Title: Workload profiles prior to injury in professional soccer players.

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This study examined if a particular profile of internal and external workload existed prior to injury. Forty-five professional soccer players were monitored over 2 seasons. For each non-contact injury, a profile of workload variables was determined for 4 weeks and expressed as i) an absolute, ii) week-to-week change and iii) relative to the player's season mean. Variables included exposure, session rating of perceived exertion (s-RPE) workload, total-, low-, high-, very-high speed running distance, mean speed, bodyload, monotony and strain. Acute:chronic workload ratio was also calculated and sensitivity of the relative workload was tested. Absolute and relative exposure and s-RPE workload were greater in all 3-weeks compared to the injury week ($p<0.05$). However, no significant differences were evident between the 3-weeks prior to injury for all variables ($p>0.05$). Acute: chronic workload ratio for s-RPE was significantly greater than acute:chronic workload ratio for very-high speed running ($p=0.04$). A workload threshold of 114% of a player's season mean reported low sensitivity and specificity for exposure (25.6[20.2-33.5]% and 73.9[22.6-28.2]%,), and s-RPE workload (16.3[12.6-24.9]% and 79.9[20.3-26.1]%, respectively). No specific load profile existed, although high-sustained exposure and s-RPE were evident for the 3-weeks prior to injury. Consequently, load prescription should be aware of sustained high workloads.

Keywords: workload, injury prevention, injury profile, professional soccer

Introduction

The dynamic and recursive nature of injuries presents complexity when attempting to identify meaningful risk factors that contribute to soccer-injuries (Meeuwisse, Tyreman, Hagel & Emery, 2007). Of note, muscle injuries account for 20-37% of all time-loss soccer injuries, which in turn are linked with negative outcomes on athlete performance and wellbeing (Ekstrand, Hägglund & Waldén, 2011; Hägglund et al., 2013). Given the modifiable nature of many non-contact injuries, such negative outcomes highlight the importance of minimising injury risk. As an example, a survey of 3 Union Européenne de Football Association (UEFA) Champions league clubs reported workload (i.e. training and match loads) as the second most importantly perceived extrinsic risk factor for soccer-injuries (McCall, Dupont, Ekstrand, 2016). Although workload is a generic concept that can be quantified via internal or external measures; thus far, the most appropriate method and workload profile preceding soccer-injuries is unknown (Brink, Nederhof, Visscher, Schmikli & Lemmink, 2010; Casamichana, Castellano, Calleja-Gonzalez, San Román & Castagna, 2013; McCall, Dupont &Ekstrand 2016).

External workload monitoring i.e. movement and physical loads (Impellizzeri et al., 2004), has increased with greater accessibility to global positioning systems (GPS) for field-based athletes. Currently, soccer related workload influences on injury risk have only been reported from external workload measures. Ehrmann et al. (2015) reported a moderate effect for an increase in mean speed and body load for one week (d=0.52 and 0.54) and 4 week blocks prior to the injury week (d=0.61 and 0.58), respectively in 16 professional Australian soccer-injuries. However, it should be highlighted that the aforementioned study is limited by the use of predicted match values based on preseason data. Bowen et al. (2016) later reported that overall contact and non-contact injury risk is significantly increased following >9254 accelerations accumulated over 3 weeks (RR=5.11) in elite youth soccer players. Within other sport contexts, increased cricket bowling injury risk existed with high external workloads, with injury risk delayed by 1 to 4 weeks following a spike in volume of balls bowled (Orchard, James, Portus, Kountouris & Dennis, 2009). Although external load monitoring can show risk from external loads, the individual responses to such loads and ensuing injury occurrence remain unknown. Hence, internal loads may offer further understanding of workload-induced injury characteristics.

Internal load monitoring refers to the individualised psycho-physiological response to a prescribed load (Impellizzeri et al., 2004). Session rating of perceived exertion (s-RPE) workload is a popular method of internal monitoring. For example, Cross and colleagues (2016) monitored the s-RPE workload of 173 professional rugby union players and reported a ‘U-shaped’ relationship between injury and workload. Whilst previous studies show how s-RPE workload can influence injury risk (Hulin et al. 2014), no soccer study has identified if s-RPE workload is an appropriate marker for predictive analyses. Hence, temporal analysis of internal workloads is necessary prior to applying particular risk factors in injury prediction models.

An acute:chronic workload ratio may be a meaningful method to highlight injury precursors by reflecting on the negative short term fatigue responses and positive long lasting fitness response to workloads (Gabbett, 2016). In team sports (cricket, Australian football and rugby league), acute:chronic workload ratio based on combined internal and external markers, illustrated a ratio range of 0.8-1.3 is considered the ‘sweet spot’ whilst 1.5 represented the ‘danger zone’ for injury occurrence (Blanch & Gabbett, 2016). Specifically, decreased injury risk was evident with intermediate loads compared to lighter or heavier workloads. Similarly, in elite youth soccer player, injury risk was also increased (RR=2.55) when a high acute load was combined with a low load but not high chronic high speed running (RR=0.47) (Bowen et al., 2016). Whilst the method of comparing workloads has merit in identifying injury risk, the variation in the markers used warranting contextual evidence to identify the most appropriate workload-injury marker for analyses.

The aforementioned collection of studies reports a potential interaction between workload and injury. Previous studies have analysed direct and momentary risk of injury from workloads. However, given the cyclic nature of injuries, simultaneous temporal profiles of the internal and external workloads can give contextual evidence prophylactic training load prescription. Therefore, the aim of the study was to determine if a particular profile of internal or external workload existed 3 weeks prior to injury in professional soccer players.

Methods

Participants

One Australian professional male soccer team (n=45) were monitored for workload and injuries over the 2013/2014 (14 weeks preseason and 32 weeks in season) and 2014/2015 (14 weeks preseason and 31 weeks in season) season of the A-League), whilst simultaneously competing in Asian Champions League. Descriptive characteristics of the players included a mean±SD; age 26.4±5.1years, height 181.3±7.1cm and body mass 74.5±12.1kg. All players provided informed written consent in which all participants made aware of the freedom to withdrawal their data from research at any time by relevant coaching staff. The data collection procedu res were approved by the institutional Human Research Ethics Committee which conformed to the Declaration of Helsinki, and were part of regular sport science servicing for all players contracted to the team.

Experimental Design

Data were collected from 211±55 sessions per participant by the sport science and conditioning staff. The study period included 75 competitive games in which GPS data was not collected due to Football Internationale de Federation Association (FIFA) regulations. A total of 87 contact and non-contact injuries were collated; however, 48 injuries were removed due to contact mechanisms, missing data and injuries sustained by goalkeepers. Missing data was the result of the injury occurring too early in the season to produce enough data or obvious unit error. Thirty-nine non-contact injuries were used to create a 4 week (i.e. 3, 2 and 1 week prior and week of injury) workload profile consisting of 21±4 sessions. Each training week was deemed to begin on Monday and finished on Sunday, as based on programming by the Head Coach. It has been indicated that high acute workloads over such a timeframe may lead to an increased injury risk (Orchard et al., 2009).

Injury

An injury was defined as "*any physical complaint sustained from a match or training session resulting in time loss*" (Fuller et al., 2006, p. 193), as dictated by the governing national body. Exposure was also determined based on the duration (min) a player had participated in training and matches in the selected time frame (Owen et al., 2015). The cost of injury was also determined as '*the number of sessions missed'* (Fuller et al., 2006). Previous epidemiological studies show the most common injuries are non-contact injuries (Ekstrand, Hägglund, Waldén, 2011), thus these injuries were included for workload profiling.

Quantifying Workloads

Workload was quantified by using both internal and external load measures. Exposure (min) was summed from every session. Previously, Impellizzeri et al. (2004) have reported s-RPE (Borg's CR-10) to be a valid marker of soccer training intensity given large correlations with heart rate based parameters ($r = 0.50 – 0.85$, $p<0.01$). Hence, s-RPE workload was quantified by multiplying s-RPE recorded approximately 30min post-session with the exposure of the session for training and matches (Impellizzeri et al., 2004). Additionally, monotony and strain were also calculated based on previously reported methods (Foster, 1998).

External loads were monitored using an individually allocated 15 Hz GPS unit (10Hz interpolated to 15Hz) with a 100Hz, 16G triaxial accelerometer (SPI HPU GPSports, Canberra, Australia) for every training session only, excluding gym and individual based sessions. The GPS units in this study have been reported to have an acceptable level of accuracy and reliability (Vickery et al., 2014). External workload measures included total distance (m), distance by speed zones (m), mean speed ($m \cdot s^{-1}$), and bodyload (Arbitrary units; AU) to reflect the session demands. GPS data for each session was analysed from the start of warm up. Speeds were predefined according to three locomotive categories, low speed running ($<14.4 km \cdot h^{-1}$); high speed running ($>14.5 km \cdot h^{-1}$), and very high speed running ($>20 km \cdot h^{-1}$) (Coutts & Duffield, 2010).

All variables were firstly expressed as cumulative absolute weekly values, which involved the summing of the weekly amount per variable. Secondly, the data was expressed as a percentage change from the previous week to determine a week-to-week change. Thirdly, all variables were expressed relative to the individual season mean. Workload variables were then used to calculate an acute:chronic workload ratio based on the difference between chronic (mean of the accumulated 3 weeks prior to injury week) and acute (the week prior to injury week) workload (Hulin et al., 2014). When considering the acute:chronic workload ratio prior to injury, the week of injury was excluded, as injuries would have confounding effect on workload variables.

Statistical Analyses

Data is presented as a mean±standard deviation (SD). A repeated-measures one-way analysis of variance (ANOVA) determined differences in the weeks prior to and of injury for each workload variable. Statistical significance was set at $p<0.05$ and post-hoc tests (Bonferroni correction) were used to determine differences between means. The Statistical Package for Social Sciences (SPSS v22.0, Chicago, IL) software was used to perform analyses.

Sensitivity and specificity was calculated and reported with a 95% confidence interval (CI) to understand the accuracy of a particular workload profile that leads to injury (Bahr, 2016). Specifically, a ‘workload threshold’ was calculated by the mean of relative individual player season mean over 3 weeks and was used to indicate hazardous workloads. The workload threshold was used to determine the proportion of true positive (high workload and injury followed) and negative (workload was not high and no injury followed) results, and false positive (high workloads without following injury) and negative results (workload was not high and injury followed) (Altman & Bland, 1994). This process allowed the description of the accuracy of identifying a hazardous workload to injury as well as sensitivity (i.e., the proportion of injured players who sustained high workloads) and specificity (i.e., the proportion of uninjured players who did not sustain high workloads) likelihood ratios (Altman & Bland, 1994).

Results

Fifty-three injuries with appropriate data were included in this study and of this count, 39 injuries were sustained through non-contact mechanisms. Muscle and tendon injuries were the most common non-contact injury types sustained and also produced the greatest costs with 9.4 ± 4.9 days lost. Of the analysed non-contact injuries, 60% ($n=23$) were sustained during match play.

Compared to the week of injury, exposure was significantly greater in weeks 3, 2 and 1 prior to injury ($p=0.04$, $p=0.03$ and $p=0.01$, respectively; Figure 1A), although did not differ between weeks 1-3 ($p>0.05$). Similarly, s-RPE workload was significantly higher in all 3 weeks than the week of injury ($p=0.03$, $p=0.01$ and $p<0.01$, respectively; Figure 1A), without differences between weeks ($p>0.05$). No significant differences were observed ($p>0.05$) for the week-to-week change in exposure or s-RPE workload between any weeks (Figure 1B). However, weeks 3, 2 and 1 prior to injury were significantly higher than the injury week for both exposure and s-RPE workload when expressed as a percentage relative to the season mean (~114%), ($p<0.01$ for all; Figure

1C), again without differences between those weeks ($p>0.05$). The mean of the 3 weeks exposure and s-RPE workload relative to individual players season means were 114±3% and 114±4%, respectively.

****Insert Figure 1****

****Insert Figure 2****

No significant differences were observed in total distance between weeks 3, 2, 1 and injury week when expressed as an absolute value ($p>0.05$; Figure 1D). Further, no significant differences were observed when total distance was expressed based on week-to-week change. Relative total distance (to season mean) was significantly greater 3 and 2 weeks prior to injury compared to the week of injury ($p=0.04$ and 0.03, respectively; Figure 1F), although not significantly different between weeks 1-3 ($p>0.05$). Absolute low speed running was not significantly different between any week ($p>0.05$). However, significantly greater distances were covered in absolute high speed and very-high speed running 2 weeks prior to injury compared to the week of injury ($p=0.03$ and $p<0.01$, respectively; Figure 2A). No significant differences were observed for the change in high-speed running or very-high speed running between respective weeks ($p>0.05$). However, significantly higher relative high-speed and very-high speed running was evident 2 weeks prior to injury when compared to the week of injury ($p=0.03$ and $p=0.01$, respectively; Figure 2C). Additionally, no significant differences existed between the weeks prior to injury for high- and very-high speed running ($p>0.05$).

****Insert Figure 3****

Compared to the week of injury no significant differences ($p>0.05$) existed between any weeks for mean speed or bodyload. Further, no significant differences ($p>0.05$) were evident in the week-to-week change for either mean speed or body-load. That said, a significantly greater relative bodyload was observed 3 and 2 weeks prior to injury compared to the injury week ($p=0.03$ and $p=0.02$, respectively; Figure 2F). Additionally, the acute:chronic workload ratio of all workload markers examined were not excessively inflated (Figure 3A), although exposure had a significantly higher acute:chronic workload ratio compared to very-high speed running ($p=0.01$). Finally, monotony and strain were not significantly different ($p>0.05$) across all weeks (Figure 3B).

The 3-week mean of relative exposure and s-RPE workload of 114% was used as a workload threshold to calculate sensitivity and specificity. Sensitivity and specificity of injuries following this threshold of high exposure were low (Table 1). Additionally, sensitivity and specificity of high s-RPE workloads as based on the above threshold were also low (Table 2).

****Insert Table 1****

****Insert Table 2****

Discussion

The objective of this study was to describe the internal and external workload profiles prior to non-contact injuries in professional soccer players. The results showed no specific profile existed before an injury other than sustained high exposure and s-RPE workload related loads in *both* absolute and relative terms. Such lack of distinct profile of either internal or external load was also reflected in the lack of week-to-week change and acute:chronic workload ratio. These findings reiterate the usefulness of s-RPE to quantify training in soccer to improve player welfare (Coutts, Rampinini, Marcora, Castagna, Impellizzeri, 2009; Impellizzeri et al. 2004), and highlights acute sustained high workloads relative to an individual player's norm existed prior to injury.

Internal loads

High training strain can lead to decrements in performance and increase the occurrence of injuries (Foster, 1998). In 53 elite Dutch youth soccer players, monotony prior to traumatic injuries of 1.07±0.25 was significantly associated with 2.59 (CI95%=1.22-5.50) compared to no injury (Brink, Nederhof, Visscher, Schmikli & Lemmink, 2010). Additionally, strain of 104±50 AU was also significantly associated to traumatic injuries by an odd ratio of 1.01 (CI95%= 1.00-1.01). The present study observed no overt differences in the week-to-week change in load markers, suggesting a more highly monotonous training schedule combined with high relative s-RPE workload (~114% of season mean) were more likely an issue (Figure 1A&C). Comparably, a study of rugby league players reported that a high chronic workload reduced injury risk when recovery between matches were short (Hulin, Gabbett, Lawson, Caputi & Sampson, 2015). Although, when workload was low or very high the injury risk increased. The combined findings suggest training at high loads are still necessary for performance benefits; however, appropriate training variation is important to avoid high monotony *and* very-high relative load to minimise injury occurrence.

External loads

Previously total distance and low speed running are reported to be protective against injury in rugby league, Australian Rules Football and soccer (Bowen et al., 2016; Gabbett & Ullah, 2012; Piggott, Netwon & McGuigan, 2009). Ehrmann et al. (2015) reported no significant differences in total distance between a 1 and 4 week injury block for 19 professional soccer injuries. Despite total distance being 2.2 times greater in the present study, the lack of difference in total distance between weeks may have been influenced by planned sustained high training load prescription of the weeks prior to injury. However, this is speculative as the respective phases of training were not differentiated in this study, despite total distance being similar to the season mean. Additionally, Bowen et al. (2016) reported no significant increase in injury risk with greater 3 weeks total distance (108,920m) despite covering double of the distance in the present study (50,816m). In comparison, Colby and his colleagues (2014) reported that over one 1 season in 46 elite Australian football players a weekly total distance range of 73,721-86,662m was associated with an odds ratio of 5.5 times greater injury risk. Given the differences between sports, direct comparison is inappropriate; nevertheless, a ‘hazardous’ total distance range may exist in elite soccer, although this remains to be elucidated from larger cross-club data sets.

Previous studies have associated increased high and very-high speed running with increased injury risk (Gabbett & Ullah, 2012; Owen et al., 2015). The exclusion of external match workload in the present study may offer reasoning for the absence of any distinct profile of high or very-high speed running preceding injury occurrence. This may particularly be the case as the predominance of injuries recorded were sustained during matches, at which in-season running loads are normally greater than training. Similarly, Ehrmann et al. (2015) also reported 11 out of 16 injuries were sustained in matches, and no significant difference in high and very-high speed running existed prior to injury in similar level soccer players, regardless of methodological differences between studies. That is, Ehrmann et al. (2015) estimated in-season match loads based on pre-season matches, and whilst no external match loads were incorporated here, both are recognised as limitations. Contrastingly, Colby et al. (2014) found sprinting distance correlated with increased injury risk with inclusion of predicted match running loads in elite Australian Football League players. Given the exclusion of match data, it is unsurprising that no differences were found between weeks prior to injury in the present study which highlight the influence of match load data on the incidence of injury (Colby et al., 2014). The deregulation of wearable technology in competitive matches warrants further workload-injury analyses.

Bodyload is a recently developed external load variable that incorporates a summed measure of the accelerometer vectors (Casamichana et al., 2013). Ehrmann et al. (2015) reported a significant reduction in bodyload for 1 week and 4 week blocks prior to injury compared to the seasonal mean, although no such reductions were evident in the current study. These different findings are perhaps expected given the exclusion of in-match data discussed previously. On the other hand, the mean weekly bodyload in the present study is comparable to the bodyload experienced by elite European soccer players (Bowen et al., 2016). An increase in bodyload acute:chronic workload ratio showed a significant increase from moderate to high bodyload (RR=1.87, 95% CI 1.12 to 3.12, p=0.016) and indicate that such a result in the present study is expected.

Ehrmann et al. (2015) also reported an increase in mean speed relative to the seasonal average. In the present study, total distance, mean speed and body-load varied between the 3 weeks before injury; however, none of the variables were above the season mean. Given that mean speed is derived from total distance and exposure, the large correlation between total distance and body-load offers a justification to a similar workload profile.

Acute: Chronic Workload Ratio

The use of acute:chronic workload ratio highlights both the positive and negative consequences of acute workload relative to the chronic workload (Gabbett, 2016). For example, a significant increase in injury risk was observed in 53 Australian National Rugby League players when high acute:chronic workload ratio was combined with 2 weeks of high GPS derived workload (Hulin et al., 2015) These results are somewhat in opposition to an increased injury risk when ‘spikes’ of 1.5 times greater workload occurred in elite cricket bowlers (Hulin et al., 2014). According to the ‘fitness-fatigue’ model (Banister, Calvert, Savage & Bach, 1975), high acute and chronic workloads consequently increase workload strain and injury risk. Similarly, in the current study the acute:chronic workload ratio of all variables were not excessively inflated from the season mean, although exposure and s-RPE workload increased more than the other variables. Additionally, s-RPE workload was increased from the relative individualised season mean despite no change to strain. Hence, some merit exists for the analysis of acute relative to chronic workloads, particularly in exposure and s-RPE workload of professional soccer players.

As suggested by Bahr (2016), accuracy measures are required to avoid future analysis of confounding injury risk factors. Gabbett (2010) previously reported large probability in the use of s-RPE workload in 91 professional rugby league players with a logistic regression injury prediction model. On the contrary, the mean of sustained high weekly exposure and s-RPE workloads showed a low level of sensitivity and specificity in the current study. The low level of accuracy may offer reasoning to the lack of distinct exposure and s-RPE workload profiles observed. Hence, contextual analysis of the data profile is necessary prior to applying prediction models. Additionally, the current results support previous studies suggesting that a >10% spike in workload may offer partial understanding of injury occurrence (Piggott, Newtown, McGuigan, 2009). The current findings did not show a sensitive or specific workload threshold to detect workload-induced injuries. Although it must be acknowledged that variability in player sessions and training cycles was not distinguished and is a limitation of the current analysis. Hence, prescribed training workload changes should be considered in future analyses.

Limitations

Although profiles of exposure and s-RPE were most indicative of ensuing injury in the present study, interpretation of the results should be met with caution. It should be highlighted that to avoid uncertainty with estimated values, external match loads were not included, though until recently, this represented common practice in many clubs. The changing of FIFA regulations regarding use of in-match GPS technology will overcome such an issue in future research. However, such exclusion of match data may explain the high variability and lack of an explicit external workload profile in this study. Additionally, injuries were not analysed separately according to time of the season. Therefore, the aforementioned limitations may result in the lack of an explicit pre-injury external load profile.

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Conclusion

The present study aimed to determine if a particular profile of workload was evident prior to injury. The findings showed that injuries followed sustained high absolute and relative load of *both* exposure and s-RPE workload. Furthermore, the absence of any obvious 'spike' in workload prior to injury occurrence was reflected in the lack of week-to-week changes and monotonous profile. Whilst exposure and s-RPE workload acute:chronic workload ratio tended to be the highest in comparison to the other load variables, additional analyses warrants contextual understanding prior to use. Furthermore, coaches should consider variability in loads when prescribing training and continuously monitor players to ensure appropriate training prescription to minimise injury risk.

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Table 1: Sensitivity and specificity of high (114%) exposure threshold to occur prior to injury.

	Relative Exposure		
	Injured	Uninjured	
Identified Workload	*True Positive* *N*=11	*False Positive* *N*=143	Positive Predictive Value 7.1%
Unidentified Workload	*False Negative* *N*=32	*True Negative* *N*=405	Negative Predictive Value 7.3%
Sensitivity	25.6 (20.2-33.5)%		
Specificity	73.9 (22.6-28.2)%		
Likelihood Ratio Positive	1.0		
Likelihood Ratio Negative	1.0		

Table 2: Sensitivity and specificity of high (114%) s-RPE workload threshold to occur prior to injury.

	Relative s-RPE Workload		
	Injured	Uninjured	
Identified Workload	*True Positive* *N*=7	*False Positive* *N*=93	Positive Predictive Value 7.0%
Unidentified Workload	*False Negative* *N*=32	*True Negative* *N*=405	Negative Predictive Value 8.9%
Sensitivity	16.3 (12.6-24.9)%		
Specificity	79.9 (20.3-26.1)%		
Likelihood Ratio Positive	0.8		
Likelihood Ratio Negative	1.0		

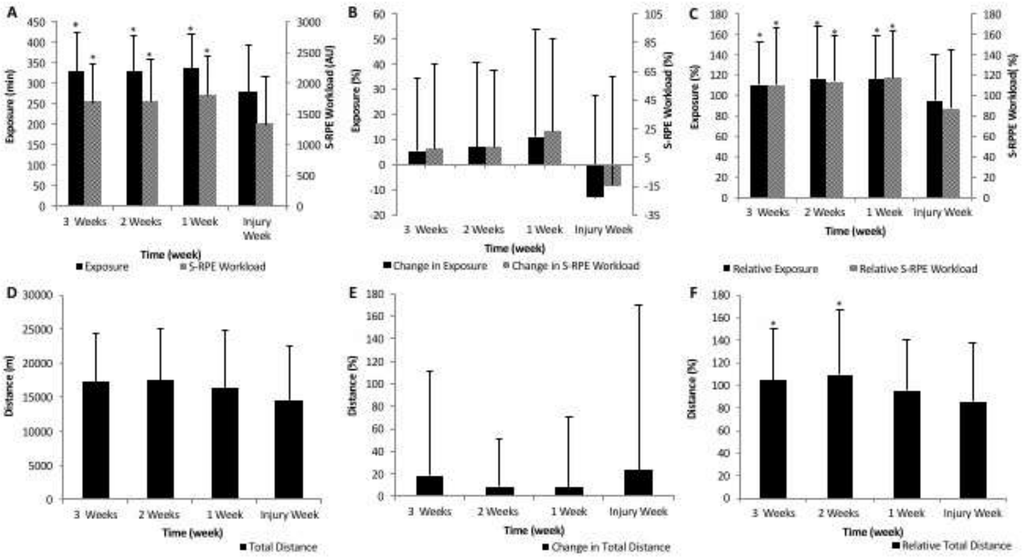

Figure 1: Temporal profile of the mean ±SD of A) absolute exposure and perceived workload; B) week-to-week change of exposure and perceived workload and C) relative exposure and perceived workload; D) absolute total distance covered E) week-to-week change in total distance and F) relative change in total distance.

AU: Arbitrary Units; *Significantly different from injury week (<0.05)

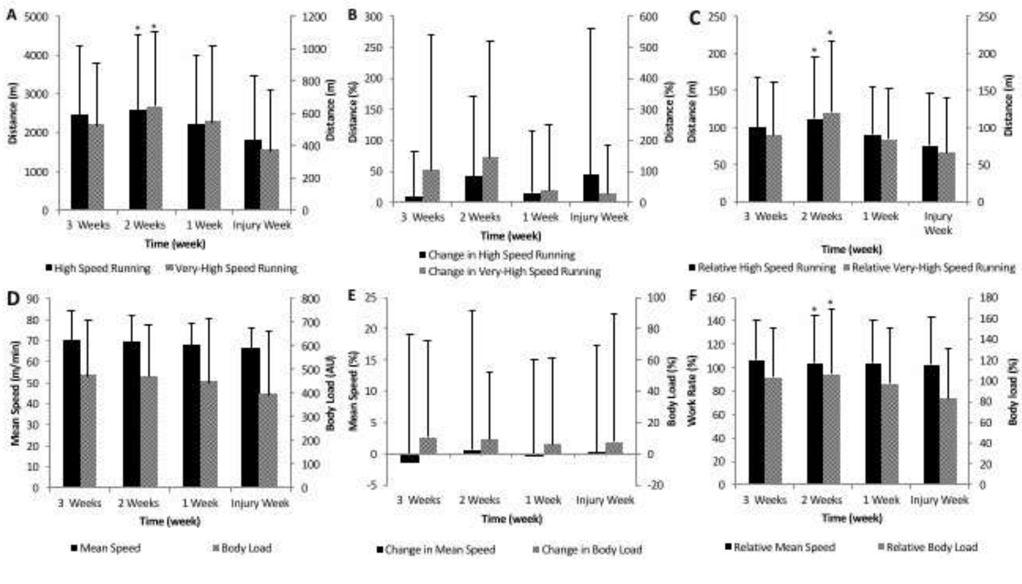

Figure 2: Temporal profile of A) absolute high speed running and very-high speed running; B) week-to-week change of high speed running and very-high speed running; C) relative high speed running and very-high speed running; D) absolute work rate and

body load; E) week-to-week change in work rate and body load; and F) relative change in work rate and body load.

AU: Arbitrary Units; * Significantly different compared to injury week (p<0.05)

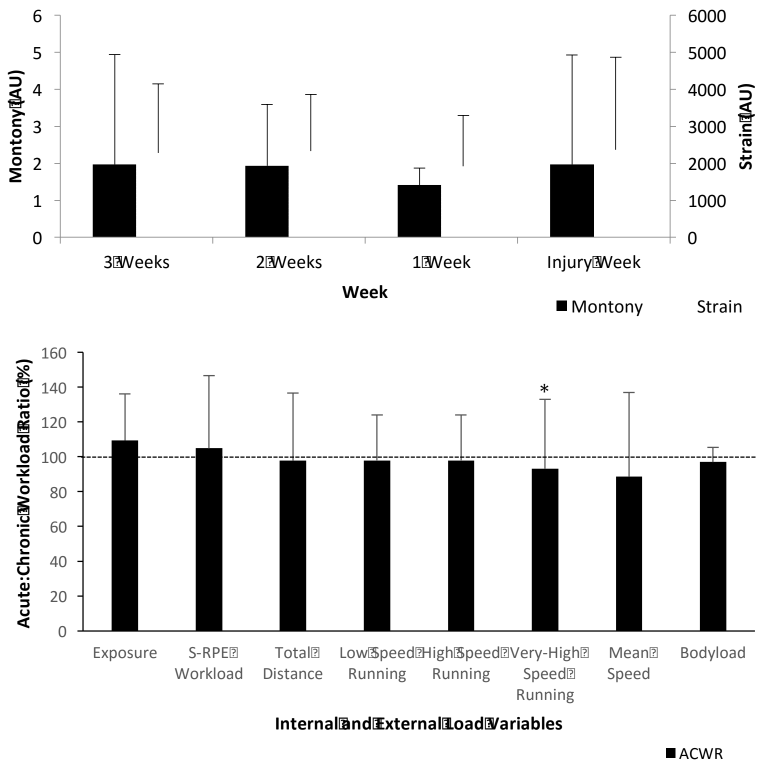

Figure 3: Mean ±SD A) Training stress balance of internal and external load markers and B) temporal profile of monotony and strain 3 weeks leading to injury occurrence.

AU: Arbitrary Units; * Significantly different compared to exposure (p=0.01).