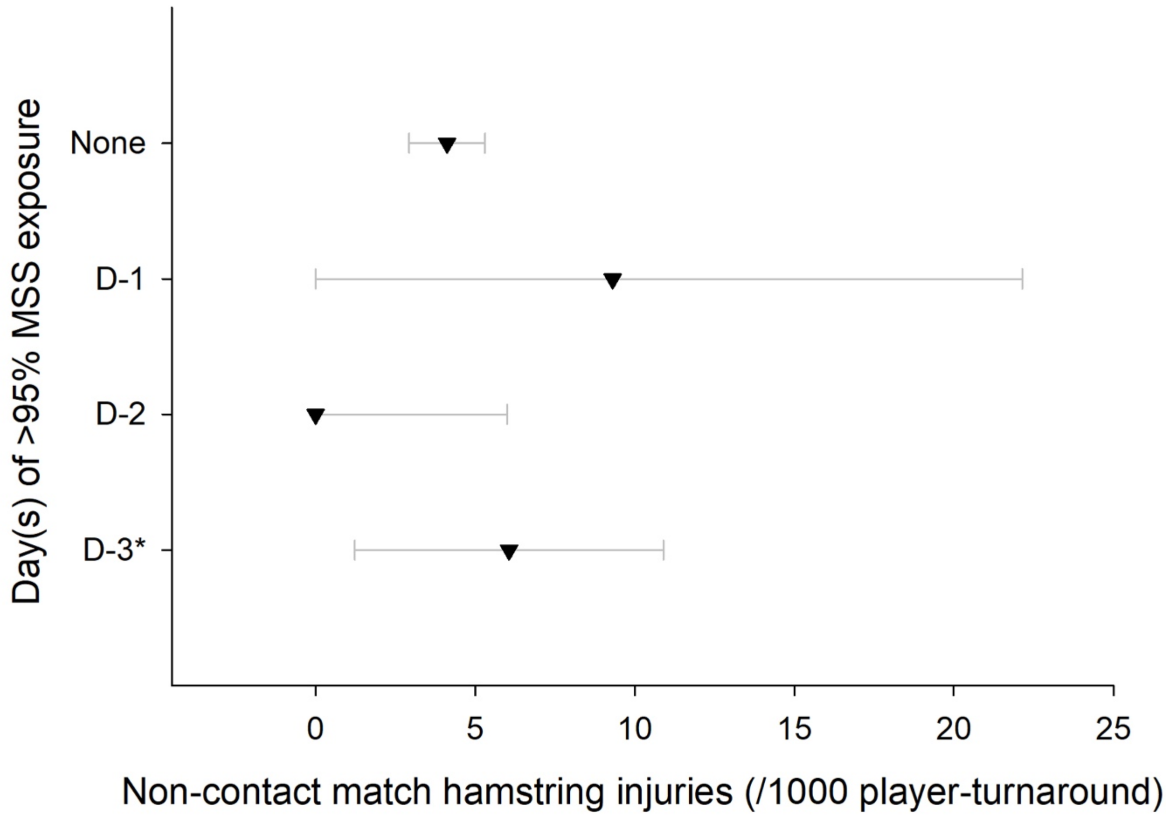

Figure 3. Match hamstring injury rate (with 95% confidence intervals, and per 1000 player-turnarounds) in relation to the training session day(s) of the turnaround when running bouts >95% MSS occurred. *Note that D-3 is an aggregation of all training session days of the turnaround before D-3 included (e.g., D-3 summarizes occurrences from D-6 to D-3 for a 7-d turnaround, see methods). Data presented here are from 4- to 8-d turnarounds pooled together; since there is no D-3 data during 3-d turnarounds, data from the entire 3-d turnarounds is excluded from this analysis.

When examining the pooled data and comparing these main four patterns, there was no observation of match hamstring injury when >95% MSS was reached at D-2 - and only for that day (Figure 3). In contrast, injuries still happened when players were not exposed at all, or when these exposures occurred at D-3 and/or earlier within the turnaround. The difference in injury rate between exposures at D-2 vs D-1 was unclear, likely due to the very low number of injuries for the latter (n=2!).

Finally, when adding the 3-d turnarounds to the analysis to increase the number of injuries up to 96 in total (Figure 4, but then removing the D-3 aggregation to be consistent), the trends were similar than in Figure 3, but there was almost no overlap anymore between the D-2 vs non-exposure alternatives (Figure 4).

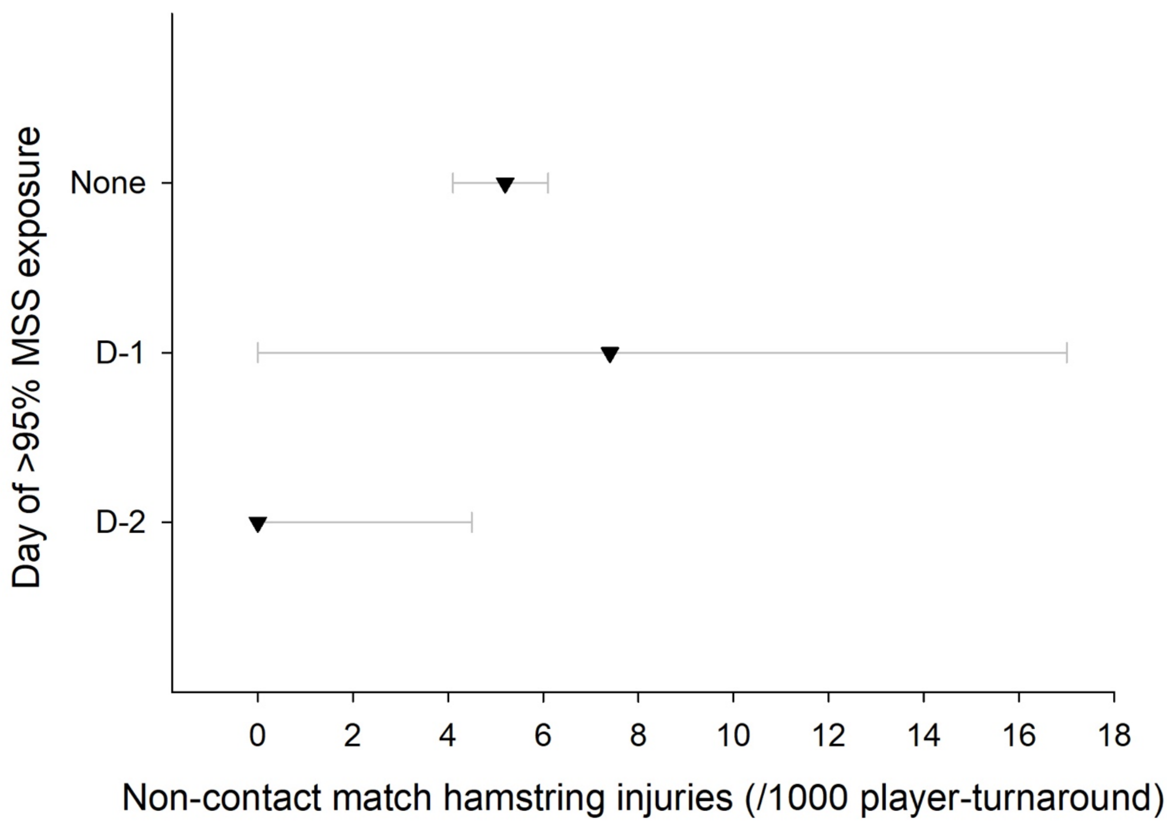

Figure 4. Match hamstring injury rate (with 95% confidence intervals, and per 1000 player-turnarounds) in relation to near-to-MSS exposure over the last two training day(s) of the turnaround - 3-d to 8-d turnarounds pooled.

DISCUSSION

This is to our knowledge the first study to examine both the occurrence of near-to-MSS running bouts within typical turnaround in elite football, and the association between the programming of near-to-maximal speed exposures and match non-contact time loss hamstring injury rates.

The main findings were the following: 1) the large majority of players arrived to the match without having been exposed to near-to-MSS running bouts during the training days of the current turnaround (60% for >85% MSS, 76% for >90% MSS and 90% for >95% MSS), 2) there were linear correlations between the number of training-sequences including near-to-MSS running exposures, and the length of the turnarounds, 3) for some of the turnarounds, there were no match hamstring injuries when players were exposed to running bouts >95% MSS during the training session days leading to matches, vs. when there was no exposures. In contrast, this was not apparent when considering running bouts only >85% or >90% MSS, and finally, 4) there were no hamstring injuries when >95% MSS exposures occurred at D-2, while in contrast, injuries still happened when players were not exposed at all, or when these exposures occurred at D-3 and/or earlier within the turnaround.

Near-to-MSS running bouts occurrences

The most common practice was not to touch near-to-MSS running speeds during training. On average, there were 3 to 10 x more player-turnarounds without near-to-MSS exposures than with, and it was only during the longest turnarounds that these higher running speeds were reached (Figure 1).

The first part of these findings is not surprising, and is likely related to the type of drills programmed by most coaches, which do not allow players to reach high speeds.[15] It is now well established that small-side games over small spaces are insufficient with this regard (since players may need to maximally sprint over at least 30 m to reach near-to-MSS speeds[16]), and that often, the only way to get players exposed to near-to-MSS exposures is to either program finishing and transition drills with enough depth[17] and/or individual sprinting drills with or without the ball.[18] The current results (discussed below) lend support to this latter practice.

The influence of the turnaround length on near-to-MSS running bout occurrence is also consistent with the results of our recent survey,[12] where the most important drivers for the programming of almost all training contents, and especially those demanding either at the neuromuscular or metabolic level, was reported to be the distance from and to the next match. With not enough time between matches, the emphasis is put on recovery, and practitioners likely consider maximal sprint work too demanding to be performed close to the previous match (the residual fatigue from the previous match may increase injury risk during sprint training itself). In fact, during periods of match congestion, the typical training programming (recovery and easy sessions) does not allow near-to-MSS exposures for starters; those higher-speed exposures may only be possible (and required, see below) for substitutes. When to program those high-speed exposures for subs is another great question for practitioners, and a tentative answer to this will be provided in the last part of the discussion.

How fast is enough?

While researches have shown associations between high-speed exposures and injury risk, there was still a lack of evidence about the minimal intensity required for those runs to be protective. In fact, large variations in relative velocities have been reported, ranging from ≥80,[9] to 85[8] or even 95% of MSS.[10] Our results show for the first time in a very large sample of elite soccer players (627 players for a total of 24486 player-turnarounds), that to be protective, near-to-MSS exposures may need to be performed >95% MSS (Figure 2). While limited with the present data, the fact that >95% MSS exposures may be superior to the lower relative speeds (85% and 90% MSS) with respect to injury rates, may be related to both higher levels of movements specificity (e.g., leg interaction, elastic energy transfer, reflexes, kinematics, kinetics)[6] and hamstring muscles recruitment that increase in parallel to running speed.

Programming near-to-MSS running bouts during the training microcycle

Previous research had suggested the existence of an optimal chronic "dose" in terms of near-to-MSS exposures (i.e., number of weekly exposure[8,10] and/or monthly cumulative distance.[9] However, this optimal chronic dose is likely specific to each population and context, and it is therefore difficult to provide guidelines for all practitioners on the back of those three studies. More importantly, those studies did not provide clear guidelines on how and when to program these near-to-MSS exposures during the weekly microcycle and during turnarounds of different lengths.

For these reasons, we believe that our results shed some light on the potential (more) optimal practices in the field.

In this very large data set, there were no match hamstring injuries when near-to-MSS exposures were programmed at D-2. Importantly, this was the case only when near-to-MSS exposures were programmed on that day (Figure 3 and 4). Despite the overlap of the CIs, this trend suggests that reaching near-to-MSS at D-2 may be the most advantageous strategy with respect to match hamstring injury occurrence.

The actual programming of MSS exposures at D-2 vs D-3 was actually one the areas the most debated among the practitioners we surveyed.[12] In accordance with the discussion around the alternance of moderate vs. light loads between D-2 and D-1, the sequence order of high-speed running (HSR) and MSS work may have some relevance in the context of injury risk. In fact, since high training loads including HSR and playing over large spaces (which are mainly programmed on D-3, irrespective of the periodization approach[12]) likely induce acute posterior chain fatigue,[19] the programming of MSS work the next day (D-2) could expose players to a higher risk of injury during those sprints (assuming that increased neuromuscular fatigue and the changes in mobility/pelvic control that follow such sessions increase injury risk).[20,21] For that reason probably, and in somewhat contradiction with the orientation of the tactical periodization approach that advises to plan speed work on D-2,[12] 75% of practitioners reported to program MSS on the same day as HSR (D-3) for both 6- and 7-day turnovers (Figure 7). This is often achieved during game-play sequences over large spaces[17] and/or through specific speed top-ups post session when speed targets are not reached.[18] Albeit anecdotal, several practitioners commented in their notes that while they had started to program MSS work at D-2 in the line of the tactical periodization paradigm, they ended up changing this specific programming aspect for the above-mentioned reasons[22,23] Another important comment in relation to this specific point, is that having ‘speed’ as the focus of the third acquisition day (following ‘strength’ and ‘endurance’[12] have been sometimes misunderstood: ‘speed’, as originally introduced, may not necessarily involve MSS work, but could simply refer to speed of execution, which is often implemented via short attacking transition work and finishing actions.

While the benefit of programming vs not programming near-to-MSS exposure is straightforward (i.e., preparing muscles to match-specific demands),[5,6] it remains unclear why exposing players at D-2 may be more appropriate than at D-1 or D-3 and earlier (if this is that clear, considering the CIs overlaps, though). This may be related to the recovery time course of the posterior chain muscles when running near-to-MSS.[24] Exposures at D-1 may not allow those muscles to be completely recovered on match day, and the stimulus (short-term conditioning effect?) may fade away when performed too early in the week (D-3 and earlier), losing it’s ‘protective effect’. Clearly, studies examining this recovery times course in ecological conditions would help better understanding this programming aspect. Practically, if D-2 was to be the most appropriate day for near-to-MSS exposures as per the current results (Figure 3 and 4), the programming of the other days of the week may need to be tailored accordingly (i.e., D-4 and D-3), so that players don’t reach D-2 with excessive levels of neuromuscular fatigue - not to be at higher risk of hamstring injuries during the exposures themselves. Additionally, while those D-2 exposures may concern the entire squad for long turnarounds (i.e., 6- to 8-d), they may only concern subs for 3- to 5-d turnarounds. In this latter scenario, practitioners reported to program these exposures either on match day immediately post-match, at D+1 or D+2 (in relation to potential days off).[12] The present D-2 practice is then straightforward when that day is either a D+1 (3-d turnaround), or a D+3 (4-d turnaround). For 5-day turnaround, the option could be to delay this exposure up to D+3/D-2, and/or spread it across multiple days (match day and then again D+3/D-2). As always, players and practitioners' experience would dictate the possible applications of the present findings in their own context.[25]

The lack of clearer differences between the different exposures scenarios (CIs overlap) - despite the very large data set - is likely related to the fact that other factors than the programming of near-to-MSS exposures *per se* may have a greater effect on injury rate, and, in turn, could have diluted/confounded the univariate analysis. This is an important limitation of the present analysis. While we thought to answer the simple question of the programming of near-to-MSS exposures, it is clear that injuries are largely multifactorial in nature[26] and that different chronic training loads and match minutes prior to the turnarounds examined, may also directly affect injury rates. However, we deliberately decided to zoom within each turnaround, since this is the way the very large majority of practitioners operate in the soccer field, taking and programming one turnaround after the other, with each of them being almost independent of the previous.[12] Additionally, the simultaneous consideration of player profiles (e.g., age, injury history, strength, mobility or flexibility) and other measures of internal training load and responses to load should also improve the analysis - while making the current outputs less straightforward for practitioners. There is in fact a trade-off between the desire for simple questions to have simple answers (e.g, when is it best to sprint?) and more sophisticated analytic approaches that may have more precision but require more effort to interpret in order to provide direct applications (i.e. results of multivariate analyses can be difficult to translate into simple yes/no answers).

Limitations

In the absence of consistent MSS testing practices across the different teams examined, player's MSS was determined from the available GPS data. While recent results have shown that players may be able to reach their true MSS during matches and some specific training sessions,[15] we were not able to verify this at the individual player level. It is therefore possible that inaccurate MSS were used in the analysis, which may have added noise to the results. Also, the low number of observations and injuries for some training sequences within some turnarounds can sometimes increase injury rate beyond its actual magnitude, which should be considered when interpreting the results. Finally, the injury records used for analysis are as good as what practitioners may have registered. Relying on injuries based on practitioners' entries is however common practice,[1] and we believe that the value of the information provided, derived from a very large sample size (n = 24486 player-turnarounds), partly outweighs those possible limitations.

Practical applications

Reaching >95% of MSS during training may be more protective against non-contact time loss match hamstring injuries than only reaching >85% or >90%. Additionally, programming 95% exposures at D-2 may be the more relevant strategy to decrease the incidence of non-contact match hamstring injuries than no programming exposures at all, or having those exposures at D-3 and/or earlier in week. If D-2 was to be the most appropriate day for near-to-MSS exposures, the programming of the other days of the week needs to be tailored accordingly (i.e., D-4 and D-3), so that players don't reach D-2 with excessive levels of neuromuscular fatigue - not to be at higher risk of hamstring injuries during the exposures themselves.

CONCLUSION

Using a very large data set (for a total of 667 players across 38 team-seasons), we showed for the first time that the large majority of players arrived at the match without having been exposed to near-to-MSS running bouts during the training days of the current turnaround. However, and while association doesn't imply causation, match hamstring injuries in elite football where systematically lower when >95% MSS exposures were programmed at D-2.

CONTRIBUTIONS

Contributed to conception and design: MB and MS
Contributed to acquisition of data: MS and MB
Contributed to analysis and interpretation of data: MB, MS, KH and DM
Drafted and/or revised the article: MB, MS, KH and DM
Approved the submitted version for publication: MB, MS, KH and DM

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