EDUCATION PROGRAMME

UEFA Research Grant Programme 2017/18 edition

Scheduling of concurrent-training preceding non-contact injuries in elite European football players by Kevin Enright, Liverpool John Moores University, England. *Project supported by the English Football Association.*

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1. Executive summary

Introduction: despite increases in our awareness of injury prevalence, the incidence of non-contact injuries has increased over the past ~10 years (Ekstrand, Waldén and Hägglund, 2015). It is likely that the increase in non-contact injury is associated with the evolving training demands and/or competition schedule of the modern game. However, at present there are no data describing the 'resistance-training load' in addition to the 'football training load' (i.e., concurrent training) prior to non-contact injury in professional football. Moreover, no studies have attempted to investigate if the distribution of training using the acute : chronic ratio (ACR) approach is different between types of non-contact injuries or for the severity of injury. **Aims:** this study aimed to 1) characterize the scheduling of concurrent resistance and football specific training in the 4 weeks prior to different non-contact injuries and 2) assess whether the 1:3 and 1:4 ACR for external training load data could differentiate between muscle versus non-muscle and hamstring versus non-hamstring non-contact injuries and 3) assess whether ACR could predict the 'severity' of the injuries sustained. **Method:** Twenty-eight days of retrospective training data prior to non-contact injuries were collected for *n*=264 injuries (age: 23.5±5.1 years; body mass: 75.5±8.1 kg, stature: 180.8±6.2 cm) (*n*=177 included in final analysis) from seven professional football teams. Injury type and severity were categorized by medical staff and 'external' training load was recorded using micro technology (S5, Catapult innovations, Melbourne, Australia). Total distance, (TD) high intensity distance (HID) and sprint distance (SD) ACRs 1:3 and 1:4 were calculated. Generalised estimating equations analysed for any association between injury type and severity with associated variables from GEE analysis categorised into 'very low' to 'very high' workload zones and checked for increased relative risks. Associated workload variables were also analysed for predictive power using receiver operating characteristic. All indices were compared using magnitude-based inferences. **Results:** No teams could provide accurate resistance training information. The ACR (1:3) for HSD and SD were associated with both muscle and hamstring injury when compared to non-muscle and non-hamstring injury ($p<0.05$). A greater risk of injury was found for players using ACR 13 SD 50^{th} – 85^{th} percentile; OR, 2.0; >85^{th} percentile; OR, 2.9) and were both deemed 'likely harmful' using magnitude based inferences. Although, all ratios showed poor predictive power (AUC <0.55). **Conclusion:** This study is the first to investigate the predictive value of ACRs on non-contact injury type and injury severity in professional football. Results highlight that whilst associations exist, the prognostic ability of acute chronic training loads to predict the type of non-contact injury or the severity of injury is poor. More work is needed to a) understand why teams have not reported resistance training activities and identify if this is a wider problem b) identify if specific training loads can predict injury severity using larger sample sizes.

2. Introduction

Injury in professional football is a significant problem that has wide reaching implications for player welfare, team performance and for football business (Ekstrand et al., 2015). Thus, understanding why players get injured is important for the key stakeholders in the sport (players, fans, medical staff, sports science practitioners and coaches). As non-contact injuries are viewed as avoidable compared to contact injuries, it is surprising that the frequency of non-contact injuries has increased over recent years and now accounts for approximately one third of all time lost in elite European professional football (Ekstrand et al., 2011). Some research indicates that an inappropriate 'training-load' has been shown to be causal to non-contact injuries (i.e., an excessive increase in 'load', or an insufficient training 'load') (Gabbett, 2015). As a result, elite teams typically monitor both 'external' (e.g., all of the movement actions during a training session) and 'internal' (e.g., the actual physiological and psychological stress imposed on the player's body) 'training-load' throughout the season (Jaspers et al., 2015). Despite the increased awareness of injury and the associated data collection, the incidence of acute non-contact injury has increased by 4% annually between 2001 and 2014 (Ekstrand, Waldén and Hägglund, 2015). The highest risk of a non-contact injury occurs during match play. Whilst this has remained stable across this period, the associated risk of sustaining a non-contact hamstring injury during training has increased in this 13 year period.

The increased incidence of sustaining a hamstring non-contact injury has coincided with relative increases in the speed of the game (Bush et al., 2016) and presumably the increased training demands associated with preparing players to perform at higher game intensities and speeds (Reilly, 2005). In this regard, teams are increasingly using a variety of additional training techniques that were not prevalent 15-20 years ago. Increasing training demands within the context of the already limited time available, inevitably leads to a situation where players perform multiple modes of training on the same day. The ergonomic model of soccer stipulates that this training is likely to be diverse (resistance based, aerobic, sprinting, speed endurance etc.). Moreover, the logistics of performing different modes of training mean that it is likely that training sessions are completed with varying amounts of recovery time between training bouts (e.g., endurance-based football-specific training and resistance exercise) (Enright et al., 2017). This training situation is more commonly referred to as 'concurrent-training' (Enright et al., 2015).

Studies to date that have investigated the training loads prior to acute non-contact injury have only quantified the demands of match-play and/or football specific training using rating of perceived exertion (RPE) and modified versions (sRPE-TL) or external training loads such as distance covered (m) using micro technology. It is surprising that considering the increased prevalence of alternative training techniques and their potential association with injury, studies have not attempted to quantify all aspects of training completed by teams. In addition, all studies to date have grouped all types of non-contact injuries together. It is plausible to suggest that each sub-type of injury might be influenced differently by the preceding training load. Therefore, the purpose of this project was to investigate how teams plan and implement all aspects of training prior to acute non-contact injuries. By attempting to collect a large sample, it was anticipated that training data between different types of acute- non-contact injuries could be compared.

3. Hypotheses & research questions

It was hypothesized that the scheduling of ‘concurrent-training’ and the associated ‘training-load’ will be different for each subtype of non-contact muscle injury (e.g., hamstring *vs.* non-hamstring, or muscle *vs.* non-muscle injuries) in the lead up to the injury.

RQ1. How do teams currently schedule concurrent resistance and football specific training in the weeks prior to a non-contact injury?

RQ2. Are there differences in the volume and frequency of ‘training-load’ in the lead up to different types of non-contact injuries?

- *2.a Can the acute chronic ratio differentiate between various non-contact injuries?*
- *2.b Can the acute chronic ratio predict the severity of non-contact injuries?*

4. Literature review

Studies investigating 'training-load' prior to non-contact injury have typically used the 'RPE' technique as a 'global' measure of internal 'training load' for all aspects of training and match-play (Impellizzeri, et al., 2004). Authors have also studied a variety of 'external' metrics derived from micro technologies (e.g., distance covered [m]) (Table 1). However, only six studies have included the 'resistance training' component of the training programme in the overall 'training-load' calculation using the 'RPE method' (Rogalski et al., 2013 Cross et al., 2011, Gabbitt, 2011, Killen et al., 2010) of which, only two studies were in professional football players (Jaspers et al., 2017; Malone et al., 2016). To the authors knowledge, no studies to date, have quantified the resistance training performed by players using the 'Volume Load' technique or reported the intensity of resistance training using percentage of 1 repetition maximum. Moreover none of these studies have specifically investigated the scheduling (order, sequence or recovery phase between exercise bouts) in the context of the soccer training environment.

Table 1: A summary of the studies investigating 'training-load' prior to 'non-contact injury' in athletes

Author/year	Number of non-contact injuries captured (n)	Population	Length of observation period	Sports specific training and match-play				Resistance training		
				Sport specific training	Match-play	sRPE-TL	Micro technology	Resistance training (sRPE)	Sequence of concurrent training	Proximity of concurrent training
Gabbett 2004	19	Semi-professional Rugby League players	1 season	✔	✔	✔	✗	✗	✗	✗
Killen et al., 2010	20	National Rugby League (17 - 32 years)	1 season	✔	✔	✔	✗	✔	✗	✗
Cross et al., 2011	465	4 English Premiership Rugby Union	1 season	✔	✔	✔	✗	✔	✗	✗
Gabbett, 2011	251	Pro Rugby league (23.3 ± 3.8 years)	4 Years	✔	✔	✔	✗	✔	✗	✗
Rogalski et al., 2013	96	AFL players (22.2 ± 2.9 years)	1 season	✔	✔	✔	✗	✔	✗	✗
Malone et al., 2016	75	Two CL teams (25.3 ± 3.1 years)	1 season	✔	✔	✔	✗	✔	✗	✗
Malone et al., 2016	91	Gaelic football (24 ± 3 years)	1 season	✔	✔	✔	✔	✗	✗	✗
Ehrmann et al., 2016	16	Australian A-League (25.7 ± 5.1 years)	1 season	✔	✗	✗	✔	✗	✗	✗
Murray et al., 2016	40	AFL players (23.5 ± 4.4 years)	2 years	✔	✔	✗	✔	✗	✗	✗
Jaspers et al., 2017	64	Eredivisie (23.2 ± 3.7 years)	2 seasons	✔	✔	✔	✔	✔	✗	✗
Lu et al., 2017	53	Australian A-League (26.4 ± 5.1 years)	2 seasons	✔	✔	✔	✔	✗	✗	✗
Bowen et al., 2017	138	Premier League Academy (17.3 ± 0.9 years)	2 seasons	✔	✔	✗	✔	✗	✗	✗
Colby et al., 2017	76	AFL players (22.9 ± 3.4 years)	4 seasons	✔	✔	✔	✔	✗	✗	✗
Carey et al., 2017	177	AFL players (22.9 ± 4.0 years)	2 seasons	✔	✔	✔	✔	✗	✗	✗
Murray et al., 2017	50	AFL players (23.1 ± 3.7 years)	1 season	✔	✔	✗	✔	✗	✗	✗
Bacon et al., 2017	85	Premier League Academy (17.8 ± 1.1 years)	2 seasons	✔	✔	✗	✔	✗	✗	✗
Fanchini et al., 2018	66	Elite Italian football players (26 ± 5 years)	3 seasons	✔	✔	✔	✗	✗	✗	✗
McCall et al., 2018	123	Elite European standard players (25 ± 4.9 years)	2seasons	✔	✔	✔	✗	✔	✗	✗

Completing 'concurrent-training' sessions on the same day and within a short period between exercise bouts is likely to increase metabolic stress and cause acute fatigue during the secondary training session (Fitts, 1994). Therefore, it is logical to suggest that an acute increase in muscle fatigue might have implications for injury risk and subsequently, the scheduling of training. A recent study investigated the effects of performing resistance exercise either immediately before or following a football-specific training session in elite football players (Lovell et al., 2016). The authors noted that when resistance exercise was performed immediately before football-training, acute fatigue was evident during the secondary exercise bout. This suggests that the organization of 'concurrent-training' in elite football players might have implications for injury risk. Moreover, authors have noticed a link between resistance-training 'workloads' and the incidence of injuries in other team sport athletes (Gabbett & Jenkins, 2011). It is possible this may also be applicable to elite football players who engage in 'concurrent-training'. However, at present, very little is known about how professional football teams schedule 'concurrent-training' within the micro-cycle. Previously, we surveyed the concurrent training practices of English professional soccer teams, observing that teams performed concurrent training in different exercise orders with diverse recovery periods between bouts. This highlighted that training practices were unsystematic (Enright et al., 2017). There are currently no evidence-based training guidelines suggesting a best practice approach to scheduling concurrent training in elite players to minimize the risk of sustaining an acute non-contact injury. Therefore, more work is needed to understand the acute responses to the concurrent training paradigms in professional soccer players.

4.1 Can acute : chronic ratios predict injury?

The acute change in training load relative to previous weeks has been suggested as a worthwhile exercise to predict non-contact injuries in professional athletes (Gabbett, 2016). This is more commonly referred to as the acute : chronic workload ratio (ACR) and can be calculated using 'internal' and/or 'external' 'training load' markers. Studies to date have used the ACR to predict injury in professional athletes. Here, generally higher workloads have been associated with injury. For example, rugby players who underwent rapid increases in acute total distance were more likely to get injured (Hulin et al., 2016). Similarly, a study assessing the workloads completed by cricket bowlers found threefold and fourfold rises in injury risk for external and internal workloads, respectively, when the training-stress balance exceeded 200%. These findings demonstrate that sudden increases in workload, above which fast bowlers are accustomed, increase the likelihood of injury in the following 1-week period (Hulin et al., 2014). Interestingly, athletes in this study with higher relative chronic ratios were at decreased risk of injury, suggesting being exposed to consistently high training loads could be beneficial. This is logical considering that training theory suggests the need to provide an appropriate balance between training and recovery to attain fitness which in turn can improve performance and reduce the chances of injury. This concept has been proposed by Professor Tim Gabbett who suggests that the way that the training is delivered (i.e., the distribution of training volume and intensity) versus the overall 'training load' per se is more indicative of injury. Indeed, Gabbett states that "excessive and rapid increases in training loads are likely responsible for a large proportion of non-contact, soft-tissue injuries. However, physically hard (and appropriate) training develops physical qualities, which in turn protects against injuries" (Gabbett, 2015 p.8). Thus, investigating the distribution of workloads for different injuries might enhance our understanding of how training prescription can influence injury outcomes. However, at present it is not known if different training prescriptions (i.e., ACR) are associated with different types of non-contact injuries. Moreover, it is not yet known if extremely high acute workloads can predict the severity of injury. Therefore, more work is required to understand the relationship between different acute chronic ratios, non-contact injury type and severity of injury.

5. A review of the proposed research design and strategy.

5.1. Justification of the design

Over the past 10 years, data capture within the football industry has increased. Largely driven by the associated increase in computing power and availability of technologies, this phenomenon has led to a situation where players are recorded daily. Information collected typically includes data derived from micro technologies (e.g., Catapult tracking devises) and subjective 'wellness', 'sleep' and 'perceived exertion' scores. Data concerning player medical status is usually stored on a central database (e.g., the premier leagues' 'performance management application [PMA]' or other 'bespoke' software designed by each football club) where the data can be organised in a logical order and tracked over time. However, the nature of working in football stipulates a significant time demand on staff, which could limit their ability to investigate the large amount of data collected. For this reason, the present study used a '*retrospective cohort study design*', which offers an opportunity to analyse this data.

5.2. Justification of the measurement approach and assumptions about the research topic

As this is secondary data there are a number of assumptions, which include;

- Clubs are categorising and recording start and end time of all types of training (i.e., resistance training, football training etc.)
- Strength and conditioning staff are collecting resistance training data (i.e., exercises, repetitions, sets, weight lifted)
- The most up-to-date hardware and software for micro technologies are being used at the time of injury.
- Each training session has been 'cropped' in the same manner to include metrics derived from actual exposure.
- All players are wearing the same GPS unit in training to minimise reliability issues.
- Clubs are not using individualized speed thresholds and that if they are then the researcher will be notified to exclude data-points

5.3. The sample frame and size

The inclusion criteria stipulated that players must have sustained a non-contact injury whilst playing for a recognised UEFA member team. Seven professional teams competing in recognised UEFA leagues participated in this study. All clubs were asked to classify non-contact injury sub-types by trained medical staff. Twenty-eight days of retrospective training data prior to the injury day were collected for n=264 injuries (age: 23.5±5.1 years; body mass: 75.5±8.1 kg, stature: 180.8±6.2 cm). Data collected contained training load and injury information across the 2015/2016 or 2016/2017 seasons. All injuries and training data recorded were retrospective.

5.4. An outline of the key variables used

5.4.1 Training frequency and organisation

For each training day (*n*=28), descriptive training information was requested. This data included; the frequency and type of training, sequence of 'concurrent-training' (e.g. football-specific endurance-training followed by resistance-training (ET-RT) or resistance-training followed by football-specific endurance-training (RT-ET). To differentiate between different types of training, the weekly sessions were categorised into five sub-components; 'football-specific endurance-training', 'resistance-training', 'match-play', 'recovery-sessions' and 'days off'. Football-specific endurance-training' (ET). Each training session or match was classified as an ‘exposure’. Data from GPS tracking devices during training sessions were also requested from each club and used to calculate acute chronic workload ratios.

5.4.2 Training load

Workload was quantified using GPS derived data collected from all on-pitch training sessions and matches (S5, Catapult innovations, Melbourne, Australia). Each specific unit was placed inside a custom-made vest supplied by the manufacturer. All devices were activated using manufacturers guidelines to allow acquisition of satellite signals. The Unit samples at 10 Hz and the accelerometers at 100 Hz. Following each session, the data were downloaded using the specialised analysis software by the club analyst. For sessions when GPS data were unavailable for a participant, data were removed from the final analysis. Due to different approaches used by each team the variables that were consistent for each team were used for the final analysis. These variables included total distance (m) (TD), high intensity distance (>5.5 m/s) (m) (HID) and sprint distance (> 6.9m/s) (m) (SD).

5.4.3 Injury data collection

All injury information was classified by the respective medical departments. Here, medical doctors and chartered physiotherapists diagnosed, collated, and recorded each injury type. Due to the differences in approaches for the purpose of the present study a non-contact injury was defined as one that involved no physical contact from another player during training and resulted in absence from future football participation (training or match-play). Injuries were also categorised by injury type (description), body site (injury location), tissue type (e.g. muscle or ligament) (appendix 1). The severity of each injury was recorded as the number of days missed from training.

5.4.4 Acute chronic ratio (ACR)

Acute chronic ratios were calculated using the GPS derived data collected across the 28-day period prior to each injury. The last session recorded before the injury was classified as 'day 1'. From this day the data was categorised into 7-day phases backward (regardless of the day of the week). The acute workload was defined as the average 'load' for the 7-days prior to the injury. Due to issues with mathematical coupling previously highlighted by Lolli and colleagues (2017), the acute training load was not included in the overall ACR. As a result, the chronic workloads were calculated as either a) the average of the 2nd and 3rd week prior to the injury (ACR13) or b) the 2nd, 3rd, and 4th week prior to injury (ACR14).

5.5. The statistical analysis strategy

Prior to analysis of acute chronic ratios, variance inflation factors (VIF) were determined to detect multicollinearity between markers; where multicollinearity was found data was excluded from the subsequent analysis. To assess the association between acute chronic ratios (1:3 and 1:4) for each variable and injury, generalised estimating equations (GEE) were used (McCall et al., 2018). The severity of injury (i.e., the number of days missed from training) was analysed using in linear (scale) function. Comparisons of 'muscle injuries *vs.* non-muscle injuries' and 'hamstring *vs.* non-hamstring injuries' were made using a binary logistic function (yes/no). For each of the above analyses an exchangeable correlation matrix based on lower quasi-likelihood under the independence model criterion was chosen (Fanchini et al., 2018). If significant ($p<0.05$) the variable was divided into four percentiles (0-15th, 15-50th, 50-85th, 85-100th) and categorised as extremely low, moderately low, moderately high and extremely high, respectively. Injury Risk (IR) was calculated by dividing the number of occurrences of the injury (e.g., hamstring) by the total number of injuries (e.g. hamstring + all 'other' / non-muscle injuries) and the Odds Ratio (OR) was calculated by the number of injuries (e.g., hamstring) divided by the number of non-injuries (e.g., all non-hamstring injuries). Magnitude based inferences were utilised to better understand the risk between each percentile (Hopkins, 2009). The smallest beneficial/harmful effect was set using the smallest worthwhile change for each variable (i.e., pooled standard deviation multiplied by 0.2). Using guidelines outlined by Hopkins (2007) effects were considered unclear if the chance of the true values of beneficial was >25% with the OR <66. If the effect was considered clear, thresholds for assigning qualitative terms of beneficial, trivial, harmful were; <0.5%, most likely; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely. Following the GEE analysis, variables deemed to be significant (i.e. $p < 0.05$) were assessed for predictive ability using receiver operating characteristics (ROC) curves. Specificity, sensitivity and the area under the curve (AUC) (± 95% CI) were calculated. Using guidelines from Menaspà et al., (2010) an AUC of >0.70 and >0.50 were suggested to have "very good" and "good" discrimination power. From all ROC curve plots the Youden Index (J) were calculated by adding the sensitivity to the specificity and subtracting 1 to determine the point where the sensitivity and specificity were optimised. Predictive ability of each variable was calculated using the equations described by Fanchini and colleagues (2018). Here, sensitivity represented a [true positive/(true positive + false negative)*100] and specificity [false positive/(false positive + true negative) *100] were calculated for each load-based marker using the 85th percentile as cut-off. Exposure data across weeks between injuries was analysed using a one-way ANOVA. Data are presented as mean ± standard deviations (mean ± SD) with significance set at 95%. Aspects of the descriptive analysis were carried out using Microsoft Excel (Redmond, Washington). Descriptive and advanced statistical analysis were completed on the statistical packages 'IBM SPSS Statistics' (version 24.0) (Armonk, New York) and MedCalc Software, (Ostend, Belgium).

5.6. The validity and reliability of the instruments and variables applied

The reliability of the micro technology devices typically ranges from 2.1 to 11.3%, for distance (TD), sprint distance (SD) and high speed distance (HS) (Rampinini et al., 2015). In order to minimise the intra-unit variability, it was confirmed that each player wore the same 'GPS device' across the observational phase.

5.7. An overview of any ethical issues and how they are addressed

This study was granted ethical approval from Liverpool John Moores University Ethics committee in February 2017. Prior to data collection all clubs were informed of the nature of the study and of their right to withdraw at any time; after which, written informed consent, were requested from both the player and the club. As this study, involved retrospective data collection, there were no physical and/or immediate risks. In order to protect the identity of the players, all data was anonymised by the club before sending the data to the researchers. The researchers were therefore unable to identify individual players. The researchers also ensured that all data was coded so that no one from outside the research team were able to identify individual clubs or players. All data was stored on encrypted desktop computers so that the data could not be accessed by anyone outside the research team. The highest ethical standards and the guidelines outlined by the World Medical Assembly were adhered to throughout this project.

6. Results and Discussion

6.1 Results

Twenty-eight days of retrospective training data was collected for a total of 264 injuries from seven professional teams. Eighty-six data sets were excluded due to inconsistent and/or missing data. One hundred and seventy-eight non-contact time-loss injuries were recorded and included in the final analysis. All teams involved in this study were unable to provide accurate training-load information for any 'resistance-training' sessions across the observational period. Therefore, no data is presented for resistance training variables from this point forward.

6.1.1 Training frequency and duration of training

Table 2 shows the weekly frequency of training and match play (exposures) for muscle injuries *vs.* all non-muscle injuries and for hamstring injuries *vs.* all non-hamstring injuries. Data is presented as cumulative 7, 14, 21 and 28 day total exposures, weekly total exposures and average duration of training for 7, 14, 21 and 28 days and weekly averages. There were no statistically significant differences between groups ($p>0.05$).

Table 2 Descriptive information for training and match-play exposures prior to hamstring, non-hamstring, muscle and non-muscle injuries.

Exposures (n)	Hamsting vs. Other muscle types		Muscle vs. Other tissue types	
-7 days	4.7 ± 1.2	4.7 ± 1.4	4.8 ± 1.3	4.6 ± 1.2
- 14 days	8.9 ± 2.1	9.1 ± 2.2	9.1 ± 2.0	9.0 ± 2.4
-21 days	13.2 ± 2.9	13.3 ± 2.8	13.4 ± 2.7	13.0 ± 3.1
-28 days	17.2 ± 3.7	17.3 ± 3.8	17.4 ± 3.5	17.2 ± 3.9
Exposures (n)				
- 1 week	4.7 ± 1.4	4.7 ± 1.2	4.8 ± 1.2	4.6 ± 1.3
- 2 weeks	4.2 ± 1.3	4.4 ± 1.6	4.4 ± 1.7	4.3 ± 1.4
- 3 weeks	4.3 ± 1.5	4.1 ± 1.6	4.3 ± 1.7	4.1 ± 1.5
- 4 weeks	4.0 ± 1.9	4.0 ± 1.6	3.9 ± 1.7	4.1 ± 1.7
Average Duration (min)				
-7 days	64.2 ± 11.1	68.2 ± 16.0	60.1 ± 16.3	59.9 ± 16.8
- 14 days	63.8 ± 10.0	68.9 ± 15.0	60.0 ± 13.4	62.3 ± 15.2
-21 days	63.3 ± 10.9	69.3 ± 14.9	59.7 ± 11.6	62.0 ± 13.7
-28 days	63.7 ± 10.6	69.9 ± 14.0	59.1 ± 11.3	61.8 ± 11.8
Average Duration (min)				
- 1 week	64.2 ± 11.1	68.2 ± 16.0	60.1 ± 16.3	59.9 ± 16.8
- 2 weeks	63.5 ± 13.7	68.9 ± 17.5	59.8 ± 17.9	66.7 ± 22.9
- 3 weeks	61.5 ± 17.4	70.0 ± 18.2	58.1 ± 16.7	61.6 ± 21.1
- 4 weeks	65.5 ± 19.0	72.5 ± 16.4	57.6 ± 20.0	61.7 ± 17.4

6.1.1 Association between external workload and non-contact injury

The results of the GEE analysis for scale data (i.e., days missed from training) and binary data (i.e., muscle *vs.* non-muscle; hamstring *vs.* non-hamstring injuries) are presented in tables 3 and 4 respectively. The acute chronic ratio (1:3) for sprint distance showed significant associations when compared between muscle *vs.* non-muscle injuries (p=0.02) and hamstring *vs.* non-hamstring injuries (p=0.05). High intensity distance also showed a significant association between muscle injuries and non-muscle injuries (p=0.02). No significant associations (p>0.05) were found for any other acute chronic ratios (Muscle injury *vs.* non-muscle injuries: total distance; ACR13 TD; p=0.60, ACR14 TD; p=0.29, HID; p=0.17, SD; p=0.31. Hamstring *vs.* non-hamstring: ACR13 TD; p=0.37, ACR13 HID; p=0.09, ACR14 TD; p=0.36, ACR14 HID; p=0.55, ACR14 SD; p=1.00).

Table 3. Association and prediction of different load markers. Odds ratios, 95% confidence intervals (95% CI) and P-level from the Generalized Estimating Equation analysis for load-based markers and linear outcome (days missed from training).

	Days of from full training	**Association Exp B (95% CI)**	**P level**	**Clinical inference**
Acute Chronic 1:3				
	Distance (m)	1.2 (0.25 - 5.6)	0.75	Likely harmful
	High intensity Distance (m)	0.7 (0.05 - 0.9)	0.17	Unclear
	Sprint Distance (m)	0.15 (0.01 - 1.76)	0.13	Unclear
Acute Chronic 1:4				
	Distance (m)	1.0 (0.35 - 3.3)	0.75	Unclear
	High intensity Distance (m)	1.0 (0.2 - 5.2)	0.40	Unclear
	Sprint Distance (m)	0.3 (0.01 - 0.9)	0.49	Unclear

Table 4: Association and prediction of acute chronic ratios for muscle injuries verses non-muscle injuries and for hamstring injuries verses non-hamstring injuries.

	Association Exp B (95% CI)	P level	Clinical inference	Predictive pover AUC (95% CI)	J	Sensitivity	Specificity
Muscle injuries vs all other							
Acute Chronic 1:3							
Distance (m)	0.7 (0.2 - 2.4)	0.60	Unclear	0.52 (0.45 to 0.60)	0.09	55.46 (46.1 - 64.6)	53.45 (39.9 - 66.7)
High intensity Distance (m)	2.2 (1.1 - 4.3)	0.02	Very likely harmful	0.51 (0.43 to 0.58)	0.05	78.99 (70.6 - 85.9)	25.86 (15.3 - 39.0)
Sprint Distance (m)	0.7 (0.5 - 0.9)	0.02	Unclear	0.53 (0.45 to 0.60)	0.12	15.97 (9.9 - 23.8)	96.49 (87.9 - 99.6)
Acute Chronic 1:4							
Distance (m)	0.4 (0.1 - 1.9)	0.29	Unclear	0.54 (0.47 to 0.62)	0.11	79.83 (71.5 - 86.6)	31.03 (19.5 - 44.5)
High intensity Distance (m)	1.7 (0.7 - 3.7)	0.17	Likely harmful	0.50 (0.42 to 0.58)	0.09	78.15 (71.5 - 86.6)	31.03 (19.5 - 44.5)
Sprint Distance (m)	0.8 (0.6 - 1.1)	0.31	Unclear	0.52 (0.44 to 0.60)	0.11	10.92 (5.9 - 18.0)	100 (93.7 - 100.0)
Hamstring injuries vs all other							
Acute Chronic 1:3							
Distance (m)	0.6 (0.2 - 1.7)	0.37	Unclear	0.54 (0.47 to 0.68)	0.13	42.59 (29.2 - 56.8)	69.92 (61.0 - 77.9)
High intensity Distance (m)	1.6 (0.9 - 2.9)	0.09	Likely harmful	0.50 (0.43 to 0.58)	0.11	38.89 (25.9 - 53.1)	72.36 (63.6 - 80.0)
Sprint Distance (m)	0.8 (0.6 - 0.9)	0.05	Unclear	0.52 (0.441 to 0.59)	0.16	24.07 (13.5 - 37.6)	91.8 (85.4 - 96.0)
Acute Chronic 1:4							
Distance (m)	0.6 (0.2 - 1.6)	0.36	Unclear	0.54 (0.46 to 0.61)	0.13	85.19 (72.9 - 93.4)	27.64 (20.0 - 36.4)
High intensity Distance (m)	1.2 (0.5 - 2.8)	0.55	Likely harmful	0.50 (0.43 to 0.58)	0.11	38.89 (25.9 - 53.1)	72.36 (63.6 - 80.0)
Sprint Distance (m)	1.0 (0.7 - 1.3)	1.00	Unclear	0.55 (0.48 to 0.63)	0.16	22.22 (12.0 - 35.6)	93.44 (87.5 - 97.1)

Odds ratios, 95% confidence intervals (95% CI) and P-level from the Generalized Estimating Equation analysis for load-based markers and binary outcome (injury: yes/no). Area Under the Curve (AUC) and 90% CI from the Receiving Operator Characteristic curve (ROC) analysis and the Youden Index (J)

6.1.2 Relative risk and odds ratio

The injury risk (IR) for comparisons between each percentile and magnitude-based inferences are presented in table 5. Players exhibiting an acute chronic ratio (1:3) sprint distance above the 50th percentile showed an increased risk of muscle injury when compared to all non-muscle injuries (RR 0.67; OR, 2.0, likely harmful and RR 0.74; OR, 2.9, Likely harmful, respectively). Players with an acute chronic ratio (1:3) sprint distance of either extremely low $<15^{th}$ percentile or moderately high (50th to 85th percentile) also showed a moderately increased risk of hamstring injury when compared to all non-muscle injuries (RR 0.5; OR, 0.5, likely harmful and RR 0.35; OR, 0.5, Likely harmful, respectively).

Table 5: Injury risk comparisons between different zones of load (<15th, 15–50th, 50–85th, >85th percentile).

Marker	Injury Risk (%)	Load Zones	Odds ratio (90% CI)	Qualitative term for clinical inference	Chances (%) the effect is beneficial/trivial/harmful
Muscle injuries (n = 119) vs. all other (n = 58)					
Acute Chronic 1:3 High Intensity Distance	0.64	< 15th < 0.52	1.8	Unclear	24/29/47
	0.69	15-50th 0.52 to 0.96	2.3	Unclear	22/44/35
	0.66	50-85th 0.96 to 1.03	2	Unclear	17/42/40
	0.68	>85th > 1.03	2.1	Unclear	44/35/21
Acute Chronic 1:3 Sprint distance	0.64	< 15th < 0.32	1.8	Unclear	22/53/25
	0	15-50th 0.32 to 0.90	0	Unclear	50/0/50
	0.67	50-85th 0.90 to 1.09	2	Likely Harmful	4/6/91
	0.74	>85th > 1.09	2.9	Likely Harmful	09/08/83
Hamstring injuries (n = 54) vs all other (n = 122)					
Acute Chronic 1:3 Sprint distance	0.35	< 15th < 0.32	0.5	Likely Harmful	5/11/84
	0	15-50th 0.32 to 0.90	0	Unclear	50/0/50
	0.35	50-85th 0.90 to 1.09	0.5	Likely Harmful	0.5/0.5/99
	0.11	>85th > 1.09	0.1	Possibly harmful	31/12/58

6.1.3 Prediction

The ROC curve (Figure 1), the values AUC (95% CI) and the Youden Index (J) for each load marker (Table 4) showed poor predictive ability of injury (AUC: 0.50–0.55). When using the 'extremely high' and 'extremely low' percentiles as cut-off points, the acute chronic ratios (1:3) for sprint distance showed moderate 'sensitivity' and 'specificity' for both predicting muscle and hamstring injuries (Muscle injury *vs.* non-muscle injuries: 60.2%, 63.8% respectively; Hamstring *vs.* non-hamstring injuries: 58.5% and 60.2% respectively) (Table 6).

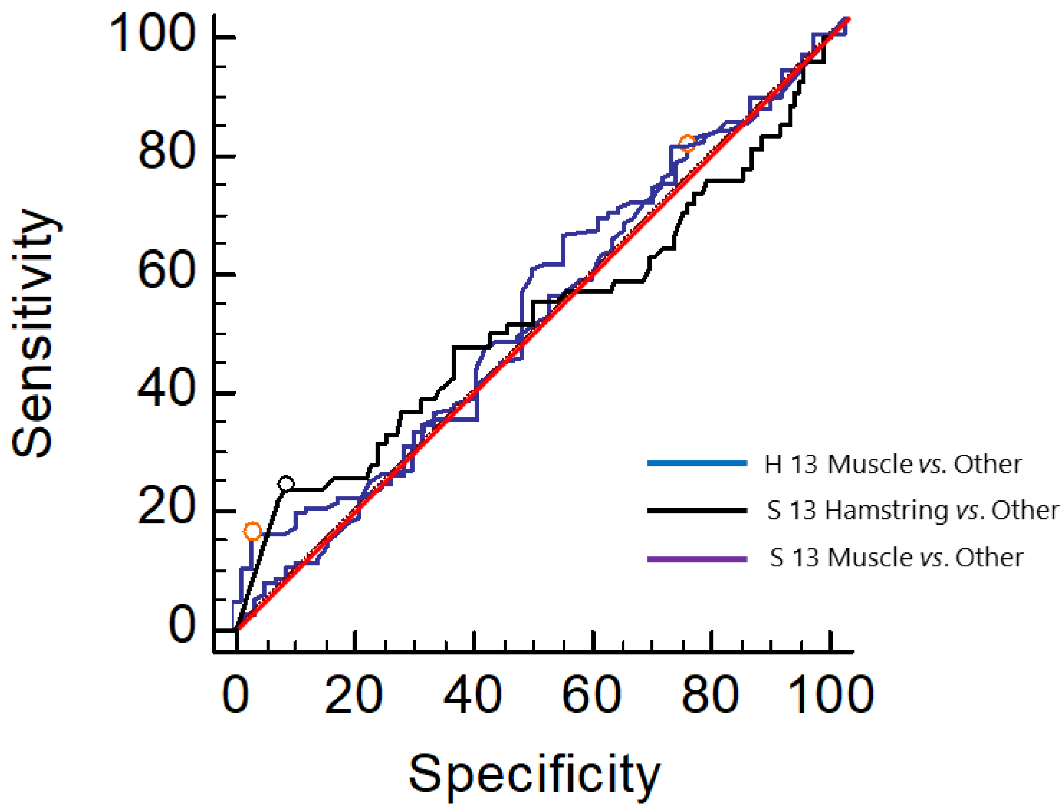

Figure 1. Receiving operating characteristic (ROC) curves for the acute chronic ratios (1:3) for high intensity distance *vs.* all non-muscle injuries (H13), and sprint distance hamstring v non-hamstring muscle (other), (S13 Hamstring *vs.* Other) and muscle tissue v non-muscle injuries (other) (S13 Muscle *vs.* non-muscle injuries [other])

Table 6. Sensitivity and specificity for each marker when the load is extremely high or extremely low (i.e., >85th percentile and <15th percentile).

	True positive	False positive	False negative	True negative	Sensitivity (%)	Specificity (%)
Muscle injuries (n = 119) vs. all other (n = 58)						
Acute Chronic 1:3 High Intensity Distance	36	18	83	40	30.3	31.0
Acute Chronic 1:3 Sprint distance	74	37	45	21	62.2	63.8
Hamstring injuries (n = 54) vs all other (n = 122)						
Acute Chronic 1:3 Sprint distance	37	74	17	49	68.5	60.2

True positive: the players with injury with marker >85th percentile; False positive: the players without injury with marker >85th percentile; False negative: the players with injury with marker <85th percentile; True negative: the players without injury with marker <85th percentile.

6.2 Discussion

The primary aim of this study was to provide a more comprehensive understanding of the 'concurrent-training load' (i.e., including resistance training and the scheduling of all aspects of training) that players experience prior to injury, than previously published. Unfortunately, all teams were unable to provide resistance training-load information. Therefore, we were unable to answer this research question. The secondary aim of this study was to understand the frequency of training before injury and to investigate if 'acute chronic workload ratios' were 1) able to differentiate between different types of acute non-contact injuries (muscle *vs.* non-muscle injury and hamstring *vs.* non-hamstring injuries) or 2) predictive of the severity of injury (days missed) in professional football players. The results highlight that there were no differences in exposure to training and match play (frequency and minutes) between injuries (Table 2). We also show an association between the ACR1:3 for high intensity distance and sprint distance for muscle injuries compared to non-muscle injuries. There was also an association between ACR13 sprint distance for hamstring injuries verses all non-hamstring injuries. However, all three of these associations had no predictive value to discriminate between players who got the injury and players who sustained the alternative injury(ies). There were no associations between injury type and injury severity.

6.2.1 Acute chronic ratios and injury severity

The results of the GEE analysis (Table 4) indicated that the acute chronic ratios 13 and 14 for total distance, high intensity distance and sprint distance were not associated with the severity of injury. This finding suggests that external ACRs derived from distance data, whilst important to monitoring in a practical sense, has no predictive value for the number of days a player will miss from training following injury. However, the relatively smaller number of severe injuries observed in this study (appendix 1) might explain this finding. More work is required to better understand whether different training loads can predict the type and severity of non-contact injuries sustained by players. At present studies have typically reported the incidence of non-contact injuries which are often mild and moderate 'lay-offs' for players (<14 days). This method alone provides an incomplete and sometimes even erroneous picture of the true impact injuries can have on a team (Bhar et al., 2017). For example; it is known that severe injuries such as a torn anterior cruciate ligament can remove a player from training and match-play for around 200 days resulting in significant distress for players and performance / financial implications for clubs (Hickey et al., 2014).

6.2.2 Acute chronic ratios: muscle *vs.* non-muscle injuries and hamstring *vs.* non-hamstring injuries

This is the first study to compare external load ACRs between muscle *vs.* non-muscle injuries and hamstring *vs.* non-hamstring injuries in a professional cohort of elite players. The results support the findings of McCall et al., (2018) and Fanchini et al., (2018) in that, despite being statistically significant (*p*<0.05) the acute chronic ratios in this study have a negligible predictive ability in differentiating between each injury type (AUC < 0.6). Although, whilst no significant associations between injury types were detected using traditional 'probability-based' statistics, magnitude-based inferences revealed 'likely harmful effects' (Table 5) for ACR 13 sprint distance (muscle *vs.* non-muscle injuries) (OR 2.9). This is in line with Colby et al. (2017) who noted that players with a 'moderate' ACR 13 sprint distance had a lower injury risk when compared to players who experience 'extremely low' and 'extremely high' sprint ACRs. This finding suggests that a 'rapid increase' in sprinting should be avoided to reduce the likelihood of muscle injuries (Duhig et al., 2016, Soligard et al., 2016). Instead, a gradual increase and maintenance of sprint-based activity over time is likely to have a preventative effect on muscle injuries.

6.2.3. Is the ACR sensitive enough to differentiate between different types of injury?

The sensitivity of each variable was calculated as the true positive/true positive + false negative multiplied by 100. This measure is said to predict if a player will sustain the injury or not. In this instance, it represents those who have sustained the injury at 'extremely high' and 'extremely low' acute chronic ratios (i.e. >85th percentile and <15th percentile). Our results show that the sensitivity for ACR13 high intensity distance (muscle *vs.* non-muscle), ACR13 sprint distance (muscle *vs.*

non-muscle), and ACR13 sprint (hamstring *vs.* non-hamstring) was 30%, 62% and 68% respectively. This means that for 36 injuries detected there were 18 false positives for (ACR13 HID) and for 74 muscle injuries detected there were 37 false positives who sustained another injury (ACR13 SD (Muscle *vs.* non-muscle). Whilst for hamstring *vs.* non-hamstring for every 37 true hamstring injuries there were 74 non-hamstring injuries (Table 6). This suggests that the present data is unable to predict muscle or hamstring injuries when compared to non-muscle and on hamstring injuries respectively. This could be because of the relatively low sample sizes, and due to a relatively low cut off point of the 85 percentiles (1.09) when compared to others (Fanchini et al., 2018; 1.26, Soligard et al., 2016; 1.5). Therefore, more work is required with a larger sample size to fully understand if different workload ratios can differentiate between different types of non-contact injury.

6.2.4 Conclusion

The present study is the first to model non-contact injury type and injury severity in professional football players. We present novel data that highlights that the frequency of exposures and the duration of training/match-play does not differ between injury types. We also highlight that whilst associations exist, the prognostic ability of acute chronic training loads to predict the type of non-contact injury is poor.

7. The limitations of the current study and future research

The nature of a retrospective study with multiple clubs has a number of inherent limitations. These include;

- All teams involved in this study were unable to provide accurate training-load information for any 'resistance-training' sessions across the observational period. Considering that resistance training history is likely to be a modifiable risk factor for future injury it is important that we understand more about this aspect of the training programme and its relationship with injury - both as a cause and as a preventative measure. Also, as all teams were unable to provide accurate records of resistance training there is a need for a standardised method to quantify resistance training between clubs so that studies investigating the effects of training on injury can control for resistance training.
- It must also be acknowledged that 86 injuries were excluded due to missing and incomplete data, if all correct this would have been the largest data set currently available. This suggests there is a need to standardise methods between clubs and share data so that larger sample sizes can be achieved. This could ultimately enhance our understanding of the impact that different training loads have on fitness, fatigue and injury.
- The nature of professional football means that the medical staff can change on an ongoing basis, which can lead to inconsistencies in the way that data is collected and stored, possibly influencing the reliability and validity of data. We

did not investigate if the medical teams changed within clubs across each respective observational period and could be a confounding factor.

- The players participated in a variety of other conditioning workloads as well as the on-field sessions that could not be quantified by GPS derived loads. Whilst, the incorporation of perceived training load values (as a measure of internal workload) may provide a more complete insight into the likelihood of injury, it could also be important to monitor the actual work completed in the gymnasium.
- In the present study two injured groups were compared, possibly limiting the differences between groups. Therefore, it is recommended that future studies include a matched non-injured control for each injury. If possible, this could provide insights into the relationships between different types of non-contact injury and training load.
- Objective measures combined with RPE-values and other data such as perceived muscle soreness, fatigue, mood, and sleep ratings might improve our understanding of the complex interplay between training load, injury and recovery.
- The greater sampling frequency of the units used in this study (10 Hz) allowed for valid and reliable assessment of high intensity activity and injury risk that was not possible in previous studies using lower sampling devices (e.g., 1 and 5 Hz). However, the measurement error has been found to increase with speed, regardless of sampling rate. This could also account for the present findings and must be considered when interpreting the present data set.

- The complexity of injury risk also suggests that there are likely to be a number of confounding factors which might influence the current findings. While GPS outcomes may be considered modifiable injury risk factors, non-modifiable factors, both internal (age, fitness level, flexibility, somatotype and injury history) and external (equipment and environmental) were not considered, despite being associated with future injury incidence. Unfortunately, assessing such variables was beyond the capacity of the present project and therefore warrants further attention.
- Only 'external load' was assessed in this study, while other studies examined internal loads (i.e., RPE); future studies should examine both internal and external measures together. This approach could allow for a more detailed understanding of the training loads players experience prior to injury.
- We examined workload across 7-day periods; future analysis could model workload on a daily or even on a sessional basis. This might allow more 'resolution' which could inform the 'daily' training loads within the applied environment.
- In the present study we compared muscle injuries *vs.* non-muscle injuries and hamstring injuries *vs.* non-hamstring injuries (binary 1/0). Our injury records contained more detailed information of the injury type and pathology (muscle, tendon, bone, ligament or joint injury); however, due to statistical power an examination of injury risk within each subclass was not possible. Therefore, future studies could aim to include a larger sample of injuries which may enable

researchers to examine the relationships between acute and chronic time windows, workload variables, different injury pathologies and the severity of injuries. In addition, whilst the sample size was one of the largest samples to date (n=177) the sample size was not large enough to allow us to conduct position specific analysis.

7.1 Operational issues, such as data access

This study originally was designed to be a joint initiative with an industry partner who provide micro-technologies to approximately 40-50% of all professional teams in Europe. It was intended that the finances from UEFA and the industry partner would fund a full time post-doctoral researcher who could concentrate solely on this project. The unfortunate withdrawal of this partner at a late stage meant that we did not have access to their contact list (personnel) within each prospective club and were also unable to appoint a fulltime individual to manage this project. This was a major limitation of the project and restricted our ability to collect a larger sample size.

7.2 Inherent partiality

The author reports no conflicts of interest

8. The impact of the research in terms of current theory, state of knowledge and/or practices, and the consequences for UEFA and football

The primary aim of this study was to characterise the concurrent-training load prior to injury. As all teams were unable to provide training information for the 'resistance-based activity'. This highlights a potential problem in that teams might not be accurately monitoring and recording resistance-training across the season. Therefore, more work is required to understand why teams are not recording this information. Development of a standardised method to record resistance training could be useful to enable comparisons to be made for future studies. Indeed, a comprehensive understanding of the 'concurrent training load' (i.e., including resistance training and the scheduling of all aspects of training) that players experience prior to injury, could allow us to investigate such training paradigms in the future.

The secondary aim of this project was to characterise the frequency of training/match-play and the distribution of 'training-load' prior to different types of non-contact injury. Specifically, we wanted to investigate if the 1:3 and 1:4 acute chronic ratios were different between muscle and non-muscle injuries and hamstring verses non-hamstring injuries and to assess any relationship between ACR and the severity of injury. Our results have highlighted that for the athletes in the present study the exposure rate (frequency and minutes) was not different between injury type and did not change across each week. Moreover, as the acute chronic ratios was not different between injury type, this suggests that on average the training distribution is relatively stable between weeks regardless of injury type. This offers a new insight to the literature and suggests that whilst acute chronic rations might be associated with injury risk, they cannot predict the type of injury or the severity of injury. This report supports the call previously put forward by Bhar and colleagues (2017) to incorporate the 'severity' of injury in all future studies that use the acute chronic ratio to predict injury. A better understanding of the 'training loads' experienced by players prior to severe non-contact injuries (e.g., ACL) could allow us to design 'smarter' training interventions in the future that could reduce the incidence of such injuries. However, much more work is required before we can definitively predict injury.

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Appendix 1

Severity of Injuries

	Frequency	Percent
1 to 3 days missed - Minimal	35	19.8
4 to 7 days missed - Mild	38	21.5
8 to 28 days missed Moderate	73	41.2
29 to 100 days missed - Severe	31	17.5
Total	177	100.0

Area of Injury

	Frequency	Percent
Hamstring	54	30.5
Adductor/Groin	35	19.8
Ankle	20	11.3
Back	9	5.1
Anterior Thigh	23	13.0
Knee	14	7.9
Foot	2	1.1
Hip	4	2.3
Calf	15	8.5
Glute	1	.6
Total	177	100.0

Tissue Type

	Frequency	Percent
Muscle	119	67.2
Ligament	18	10.2
Bone	14	7.9
Joint	3	1.7
Cartilage	3	1.7
Nerve	2	1.1
Tendon	15	8.5
Unknown	3	1.7
Total	177	100.0