Manuscript Title: Heart rate' based training intensity and its impact on injury incidence amongst elite level professional soccer players.

Brief running head: Training intensity duration and injury

ABSTRACT

Elite level professional soccer players are suggested to have increased physical, technical, tactical and psychological capabilities when compared to their sub-elite counterparts. Ensuring these players remain at the elite level generally involves training many different body systems to a high intensity or level within a short period of time. This study aimed to examine whether an increase in training volume at high intensity levels were related to injury incidence, or increased the odds of injury. Training intensity was assessed through time spent in two high- and very high- intensity zones of 85-<90% and ≥90% of maximal heart rate (T-HI and T-VHI, respectively), and all injuries were recorded over two consecutive seasons. Twenty-three elite professional male soccer players (mean±SD age 25.6±4.6 years, stature 181.8±6.8 cm, and body mass of 79.3±8.1 kg) were studied throughout the 2-yrs span of the investigation. The results showed a mean of total injury incidence of 18.8 (95% CI 14.7 to 22.9) injuries per 1000 h of exposure. Significant correlations were found between training volume at high intensities and injury incidence (r=0.57, p=0.005). It was also revealed that players achieving more time in the T-VHI zone during training increased the odds of sustaining a match injury (odds ratio=1.87, 95% CI 1.12 to 3.12, p=0.02), but did not increase the odds of sustaining a training injury. Ensuring that training loads are not significantly exceeded causing accumulative fatigue within competitive matches may assist in reducing the number of injuries at the elite level of professional soccer.

Key Words: Football; athletic injuries; heart rate; odds ratio; risk.

INTRODUCTION

The implications of a high number of training days and matches lost due to injury is suggested to be to the detriment of team success (2), especially for soccer teams unable to replace players of similar abilities due to limited resources. Recently, Eirale et al. (48) even showed a clear relationship between teams' ranking and injury rate. Indeed, in the Qatari Professional league it resulted that lower injury incidence rate was strongly correlated to team success over an entire season.

Soccer is a high intensity intermittent contact sport exposing elite level players to continual physical, technical, tactical, psychological and physiological demands (34, 35). The stressors encountered during actual match-play have been suggested to show no detrimental effect of consecutive games' physical performance, but a greater injury risk (10). From training prospective, cardiovascular and neuromuscular adaptations are suggested to be stimulated through a high training load, induced through manipulation of intensity, duration and frequency of training (7). However, if the intensity or volume is increased by an amount above the level at which various physiological systems can adapt, injury may result (22,23,41). Even if both training zones could overlap, with the high load training zones (i.e., combination of training intensity and training volume) resulting in further positive adaptations being already located in the lower part of the ‘‘high risk of injury zone'', it would be important to understand the optimal training load at which adaptation occurs without drastically increase the risk of injury; this, in order may provide a safe and progressive training adaptation process.

In soccer, high intensity training (HIT) has increasingly been suggested and used to bring about cardiovascular adaptations (8,28,34,35), although often this training type is reported to require players working at high to very high intensities, as indicated by high heart rate responses (>85%HRmax) (35). In this context, most of the studies report mean match HRs of about 85%

HRmax, but it is obvious that these averaged values are composed of numerous parts of the games when the players are recovering or just exercise at low intensity, and, also bursts of very high intensity efforts with HR exceeding 95% HRmax (49).

The HI nature of soccer match play, combined with multiple HIT units at the elite professional level, impose bodily strain (38), potentially causing performance decrements and increasing the risk of injury (23). Indeed, injury incidence in soccer is high with approximately 20 to 35 injuries occurring per 1000 h of match exposure (13,15) and injuries during training sessions ranging between 5.8 to 7.6 per 1000 hours (2,44). Some, report that a greater number of overuse injuries occur in the pre-season training period (26,29,50), suggesting that training volume and intensity of HIT and usually performed at pre-season, could be associated with increased injury risk. Subsequently, it may be important to consider whether training intensity training relates to injury incidence, in order to educate coaches or other sport professionals involved within the physical progression of players. Program or session design must ensure that training load is not significantly exceeded to manifest itself in an accumulative fatigue nature leading to players missing training/matches due to injury.

Gabbett and Dumrow (23) found that training load (volume x intensity) increased the odds of sustaining an injury, however, this particular study involved rugby players, and injury exposure was estimated based on average training duration, rather than calculated per player. Furthermore, ratings of perceived exertion (RPE) scores were used as a measure of intensity (training load = RPE x training duration). Although popular owing to its ease of use (1,6), this method depending upon the personal perception of physical effort (30,6) does provide a valid estimates of total session mean intensity, but does not provide data about the periods spent at various training intensities (47). Heart rate training zones (HR_Z) have been used as an alternative and objective measure of estimating training intensity (5,14,19,35), with HR being reported as a valid and reliable indicator of exercise intensity within soccer training (28,31). Currently, there are no studies investigating the relationship between injury incidence and HIT quantified through HR within elite level professional soccer.

Based on the lack of research within this area, the purpose of the current study was to examine whether individual week training load through time spent in HR_Z (T-HI and T-VHI, time spent in High intensity- and very high intensity- zones, respectively), was related to injury incidence or increased the odds of sustaining an injury in both training and matches. It was hypothesized that a greater time spent in the T-VHI HR_Z would increase the odds of injury and therefore, would be associated with a higher injury incidence.

METHODS

This prospective, cohort, surveillance study was carried out throughout two competitive seasons (2008/09 and 2009/10). To examine if a greater time spent at 85–<90% (T-HI) and ≥90% (T-VHI) of HR_{max} is associated with a higher injury incidence, the relationship between training intensity and injury incidence was determined. Secondary outcome measures including injury severity, type, and frequency were also measured. Furthermore, odds ratios were determined in order to examine if higher individual training load would increase the odds of injury. Injury incidence was presented as the number of injuries per 1000 h of exposure, with exposure recorded for each player rather than being estimated for the group (24). Since relationships have been previously reported between injury incidence and players' age (27), body composition (4), maximal oxygen consumption (VO_2max) (17), and vertical jump height (3), these variables were measured in the present study to examine their impact on injury.

Subjects

Twenty-three elite male professional soccer players from a Scottish Premier League team and who were at the time competing at UEFA Champions League level participated to the investigation. At the initiation of the study players involved had a mean ±SD age of 26.8±4.6 (range: 18 to 38) years, stature of 181.8±6.8 (1.70 to 1.92) cm, and body mass of 79.3±8.1 (62.5 to 93.6) kg. All participants had been playing soccer for 10 years or more, and all but three of them were also competing at an international level. Participants were informed that they were free to withdraw from the study at any time without penalty. Procedures followed were in accordance with the Helsinki Declaration of 1975, approved by the ethical committee of the collaborating University and followed the standards of the sport science and medical department of the researching soccer club.

Measure of injury

The injury definitions and recording methods used for analysis of each injury followed guidelines recommended by the International Soccer Injury Consensus Group (20,24). In this regard, an *''injury was defined as any physical complaint sustained by the soccer player either in training or in competition, which prevented the injured player from participating in competition or normal training for at least one day, but not including the day of the injury''* (20). This type of injury has been referred to as a time-loss injury (20). Injury incidence was categorized according to incidence per match (i.e., the number of match injuries in relation to the time spent in matches), and incidence per training (the number of injuries during time spent in training), as well as total injury incidence (sum of training and match injuries in relation to overall training and match exposure) (20,24). The severity of each injury was defined by the time lost from usual training or competition, and was categorized in the following way: slight as 1 to 3 days; minor as 4 to 7 days, moderate as 8 to 21 days, and major as >21 days (26,40). Injuries were classified according to whether they were overuse or traumatic (20). Other information recorded about the injury included: the nature of the injury (sprain, fracture, etc.), the location (body part), the date, and whether or not the injury was a preceded by a previous one (recurrent), the latter being defined as an injury that had occurred previously at the same location and of the same nature (20). All injuries were diagnosed and recorded by the club's medical staff, to which the players had free access. Injuries were recorded throughout both seasons. Illness was not taken into account within the present study.

Training load

A laboratory-based maximal incremental running test was carried out prior to the training period with the use of a computerised treadmill (Technogym, Run 500 model, Italy) in order to determine the precise individual maximal oxygen uptake (VO_2max) and HRmax. Players followed the VO_2 max running protocol of Hoff et al (28) and a pre-calibrated breath-by-breath metabolic system was used (Medical Graphics Cardiopulmonary Exercise System, CPX/D, Medgraphics Corp., St. Paul, Minnesota). Individual HR_{max} and VO_2max were derived by using the mean of the two highest 15-s averages achieved during the final stage of the VO_2max test. A true HR_{max} and VO_2max were considered to have been achieved, if both variables failed to increase despite an increase in exercise intensity (42). The protocol used is commonly utilized for testing endurance performance in professional football players (28) and involved participants running on the treadmill set at a 3° incline with a precise speed increase of 1 km/h every minute until exhaustion. Before the protocol test, players performed a 3min warm up eliciting a HR of approximately 70% HRmax in addition to self selected stretching exercises .

Heart rate was continuously monitored on outfield players throughout the training sessions for the duration of the study and recorded at 5s intervals by lightweight and portable HR monitors (Polar Team System, Polar Electro OY, Kempele, Finland) (35). Goalkeepers were not measured for HR during the sessions. After each testing session HR data was downloaded to a computer using dedicated software (Polar Precision S-Series Software SW 3.0; Polar Electro, Kempele, Finland) and stored for analysis. The mean and %HRmax achieved during each game was calculated for each player, and each player's total time spent in specific HR zones as used by a previous study (22): ≤50%; 50-<60%; 60-<70%; 70-<85%; 85-<90% HRmax (T-HI) and ≥90%HRmax (T-VHI). However, for the purpose of this particular study the time spent within the higher intensity zones T-HI and T-VHI have been assessed and reported to differentiate between 'training intensity' (9). These two HR_Z categories were chosen since previous research in elite level soccer has reported how HR >85% are key when discussing training adaptations (35).

Statistical Analyses

Prior to analysis, injury incidence and HR data were explored (and confirmed) for normality and for equality of variances. Data are expressed as mean±SD, percentages and 95% confidence intervals (CI), where relevant. Statistical significance was set at $p<0.05$.

Pearson correlations were used to examine the relationships between training load and injury (incidence, severity, type, and frequency), as well as between injury incidence and physiological/anthropometrical data. The magnitude of the correlations was determined using the modified scale by Hopkins (2000): trivial: $r < 0.1$; low: 0.1-<0.3; moderate: 0.3-<0.5; high: 0.5-<0.7; very high: 0.7-<0.9; nearly perfect ≥ 0.9; and perfect: 1.

A stepwise, multiple linear regression analysis was used to predict injury incidence; variables having a higher correlation coefficient than r=0.50 (and a significant relationship) were included in the analysis (51). The adjusted R^2 was used to assess the proportion of the variance explained by the independent variables.

Odds ratios (OR) were used to examine whether the training load increased or decreased the odds of injury. Odds ratios were derived by tallying the frequency of injury on a monthly basis, since training was organized into mesocycles (4 weeks). Training load per mesocyle was categorized according to whether it was considered to be a 'high training load' or a 'low training load', by using a median split of the data. Odds of training load increasing the frequency of match injuries, training injuries, traumatic and overuse injuries, and total injuries, and of increasing the frequencies of injury severity, were examined.

A Chi-squared test (χ^2) was used to determine whether the observed injury frequency differed from the expected injury frequency**.** Expected injuries were calculated as the same proportion of the total injuries as the mesocycle training load score was of the total training load score, following the method of Gabbett (21).

The training load within the previous mesocycle prior to the injury being sustained was determined and assessed to provide an accurate picture of the relationship between training load and injury. This was due to anticipation that training loads would be lower in the month that an injury was sustained due to reduced training availability. An independent samples t-test was then used to examine whether training load, training exposure and match exposure differed significantly in the mesocycle prior to injury, compared to the mesocycles when injury did not occur.

RESULTS

Over the two seasons, the players were exposed to a total of 1704.4 h of match-play, and 5350.0 h of training, which equated to an average of 4.8±3.8 h of training time per match hour. The team played 116 matches, 54 in season one and 62 in season two, with the higher number in season two due to UEFA Champions League fixtures. There were a total of 130 injuries recorded over the two seasons. In addition, there were two players who missed training or match play due to ‘’illness’’ one time each. Five of the 130 injuries (3.9%) were sustained outside of soccer hours (recorded as ‘other’). Recurrent injuries accounted for 4.6% (n=6) of all injuries. ‘’Other’’ injuries and ‘’illnesses’’ were excluded from further analysis regarding injury incidence, injury type, cause, site and severity, leaving a total of 119 injuries. Recurrent injuries were excluded when describing injury type, cause and severity, so as not to falsely elevate these values. Of the remaining 119 injuries, 87 were match injuries and 39 were training injuries. Thirty-nine (45%) of the 87 match injuries were overuse and 48 (55%) were traumatic. Seventeen (53%) of the 32 training injuries were overuse, and 15 (47%) were traumatic. Total injury incidence was 18.8 (95% CI 14.7 to 22.9) injuries per 1000 h of exposure. Training Injury incidence was 6.7 injuries per 1000 h of training exposure (95% CI 3.7 to 9.6), and match injury incidence was of 54.1 (95% CI 39.7 to 68.6). Type and site of injuries (for both match play and training) are given in Tables 1 and 2, respectively. Of the match injuries, 9.2% (injury incidence of 8.7) were slight, 35.6% (21.7), were minor, 33.3% (24.64) were moderate, and ~~2.2~~21.8% (15.6) were major. Of the training injuries, 28.1% (injury incidence of 2.03) were slight, 21.9% (1.61) were minor, 28.1% (1.67) were moderate, and 21.9% (1.44) were major.

Commented [KC1]: Sorry sum 80.3 and not 100% for sub-groups of match injuries.. please check

Commented [KC2]: Here the sum is 100µ BUT the 28.1 is repeated twice with each time a different incidence 2.03 and 1.67 please check.

Commented [FJ3]: Values are correct because injury incidence was calculated based on actual time spent in training/match play per player; incidence differed per player.

Insert Tables 1 and 2 here

Data for injury frequency and training intensity are given in Figure 1. There was a significant correlation between total injury incidence and training intensity (T-HI: r=0.57, p=0.005; T-VHI: r=0.568, p=0.005). There was also a significant correlation between training injury incidence and training intensity, but only for T-HI (r=0.48, p=0.02). Correlations were low between match injury incidence and training intensity (T-HI: r=0.09, p=0.69; T-VHI: r=0.19, p=0.38). Correlations were significant for number of days off due to injury (an indication of injury severity) and training intensity (r=0.51, p=0.01 for T-HI, and r=0.47, p=0.02 for T-VHI). There was a significant correlation between training intensity and total number of traumatic injuries (r=0.42, p=0.04 for T-HI, and r=0.44, p=0.03 for T-VHI).

Insert Figure 1 here

Percentage body fat for the 23 players was 10.1±2.7 (5.1 to 16.3)%, and mean VO_2max was 53.7±4.3 (52.1 to 68.6) $ml \cdot kg^{-1} \cdot min^{-1}$. A significant negative correlation was observed between injury incidence and percentage body fat (r=-0.43, p=0.04), but correlations between injury incidence and all other anthropometrical/physiological variables were low and non-significant.

A forward stepwise linear regression, with T-HI and T-VHI in the model, gave an adjusted R^2 of 0.28, p=0.014 for injury incidence; hence, training intensity explained 28% of the variance in injury incidence.

The odds ratios of sustaining an injury due to training intensity are given in Table 3. Only one of these values was significant, with a greater time spent in T-HI resulting in a greater odds of sustaining a match injury (χ^2= 7.22, p=0.059).

Insert Table 3 here

There was a significant difference between the observed total injury frequency and the expected injury, as determined as a proportion of training intensity (mean T-HI, χ^2=33.2, p=0.04; mean T-VHI, χ^2=33.5, p=0.04). Differences were also significant when separately analysing training injuries (for T-HI, χ^2=38.0, p=0.01; and T-VHI, χ^2=36.7, p=0.02), and match injuries (for T85, χ^2=48.4, p<0.001; and T90, χ^2=48.3, p=0.001).

Mean differences (including significance) in time spent in each intensity zone in the month preceding an injury and in the mesocycle when an injury did not occur are given in Figure 2.

Insert Figure 2 here

DISCUSSION

The main purpose of this study was to examine whether training intensity, as assessed using T-HI and T-VHI, increased the odds of sustaining an injury. In this sample of 23 professional, male soccer players, individual training load was highly related to total injury incidence ($r=0.57$, $p=0.005$). Training intensity (T-HI and T-VHI) explained 28% of the variance in injury incidence. Odds ratios for training intensity and injury incidence were negligible with no discernable pattern apparent. For instance, an increased proportion of time spent at 85-<90% HRmax significantly increased the odds of sustaining a match injury, but did not increase the odds of sustaining a training injury (Table 2).

Accumulative fatigue from training may have played a fundamental role whilst carried over into match-play, which could explain this higher odds ratios for match injury incidence. Using χ^2 analysis, the observed total injury frequency and the observed training injury frequency were significantly different ($p<0.05$) from the number of injuries that were expected to occur based on training intensity, which suggests that training intensity and injury frequency were not associated. It seems, therefore, that training load approach, assessed using HR_Z, has only a moderate effect on injury incidence, and does not increase the odds of injury. This finding is contrary to what reported by Gabbett and Dumrow (23), who found that high training load increased the odds of injury in rugby players. The discrepancy in relation to the current study may be explained by how Gabbett and Dunrow (23) estimated training intensity (ratings of perceived exertion (RPE) were used and defined as ‘training load’, as opposed to heart rate in the current study), and how exposure was calculated (the number of players were multiplied by session duration to give an average exposure, as opposed to individual exposure data used in the current study), as well as because of the study sample (rugby players versus soccer players in the current study). Similar to the current study, Killen et al (30) found no relationship found between training load (as assessed using RPE) and training injury incidence in rugby players. Their suggestion was that the high-calibre nature of the athletes was protective against injury, which may also account for the current findings. However, significant relationships have been found between individual session-RPE and HR-based training loads, therefore strengthening the use of HR as a valid method of assessing training load in sports (53).

It may be suggested that injury results from an accumulation of training load. For these reasons, an attempt was made to analyse whether differences in training load occurred prior to the injury being sustained, by considering the training load in the preceding mesocyle. When injuries did occur, time spent at the highest training intensity (T-VHI) was significantly greater in the preceding mesocycle as compared to the T-VHI if an injury had not occurred (Figure 2). Although training intensity was related to injury incidence, and did not increase the odds of training injuries occurring, accumulation of training at high intensities may affect injury incidence. When analysing injuries, both training intensity and load over time should be considered, and coaches should try to ensure that excessive accumulated training at these high levels are avoided through appropriately periodization.

On a month-by-month basis, using χ^2-analysis, the frequency of training injuries reflected training exposure (Figure 3); for instance, in months where training duration were long, such as in the pre-season period, injury frequency was high. The frequency of training injuries did not, however, reflect the training intensity. Therefore, it could be suggested that when training intensity is ≥85% HRmax, injury does not necessarily result, but when exposure to training is prolonged more injuries could occur. In agreement with the present findings, other researchers have found a similar relationship between exposure and injury frequency (16,18). In the current study, the players did not train for long periods of time in comparison to that reported by others (15). Indeed, training was often of a high intensity but short duration, using a predominance of SSGs (small sided games) and soccer specific intermittent training. This approach to training might explain the high relationship found between injury incidence and training intensity.

The low injury incidence for training (6.7 injuries per 1000 h of training exposure) was comparable with that previously reported (12) although match injury incidence (54.1 injuries per 1000 h of match exposure) was higher (12). Match injury incidence has been found to be higher in certain circumstances. For instance, Dupont et al (10) reported a match injury incidence of 97.7 per 1000 h of match exposure when players played in 2 matches a week. Dvorak et al (13) reported a match injury incidence of 81 per 1000 h of match exposure in the 2002 FIFA World Cup.

The site, type and severity of injuries reported for these 23 players were within the ranges reported previously among other professional soccer players. For instance, a greater proportion of injuries occurred to the lower extremities (Table 1), consistent with the findings of others (25,29,32). A high number of injuries, both during match and training, consisted of muscle strains, contusions and ligament sprains (Table 2), as also reported elsewhere (15,26,33). Therefore the present sample of injuries in the studied team is representative of usual soccer injuries and the conclusions of the study are more likely to be interpreted as providing knowledge on actual soccer.

Relationships between injury incidence and anthropometrical and physiological variables were weak in the current study, as also reported by others (17,36), possibly explained by the homogenous nature of the players. Considering that training intensity did seem to effect injury incidence, interestingly anthropometrical and physiological variables did not relate to injury incidence, other intrinsic risk factors such as joint instability, functional skill, psychology (32,36), and other extrinsic factors such as playing surface, weather conditions, and foul play (36) may have contributed to injury. Based on this information it can be confirmed that cause of injury is multi-factorial, with the present study showing that training intensity being a contributing factor.

One of the limitations of the study was that subject numbers were low due to players being recruited from only one professional club. The participants were, however, high-calibre footballers, and were unique in this respect in comparison to some other studies on injury incidence and training intensity (e.g., 21,23). As commented on by Killen et al (30), it is difficult to compare results obtained from semi-professional/amateur players with professional players; therefore, they suggested that research on professional players is required. Amateur players generally have a lower cardiovascular endurance capability, and skill base, which may predispose them to a greater injury risk; as having a high VO_2max may be protective of injury (23). The present study is the only one having investigated the relationship between HR intensity and injury incidence in professional soccer players. The team physician/medical staff and sports scientist recorded all data for injury, exposure and heart rate during training, to provide a complete picture of each player on a case-by-case basis, rather than a more generic picture of a large group of players. The a priori sample size estimate was used to ensure sufficient power in the correlation analysis, and the sample size in the current study was similar to that used in other studies of a similar design (30,52). In regards to the limitation of a small sample size, caution should be taken in making inferences from the data, the practical implication that injury incidence is highly related to HI training is important considering the professional nature of the players, and the individual auditing.

Practical applications

In professional soccer, training is generally comprised of a variation of small, medium and large sided games alongside HI intermittent bouts used as a time efficient and effective means of enhancing cardiovascular fitness (8,28,34,35). Such training methods may impose more stress on the body than more traditional training methods, with heart rates of >85% often being elicited (8,35). This is the first study to have examined the relationship between HR based assessment of training intensity and injury incidence in soccer. Based on the data collected in the current study, it is recommended that training intensity be considered as one of many factors in injury prevention. Therefore, monitoring training to ensure optimal loading is not significantly exceeded should be considered as vitally important at the elite level of professional soccer with respect to injury prevention.

References

1 Alexiou, H, and Coutts, AJ. A comparison of methods used for quantifying internal training load in women soccer players. *Int J Sports Physiol Perform* 3: 320-30, 2008.

2 Arnason A, Andersen, TE, Holme I, Engebretsen, L, and Bahr, R. Prevention of hamstring strains in elite soccer: an intervention study. *Scand J Med Sci Sports* 18: 40-48, 2008.

3 Arnason, A, Sigurdsson, SB, Gudmundsson, A, Holme, I, Engebretsen, L, and Bahr, R. Physical fitness, injuries, and team performance in soccer. *Med Sci Sports Exerc* 36: 278-285, 2004.

4 Bahr, R, and Krosshaug T. Understanding injury mechanisms: a key component of preventing injuries in sport. *Br J Sports Med* 39: 324-9, 2005.

5 Banister, EW. Modelling elite athletic performance. In: Physiological Testing of the High-Performance Athlete. MacDougall JD, Wenger HA, Green HJ, eds. Champaign, IL, Human Kinetics, 1991. pp. 403-245.

6 Borresen, J, and Lambert, MI. Quantifying training load: a comparison of subjective and objective methods. *Int J Sports Physiol Perform* 3: 16-30, 2008.

7 Coyle, EF. Physical activity as a metabolic stressor. *Am J Clin Nutr* 72: 512S–520S, 2000.

8 Dellal A, Chamari K, Pintus A, Girard, O, Cotte, T, and Keller, D. Heart rate responses during small-sided games and short intermittent running training in elite soccer players: a comparative study. *J Strength Cond Res* 22: 1449-1457, 2008.

9 Desgorces, FD, Sénégas, X, Garcia, J, Decker, L, and Noirez, P. Methods to quantify intermittent exercises. *Appl Physiol Nutr Metab* 32: 762-769, 2007.

10 Dupont, G, Nedelec, M, McCall, A, McCormack, D, Berthoin, S, and Wisløff, U. Effect of 2 soccer matches in a week on physical performance and injury rate. *Am J Sports Med* 38: 1752-1758, 2010.

11 Durnin, JV, and Womersley, J. Body fat assessed from total body density and its estimation from skinfold thickness measurements on 481 men and women from 16 to 72 years. *Br J Nutr* 32: 77-97, 1974.

12 Dvorak, J, and Junge, A. Football injuries and physical symptoms. A review of the literature. *Am J Sports Med* 28: S3-S9, 2000.

13 Dvorak, J, Junge, A, Grimm K, and Kirkendall, D**.** Medical report from the 2006 FIFA World Cup Germany. *Br J Sports Med* 41: 578-581, 2007.

14 Edwards, S. The Heart Rate Monitor Book. Sacramento, CA: Fleet Feet Press, 1993.

15 Ekstrand, J, Hägglund, M, and Waldén, M. Injury incidence and injury patterns in professional football: the UEFA injury study. *Br J Sports Med* 45: 553-558, 2011.

16 Ekstrand, J, Waldén, M, and Hägglund, M. Risk for injury when playing in a national football team. *Scand J Med Sci Sports* 14: 34-38, 2004.

17 Eriksson, LI, Jorfeldt, L, and Ekstrand, J. Overuse and distortion soccer injuries related to player's estimated maximal aerobic work capacity. *Int J Sports Med* 7: 214-216, 1986.

18 Faude, O, Jung, A, Kindermann, W, and Dvorak, J. Risk factors for injuries in elite female soccer players. *Br J Sports Med* 40: 785-790, 2006.

19 Foster, C, Florhaug, JA, Franklin J, Gottschall, L, Hrovatin, LA, Parker, S., Doleshal, P, and Dodge, C. A new approach to monitoring exercise training. *J Strength Cond Res* 15: 109-115, 2001.

20 Fuller, CW, Ekstrand, J, Junge, A, Andersen, TE, Bahr, R, Dvorak, J, Hägglund, M, McCrory, P, and Meeuwisse, WH. Consensus statement on injury definitions and data

collection procedures in studies of football (soccer) injuries. *Br J Sports Med* 40: 193-201, 2006.

21 Gabbett, TJ. Influence of training and match intensity on injuries in rugby league. *J Sports Sci* 22: 409-417, 2004.

22 Gabbett, TJ. Changes in physiological and anthropometric characteristics of rugby league players during a competitive season. *J Strength Cond Res* 19: 400-408, 2005.

23 Gabbett, TJ, and Domrow, N. Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *J Sports Sci* 25: 1507-1519, 2007.

24 Hägglund, M, Waldén, M, Barhr, R, and Ekstrand, J. Methods for epidemiological study of injuries to professional football players: developing the UEFA model. *Br J Sports Med* 39: 340-346, 2005.

25 Hägglund, M, Waldén, M, and Ekstrand, J. EUFA injury study-an injury audit of European Championships 2006 to 2008. *Br J Sports Med* 43: 483-489, 2009.

26 Hawkins, RD, Hulse, MA, Wilkinson, C, Hodson, A, and Gibson, M. The association football medical research programme: an audit of injuries in professional football. *Br J Sports Med* 35: 43-47, 2001.

27 Henderson, G, Barnes, CA, and Portas, MD. Factors associated with increased propensity for hamstring injury in English Premier League soccer players. *J Sci Med Sport* 13: 397-402, 2010.

28 Hoff, J, Wisløff, U, Engen, LC, Kemi, OJ, and Helgerud, J. Soccer specific aerobic endurance training. *Br J Sports Med* 36: 218–221, 2002.

29 Ispirlidis, I, Fatouros, IG, Jamurtas, A, Nikolaidis, MG, Michailidis, I, Douroudos, I, Margonis, K, Chatzinikolaou, A, Kalistratos, E, Katrabasas, I, Alexiou, V, and Taxildaris, K. Time-course of changes in inflammatory and performance responses following a soccer game. *Clin J Sport Med* 18: 423-431, 2008.

30 Killen, NM, Gabbett, TJ, Jenkins, DG. Training loads and incidence of injury during the preseason in professional rugby league players. *J Strength Cond Res* 24: 2079-2084, 2010.

31 Little, T, and Williams, AG. Suitability of soccer training drills for endurance training. *J Strength Cond Res* 20: 316-319, 2006.

32 Mallo, J, González, P, Veiga, S, and Navarro, E. Injury incidence in a Spanish sub-elite professional football team: A prospective study during four consecutive seasons. *J Sports Sci Med* 10: 731-736, 2011.

33 Östenberg, A, and Roos, H. Injury risk factors in female European football. A prospective study of 123 players during one season. *Scand J Med Sci Sports* 10: 279-285, 2000.

34 Owen, AL, Wong del, P, Paul, D, and Dellal A. Effects of a periodized small-sided game training intervention in elite professional soccer. *J Strength Cond Res* 26: 2748-2754, 2012.

35 Owen, AL, Wong del, P, McKenna M, and Dellal A. Heart rate responses and technical comparison between small-vs. large-sided games in elite professional soccer. *J Strength Cond Res* 25: 2104-2110, 2011.

36 Pakkari, J, Kujala, UM, and Kannus, P. Is it possible to prevent sports injuries? Review of controlled clinical trials and recommendations for future work. *Sports Med* 31: 985-995, 2001.

37 Reilly, T, Atkinson, G, Gregson, W, Drust, B, Forsyth, J, Edwards, B, and Waterhouse, J. Some chronobiological considerations related to physical exercise. *Clin Ter* 157: 249-264, 2006.

38 Reilly, T, and Ekblom, B. The use of recovery methods post-exercise. *J Sports Sci* 23: 619-627, 2005.

39 Rhea, MR, Lavinge, DM, Robbins, P, Esteve-Lanao, J, and Hultgren, TL. Metabolic conditioning among soccer players. *J Strength Cond Res* 23: 800-806, 2009.

40 RID-DOR [Reporting of Injuries, Diseases and Dangerous Occurrences Regulations]. London: HMSO, 1995.

41 Vetter, RE, and Symonds, ML. Correlations between injury, training intensity, and physical and mental exhaustion among college athletes. *J Strength Cond Res* 24: 587-596, 2010.

42 Whyte, GP, George K, Shave R, Middleton N, and Nevill, AM. Training induced changes in maximum heart rate. *Int J Sports Med* 29: 129-133, 2008.

43 Carling C, Le Gall F, Dupont G. Are physical performance and injury risk in a professional soccer team in match play affected over a prolonged period of fixture congestion. *Int J Sports Med*. 2012;33(1):36-42.

44 Schmikli. S.L., de Vries. W.R., Inklaar. H. Backx. F.J.G., (2011). Injury prevention target groups in soccer: injury characterstics and incidence rates in male junior and senior players. Journal of Science and Medicine in Sport. 14, 199-203

45 Owen et al., (2013b) injury prevention intervention

46 Rampinini, E, Impellizzeri, FM, Castagna, C, Abt, G, Chamari, K, Sassi, A, and Marcora, SM. Factors influencing physiological responses to small-sided soccer games. *J Sports Sci* 25(6): 659-666, 2007.

~~42~~47 Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of RPE-based training load in soccer. Med Sci Sports Exerc. 2004 Jun;36(6):1042-7. PubMed PMID: 15179175.

48 Eirale (Eirale C, Tol JL, Farooq A, Smiley F, Chalabi H. Low injury rate strongly correlates with team success in Qatari professional football. Br J Sports Med. 2013 Aug;47(12):807-8. doi: 10.1136/bjsports-2012-091040. Epub 2012 Aug 17.

~~43~~49 Stolen, T, Chamari, K, Castagna, C, and Wisloff, U. Physiology of soccer: an update. *Sports Med* 35: 501-536, 2005.

~~44~~**50** Owen A, Wong DP, Dellal A, Paul D, Orhant E, Collie S. (2013b). Effect of an Injury Prevention Intervention on Muscle Injuries in Elite Professional Soccer. J Strength Cond Res, 27(12), 3275-3285.

~~45~~51 Coutts AJ, Rampinini E, Marcora SM, Castagna C, Impellizzeri FM. Heart rate and blood lactate correlates of perceived exertion during small-sided soccer games. J Sci Med Sport 12(1):79-84, 2009.

~~46~~52 Chamari K, Haddad M, Wong del P, Dellal A, Chaouachi A. Injury rates in professional soccer players during Ramadan. J Sports Sci. 2012;30 Suppl 1:S93-102. doi: 10.1080/02640414.2012.696674. Epub 2012 Jun 15. PubMed PMID: 22697802.

~~47~~53 Haddad M, Chauochi A, Castagna C, Wong DP, Behm DG, Chamari K. (2011). The construct validity of session RPE durin an intensive camp iin young male taekwondo athletes, Int J Sports Phys & Performance, 6:2, 252-263

Figure Legends

Figure 1. Individual training intensity (time spent in HR zone) and frequency of training injuries on a monthly basis.

t85 = mean time spent in the 85% to 89% heart rate training zone.

t90 = mean time spent at or above 90% maximum heart rate.

Figure 2. Mean differences (including SD represented by error bars) in time spent in each heart rate zone (t85 and t90) in the month preceding an injury, and in the month when an injury did not occur.

t85 = mean time spent in the 85% to 89% heart rate training zone.

t90 = mean time spent at or above 90% maximum heart rate.

Figure 3. Number of training injuries and monthly hours of training over the two seasons.