Factors Associated With Noncontact Injury in Collegiate Soccer

A 12-Team Prospective Study of NCAA Division I Men's and Women's Soccer

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Background: Multiteam, multi-institution prospective studies of both women's and men's sports are essential for collectively investigating injury and primary to the generalization and individualization of injury prevention strategies.

Hypothesis: Characteristics of workload, sleep, and contextual factors will be associated with injury risk in collegiate soccer athletes.

Study Design: Cohort study; Level of evidence, 2.

Methods: Injuries, workload, and sleep characteristics were recorded daily throughout a complete season for 256 athletes from 12 separate National Collegiate Athletic Association Division I men's and women's soccer teams. Workload and contextual factors were assessed via multilevel Poisson regression to capture differences in injury incidence rate ratio (IRR). Paired *t* test and multilevel logistic regressions were used to assess the relationship between sleep behavior and injury.

Results: Collegiate soccer athletes had lower rates of noncontact injury in the in-season (IRR, 0.42) and postseason (IRR, 0.48) compared with preseason, lower rates of injury in training (IRR, 0.64) compared with matches, and higher injury rates with only 1 day of rest in the previous week (IRR, 1.58) compared with $>$1 day. Injury rates peaked when training occurred 4 days before a match (IRR, 2.24) compared with a match. Injury rate increased exponentially with increases in the number of noncontact injuries incurred throughout the season (IRR, 2.23). Lower chronic loading, higher training monotony, and acute spikes and lulls in workload were associated with higher noncontact injury rates. Alterations in previous week sleep quality were associated with injury, while chronic sleep behavior and acute alterations ($<$7 days) in sleep behavior were not ($P > .05$).

Conclusion: Athlete and schedule-specific contextual factors, combined with characteristics of workload and weekly sleep behavior, are significantly associated with injury in collegiate soccer. Multiteam prospective cohort studies involving objective and subjective monitoring allow for the identification of multiple injury risk factors in sports, which can be used to guide injury prevention strategies. Maintaining higher chronic workloads, lowering training monotony, minimizing acute spikes or lulls in workloads, managing workloads during preseason and for athletes with previous injury, integrating more rest and recovery during congested periods, and optimizing sleep quality are all practical considerations for reducing injury risk in collegiate soccer.

Keywords: noncontact injury; workload; sleep; soccer

Injuries can negatively affect competitive performance[36] and threaten long-term athlete well-being[54]; therefore, optimizing injury prevention practices is a key focus for scientists and practitioners in sports medicine. Prevention of injury has been described by van Mechelen and colleagues[56] as a process requiring the identification of risk factors contributing to injury occurrence. However, sports injuries are complex and no single risk factor is adequate to explain all injury occurrences.[7] It is therefore pertinent that multiple risk factors be considered when investigating injury determinants in sports. However, injury risk factor research is typically conducted on isolated subsets of factors (eg, workload, previous injury, calendar congestion, sleep, or athlete characteristics), and although isolated investigations are important for injury risk factor identification, viewing complex phenomena

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without taking multiple factors into consideration fails to provide adequate context and can support a 1-dimensional view of injury.[7] Further, many investigations are limited to 1 team, either men or women, a small number of players, or an isolated period of a season, in which the results are limited in generalizability across an entire league and an entire season.[24] As indicated by Ekstrand,[24] large-scale, multiteam, and multi-institution studies investigating multiple risk factors collectively are needed to answer important and practical questions regarding injury in sports.

Soccer, being the world's most popular sport,[41] has received considerable attention with regard to the identification of risk factors associated with injury.[4,23,34] Evidence suggests athlete-specific risk factors such as previous injury,[35] playing experience, player role on the team (starter vs reserve), and playing position[19] have potential to influence workload demands and therefore injury risk. Workload, which is recognized by Windt and Gabbett[58] as a precondition for injury in sport, is a primary modifiable risk factor.[47] Workload characteristics, such as low chronic workload[38] and "spikes" in workload relative to the player's chronic baseline (ie, acute chronic workload ratio [ACWR]),[39] are key areas of interest with regard to injury risk modification through workload management. Periods of workload intensification, such as the preseason and calendar-congested periods, have additionally been identified as key areas of focus for preventative practices.[5,21] Sleep also represents an important recovery behavior to consider from both an acute (ie, fluctuations in sleep duration or quality) and chronic (ie, normal sleep patterns) perspective. Inadequate sleep has been identified as a risk factor for injury in adolescent athlete populations[48,57] and additionally in professional male soccer players,[44] with research indicating that aspects of sleep quality may be compromised before injury.[50]

There is a need to collectively examine a host of injury risk factors in soccer using a multiteam cohort that is inclusive of both men and women athletes. Multiteam prospective cohort studies involving multidimensional (eg, athlete-specific and session-specific contextual factors, workload, and sleep characteristics) monitoring practices support the modeling of multiple injury risk factors in sports and can be used to generalize and individualize injury prevention strategies. The purpose of this study was therefore to investigate potential workload, sleep, and contextual factors on noncontact injury risk in National Collegiate Athletic Association (NCAA) men's and women's soccer.

METHODS

Participants

A prospective cohort study of 256 NCAA Division I athletes from 12 separate university teams was conducted over the 2016 (2 teams), 2017 (6 teams), and 2018 (4 teams) seasons. In total, 139 of the participants were female (age, 20 ± 1 years; body mass, 64.7 ± 6.1 kg; height, 166.8 ± 6.2 cm; VO_{2max}, 46.8 ± 4.0 mL·kg^{-1}·min^{-1}) and 117 were male soccer players (age, 20 ± 2 years; body mass, 77.4 ± 5.1 kg; height, 179.9 ± 6.5 cm; VO_{2max}, 53.8 ± 4.1 mL·kg^{-1}·min^{-1}). All participants were medically cleared for physical activity by their respective university's sports medicine department and free of any debilitating musculoskeletal injuries or contraindicated medical conditions. Institutional review board (IRB) and ethics approval was obtained from all institutions, with primary oversight and coordination provided by the University of Connecticut (IRB approval ID: H17-134). All participants provided written informed consent before the season. When the participant was under the age of 18 years, parental consent was obtained.

Injury Classification

Injuries were diagnosed and recorded by a single member of each team's medical staff (ie, certified athletic trainer). Each team's medical staff member was provided a custom injury recording spreadsheet consistent with data reporting procedures of the NCAA Injury Surveillance Program[20] and received on-site and in-person training by research personnel on its use before the start of each season. Information such as injury date, type, body part, side, mechanism, time of season, event type, and date of return was recorded and delivered to researchers in a deidentified format. Injuries were recorded according to the current consensus statement on the recording of soccer injuries,[28] which states that an injury is "any physical complaint sustained by a player that results from a football (soccer) match or football (soccer) training, irrespective of the need for medical attention or time loss from football (soccer) activities."[28] For this study, all noncontact injuries resulting from NCAA-sanctioned practices or games that required medical attention, irrespective of time loss, were considered. Research indicates that noncontact injuries may be "preventable" or at least reduced with intervention-based exercise programs.[55]

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Athlete, Session, and Congestion

Several athlete-specific, session-specific, and seasonal congestion factors with the potential to influence injury risk were selected for analysis. To assess differences between player role within the team, athletes were classified as starters if they competed in >60% of the total match time and started in >60% of the total matches in the season[3] or reserves if they did not meet the aforementioned criteria. Athletes were additionally divided into position groups consisting of defenders, midfielders, and forwards. Athletes were further grouped by the number of years they had been competing in intercollegiate athletics (range, 1-6 years). To examine the effect of season phase, injury risk during preseason, in-season, and postseason was considered, with postseason referring to the period in which conference and NCAA tournament play occurred. Daily exposures were additionally classified by days relative to an upcoming match (match day minus [MD-]) and were analyzed for 1 (MD-1), 2 (MD-2), 3 (MD-3), 4 (MD-4), 5 (MD-5), and 6 or greater (MD-6+) days before a match. Further, exposures were classified as either a training or a match session. The effect of session and match congestion on injury risk was determined by grouping individual exposures by the number of sessions or matches completed by that individual in the previous 7 days. Session congestion consisted of groupings <6 sessions (>1 day off) or 6 sessions (1 day off) in the previous 7 days. Match congestion grouping consisted of either 0 or 1, or 2 or 3 calendar matches in the previous 7 days. To examine the effect of previous injury on injury risk, rather than classify it as a binary outcome (injury vs no injury), which does not consider the total number of injuries sustained previously, a rolling cumulative sum was calculated for each player over the season.

Workload

Global positioning satellite (10 Hz) player tracking devices were used to capture workloads during all training sessions and matches (Polar Team Pro; Polar Electro). The player tracking device has reported accuracy and reliability outdoors.[33] To reduce interunit error, players wore the same device for each training session.[40] Players donned the player tracking device before the beginning of the session warm-up to the end of the last organized training activity.

For this investigation, all training and match exposures were considered.[28] Workload metrics were aggregated into daily sum totals and lagged by 1 day so that injury risk was assessed based on previous workloads. Several workload features were engineered from total distance covered (TD) and total high-speed distance covered (HSD; $>14.4\ km \cdot h^{-1}$). Exponentially weighted moving averages (EWMAs), which account for the decaying effect of workload, were calculated for 7 and 28 days of TD and HSD. Research by Murray et al[49] suggests that ACWR methods using EWMAs instead of standard rolling average may be more sensitive to injury. ACWR for TD ($ACWR_{TD}$) and ACWR for HSD ($ACWR_{HSD}$) were calculated by dividing the 7-day EWMA by the 28-day EWMA. ACWR windows of 7 and 28 days were used, as these are customary in workload-injury investigations.[32] Both rolling 7-day means and rolling 7-day standard deviations of TD and HSD were computed to model workload monotony. Monotony was calculated by dividing each day's rolling average of the previous 7 days by the rolling standard deviation of the previous 7 days. Additionally, rolling 7-day and 28-day sums were computed to represent traditional acute and chronic workload features, respectively.

Sleep Diary

Acute and chronic sleep behavior was assessed via the Karolinska Sleep Diary (KSD),[2] which has been utilized previously to assess subjective sleep duration and aspects of sleep quality in NCAA Division I athletes.[6] The KSD is an 11-item questionnaire used to evaluate several facets of sleep, including quantity and perceived quality. The KSD has shown strong association with objective measures of sleep taken via the gold standard of sleep assessment, polysomnography (PSG). Specifically, subjective sleep duration and sleep latency have been shown to have high intraindividual correlations with objective measures taken via PSG ($r = 0.55$ and $r = 0.64$, respectively), and several subjective measures of sleep quality have been shown to have moderate to high correlations with objective sleep efficiency ($r = 0.41$-0.78).[1] The KSD questionnaire was administered daily through an athlete management system (CoachMePlus), which allowed recording of the KSD items via smartphone application. Before the start of the study, participants downloaded the application on their smartphone and received in-person instructions on filling out each item of the questionnaire. Participants were encouraged to complete the questionnaire upon waking.

Statistical Analysis

Statistical analysis was conducted in the R statistical programming language (R Core Team). Daily workload-injury relationships were investigated using generalized multilevel regressions with a Poisson distribution, log link function, and unstructured covariance matrix. Mixed-effects modeling was used for its ability to handle unbalanced fix factors and to account for repeated measures,[14] which was seen with multiple exposures per player. During null model construction, player (ie, each individual player) and player sex (ie, male or female) were entered as clustering variables; however, intraclass correlation coefficient values for player sex were 0, indicating no additional variance was being explained by this factor. Therefore, a random effect of players was included in all contextual and workload-injury modeling. In light of previous reports of nonlinear relationships between workload variables (ie, ACWR) and injury,[9] both linear and nonlinear workload-injury models were compared via chi-square tests, to test whether or not there was a statistically significant reduction in the residual sum of squares. If there was no statistically significant difference between linear and quadratic models (second-order polynomial), a linear model was used.

Sleep-injury associations were assessed via 3 separate analyses. First, statistical differences were assessed via paired *t* test between seasonal average sleep and the sleep directly preceding an injury, an average of 3 days before an injury and an average of 7 days before an injury. Second, seasonal average sleep, taken to be a representation of the participant's chronic sleep habits over the season, was assessed as a potential risk factor for injury incidence over the season using logistic regression with a binary outcome distribution and logit link function. Finally, sleep measures were averaged by week and the likelihood of incurring an injury in the subsequent week was assessed via univariate generalized multilevel regressions with a Poisson outcome distribution, log link function, and unstructured covariance matrix. The statistical significance level of $P < .05$ was set a priori for all analyses.

RESULTS

A total of 191 noncontact injury incidences were recorded, with 182 resulting from participation in NCAA-sanctioned on-field practices or games. Noncontact injury rates were 10.22 per 1000 athlete-exposures or 4.95 per 1000 exposure-hours.

Athlete, Session, and Congestion

Associations between injury rate and athlete, season, calendar congestion, and session-specific factors are displayed in Table 1. Results indicated that athlete sex, role, collegiate playing experience, and position were not significantly associated with noncontact injury. Previous injury was significantly associated with subsequent injury with rates increasing by 2.23 times (95% CI, 2.05-2.42; $P < .001$) for each additional injury. The predicted likelihood of subsequent injury increased exponentially with increased number of noncontact injuries throughout the season (Figure 1). Season phase was also identified as a factor affecting injury rate with both in-season and postseason incidence rates being 58% (incidence rate ratio [IRR], 0.42; 95% CI, 0.31-0.57; $P < .001$) and 52% (IRR, 0.48; 95% CI, 0.28-0.82; $P = .008$) less when compared with the preseason, respectively. Injury incidence rates were significantly lower (36%) in training as compared with a match (IRR, 0.64; 95% CI, 0.47-0.86; $P = .003$). Injury likelihood (%) by days relative to an upcoming match is presented in Figure 2. Injury rates were 66% lower on MD-1 (IRR, 0.34; 95% CI, 0.21-0.55; $P < .001$) and 65% on MD-2 (IRR, 0.35; 95% CI, 0.20-0.61; $P < .001$) compared with a match. The rate of injury 4 days before a match (MD-4) was 2.24 times (95% CI, 1.49-3.38; $P < .001$) the rate of injury in matches. Injury rates were also higher when athletes had 1 day off in the previous 7 days as compared with >1 day off ($P = .04$). The differences in injury rate for 0 and 1 matches in the previous 7 days compared with 2 and 3 matches in the previous 7 days did not reach significance ($P = .06$).

Workload

Quadratic modeling (second-order polynomial) of ACWR-injury relationships for both $ACWR_{TD}$ and $ACWR_{HSD}$ showed significant reductions in residual variance compared with linear models ($\chi^2 = 6.37$; $P < .001$); therefore, quadratic functions were used. Residual variance was not statistically different between linear and quadratic models for monotony, acute workload, and chronic workload; therefore, linear models were used.

Univariate multilevel Poisson regression results for workload-injury models are shown in Table 2. Workload-injury plots for ACWR and chronic workload are shown in Figure 3. Our findings indicated there was a significant quadratic relationship between ACWR and injury for both $ACWR_{TD}$ and $ACWR_{HSD}$. Injury rates increased by 1.52 times (95% CI, 1.26-1.83; $P < .001$) per 1-unit increase in $ACWR_{TD}$ and by 1.43 (95% CI, 1.20-1.71; $P < .001$) per 1-unit increase in $ACWR_{HSD}$. Chronic workload was negatively associated with injury rate, with the rate of noncontact injury decreasing by 6% (IRR, 0.94; 95% CI, 0.90-0.98;

TABLE 1
Association Between Athlete, Season, and Schedule-Specific Factors and Noncontact Injury[a]

Variable	IRR	95% CI	*P* Value
Sex			
Women	Reference		
Men	1.09	0.72-1.64	.693
Status			
Reserve	Reference		
Starter	1.17	0.78-1.76	.452
Collegiate playing experience			
Per 1-year increase	1.16	0.96-1.39	.121
Position			
Defender	Reference		
Forward	0.93	0.55-1.59	.798
Midfielder	0.88	0.54-1.42	.596
Previous injury			
Per 1-injury increase	2.23	2.05-2.42	**<.001**
Season phase			
Preseason	Reference		
In-season	0.42	0.31-0.57	**<.001**
Postseason	0.48	0.28-0.82	**.008**
Session type			
Match	Reference		
Training	0.64	0.47-0.86	**.003**
Day relative to match			
MD	Reference		
MD-1	0.34	0.21-0.55	**<.001**
MD-2	0.35	0.20-0.61	**<.001**
MD-3	0.59	0.34-1.01	.053
MD-4	2.24	1.49-3.38	**<.001**
MD-5	1.45	0.77-2.75	.250
MD-6+	0.80	0.42-1.52	.496
Session congestion (per week)			
>1 day off	Reference		
1 day off	1.58	1.02-2.46	**.041**
Match congestion (per week)			
0-1 matches	Reference		
2-3 matches	0.76	0.56-1.01	.062

[a]Incidence rate ratio (IRR) >1 indicates an increased rate of injury above the reference (categorical variable) or an increased rate of injury per 1-unit increase (numeric variable). Boldface type indicates statistical significance ($P < .05$). MD, match day.

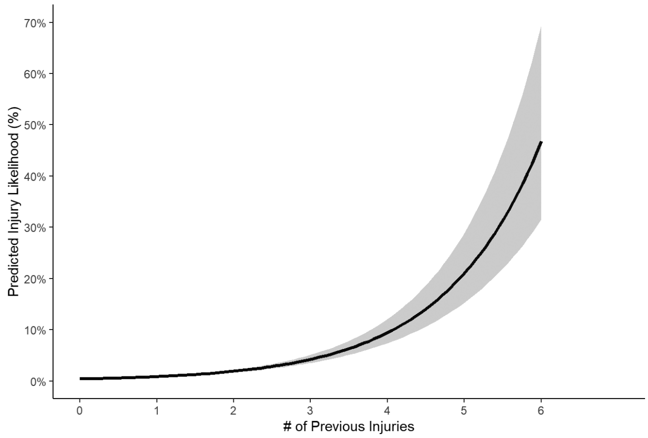

Figure 1. Predicted likelihood (95% CI) of incurring a noncontact injury by the number of previous noncontact injuries incurred throughout a season.

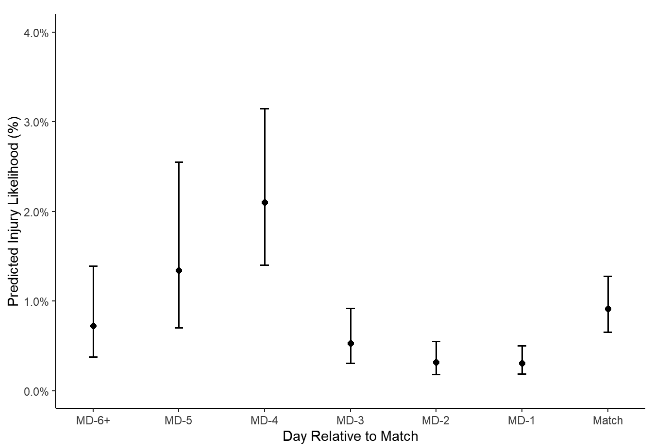

Figure 2. Predicted likelihood (95% CI) of incurring a noncontact injury by the day relative to a match. MD-1 through MD-6+ include practice sessions only. MD, match day; MD-1, 1 day before match; MD-2, 2 days before match; MD-3, 3 days before match; MD-4, 4 days before match; MD-5, 5 days before match; MD-6+, 6+ days before match.

$P < .01$) per every 10-km increase in $\text{Chronic}_{\text{TD}}$ and by 8% (IRR, 0.92; 95% CI, 0.88-0.97; $P < .001$) per every 1 km in $\text{Chronic}_{\text{HSD}}$ (Figure 3). Total distance monotony ($\text{Monotony}_{\text{TD}}$) was also positively associated with noncontact injury, with injury rates increasing by 51% per 1-unit increase in $\text{Monotony}_{\text{TD}}$ (IRR, 1.51; 95% CI, 1.18-1.92; $P < .001$).

Sleep

Multinomial logistic regression results displaying the odds of sustaining a noncontact injury based on average sleep behavior during a season are presented in Table 3. The results indicate that the seasonal average sleep duration and aspects of sleep quality were not statistically associated with increased odds of sustaining a noncontact injury over the season ($P > .05$). The effect of average weekly sleep behavior on subsequent noncontact injury rates during the week are also shown in Table 3. Specifically, sleep latency showed a positive association with increased injury incidence with a 2.43 times (95% CI, 1.03-5.73; $P = .04$) increase in injury incidence rate per 1-hour increase in time needed to fall asleep. Increases in perceived sleep quality, calmness of sleep, and ease of falling asleep were associated with a decreased injury incidence rate by 41%, 43%, and 33% per 1-unit increase, respectively. Additionally, there were no significant differences found between the seasonal average sleep duration or quality and the night before an injury, an average of 3 nights before an injury, or an average of 7 days before an injury ($P > .05$) (Table 4).

DISCUSSION

Our key findings were that collegiate soccer players are at higher risk for noncontact injury during the preseason compared with other phases of the competitive cycle, during matches compared with training, and when only 1 day of rest in the previous 7 days occurred compared with >1 day of rest, and injury rates peaked when training occurred 4 days before a match. Injury risk increased exponentially with increases in the number of previous injuries throughout the season. Also, lower chronic loading, higher training monotony (ie, lower training variability), and increased acute spikes or lulls in loading were associated with higher noncontact injury risk.

Athlete and Schedule-Specific Factors

Noncontact injury rates were not different between male and female players, which is supported by epidemiological injury surveillance research in collegiate soccer.[53] Although noncontact injury was not directly investigated by Roos et al,[53] they reported no differences in injury rates between men and women for either time-loss or non–time-loss injuries in a large investigation of 167 collegiate team-seasons. Our findings further support that noncontact injury rates are not different between women and men in NCAA Division I soccer.

Since injury rates have consistently been found to be higher in matches compared with training,[51,53] including in the current study, it is interesting that noncontact injury rates were not elevated for starters compared with reserves. Starters in NCAA Division I soccer have been found to accumulate more seasonal total and match workloads throughout a season compared with their reserve counterparts.[18] This finding would suggest that starters are subjected to higher workloads and thereby would be expected to incur higher injury rates throughout a competitive soccer season. NCAA Division I reserves do, however, accumulate slightly more workload in training compared with starters, although this difference was not significant when average daily training workloads were assessed,[17]

TABLE 2
Association Between Workload Characteristics and Noncontact Injury[a]

	IRR	95% CI	*P* Value
Distance			
$ACWR_{TD}$ (per 1-unit increase), au	1.52	1.26-1.83	**<.001**
$Monotony_{TD}$ (per 1-unit increase), au	1.51	1.18-1.92	**<.001**
$Acute_{TD}$ (per 10-km increase in rolling 7-day sum)	0.93	0.78-1.09	.361
$Chronic_{TD}$ (per 10-km increase in rolling 28-day sum)	0.94	0.90-0.98	**.002**
HSD			
$ACWR_{HSD}$ (per 1-unit increase), au	1.43	1.20-1.71	**<.001**
$Monotony_{HSD}$ (per 1-unit increase), au	1.47	0.73-2.97	.285
$Acute_{HSD}$ (per 1-km increase in rolling 7-day sum)	0.91	0.78-1.05	.180
$Chronic_{HSD}$ (per 1-km increase in rolling 28-day sum)	0.92	0.88-0.97	**<.001**

[a]ACWR, acute chronic workload ratio; au, arbitrary units; HSD, high-speed distance (>14.4 km h^{-1}); TD, total distance. Incidence rate ratio (IRR) >1 indicates an increased rate of injury per 1-unit increase. IRR <1 indicates a decreased rate of injury per 1-unit increase. Boldface type indicates statistical significance ($P < .05$).

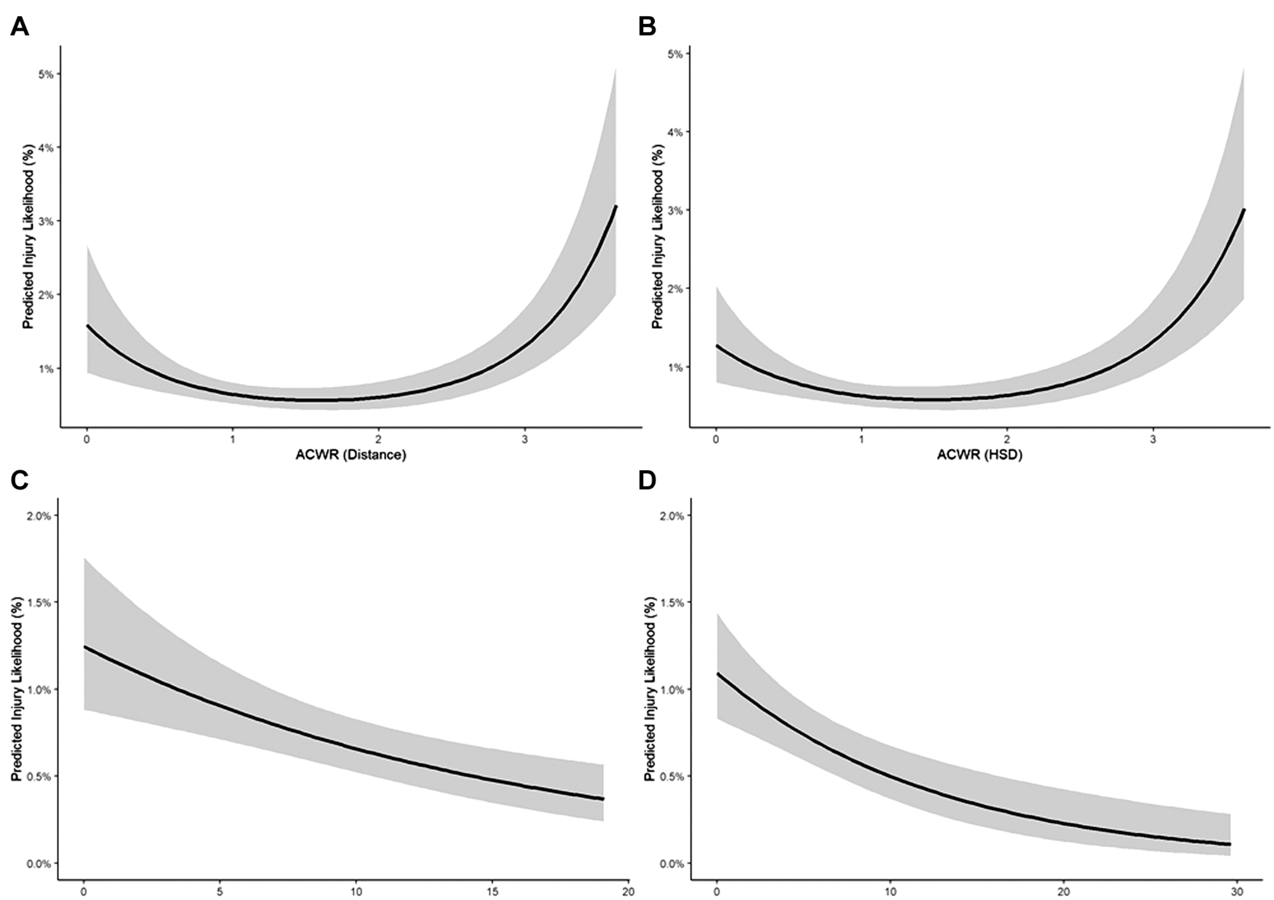

Figure 3. Predicted likelihood (95% CI) of incurring a noncontact injury by (A) acute:chronic workload ratio for total distance ($ACWR_{TD}$), (B) acute chronic workload ratio for high-speed distance ($ACWR_{HSD}$), (C) rolling 28-day sum of total distance ($Chronic_{TD}$), and (D) rolling 28-day sum of high-speed distance ($Chronic_{HSD}$). $ACWR_{TD}$ and $ACWR_{HSD}$ show a U-shaped (quadratic) relationship with predicted injury likelihood. $Chronic_{TD}$ and $Chronic_{HSD}$ show a linear, negative relationship with predicted injury likelihood.

TABLE 3
Association Between Chronic Sleep Behavior and Weekly Changes in Sleep and Noncontact Injury[a]

Measure	Seasonal Average Sleep		Previous Week Sleep	
	OR (95% CI)	*P* Value	IRR (95% CI)	*P* Value
Sleep duration, h	1.13 (0.87-1.48)	.35	1.22 (0.94-1.59)	.143
Sleep latency, h	1.12 (0.86-1.46)	.40	2.43 (1.03-5.73)	**.042**
Sleep quality (1-5)	0.95 (0.27-3.35)	.93	0.59 (0.39-0.88)	**.009**
Calm sleep (1-5)	1.74 (0.46-6.68)	.42	0.57 (0.39-0.84)	**.005**
Sleep planned length (1-5)	0.94 (0.45-1.96)	.87	0.73 (0.52-1.04)	.081
Ease of awakening (1-5)	0.99 (0.53-1.86)	>.99	1.10 (0.74-1.64)	.642
Ease of falling asleep (1-5)	0.52 (0.19-1.39)	.19	0.67 (0.46-0.98)	**.041**
Dream (1-5)	0.99 (0.68-1.44)	.98	0.90 (0.67-1.21)	.475
Sleep disturbances (count)	1.06 (0.84-1.32)	.63	0.95 (0.78-1.14)	.572

[a]Odds ratio (OR) and incidence rate ratio (IRR) >1 indicate a positive association. OR and IRR <1 indicate a negative association. Boldface type indicates statistical significance ($P < .05$).

TABLE 4
Comparison of Previous Sleep Behavior With Seasonal Average for Noncontact Injury (n = 91 Injury Incidences)[a]

Sleep Measure	Season Avg	1 Night Before		3 Nights Before (Avg)		7 Nights Before (Avg)	
	Mean (SD)	Mean (SD)	*P* Value	Mean (SD)	*P* Value	Mean (SD)	*P* Value
Sleep duration, h	7.98 (1.15)	7.80 (1.87)	.66	7.72 (1.68)	.11	7.86 (1.48)	.83
Sleep quality (1-5)	3.58 (0.56)	3.54 (0.99)	.69	3.53 (0.80)	.92	3.57 (0.72)	.55

[a]*P* values are shown versus the season average (Avg).

with effect size (ES) differences being small to moderate (ES, 0.49-0.72) when accumulated seasonal training workloads were assessed.[18] Although not directly investigated in this study, the injury likelihood may be influenced by the interaction between player role and session type, whereby starters have higher injury rates specifically in matches and reserve higher rates during training. Further investigation of this interaction is warranted.

The current investigation identified preseason as a particularly relevant phase for increased injury rates. This is to be expected, as previous reports of NCAA Division I men's soccer indicated that average preseason workloads were greater when compared with in-season for both external (ie, TD and HSD) and internal (ie, subjective rating of perceived exertion, high-intensity heart rate time) measures.[17] On average, collegiate male soccer players cover significantly more TD (+651 m; ES, 0.48) and HSD (>14.4 $km \cdot h^{-1}$; +157 m; ES, 0.48) during preseason compared with the in-season phase.[17] The direct relationship between increased volume and intensity of loading and increased injury rates in the preseason has important implications for coaches and practitioners, as the primary purpose of the preseason is to rebuild physical capacities such as aerobic fitness.[52] A study by Eliakim et al[25] showed that increases in VO_{2max} attained during preseason were nearly eliminated for those players who incurred an injury during 6 weeks of preseason in Israeli professional soccer players (0.9% [injured] vs 10.4% [not injured]; $P < .05$), which directly undermines the purpose of the phase. Preventative considerations are warranted, such as increased development before preseason, gradually progressing workload volume and intensity, and balancing intensified training with appropriate rest during preseason.

While injury rates were significantly higher in matches compared with training, more interesting is the structure of injury rates on training days leading up to a match. As expected, rates are lowest 1 day before a match where the session intent, physiologically speaking, is to minimize fatigue and maximize readiness for the upcoming game. Indeed, NCAA Division I soccer workloads have been shown to be significantly decreased 1 day removed from a match when compared with other training days[17]; this has also been shown at the highest level of professional soccer.[45] Our results indicate training injury rates are similar to an "epi-curve" that slowly builds from MD-1 to MD-3, sharply increases 4 days removed from a match, and then slowly declines afterward. This is surprising given that previous research in NCAA soccer has indicated that there are no differences in either internal or external workloads from days 2 to 4, with workloads 5+ days from a match being significantly higher than all other training days.[17] These results may support a fatigue-related mechanism underpinning noncontact injury, or a lag effect, where injury rates may spike in the day after sessions with the highest workloads. Important to note is that the NCAA soccer teams average 1 match approximately every 4 days[19]; therefore, a larger portion of 4 to 5+ training days may be incurred during the preseason, which has consistently been shown to produce the highest injury rates. While this study did not assess the interaction between days relative to a match and season phase on injury rates, this may be a relevant relationship that requires further investigation.

Previous injury is a well-established risk factor for subsequent injury in soccer.[35] Athletes with previous injuries have been found to have 4 to 7 times greater risk of subsequent injury.[4] We found not only that the number of previous injuries was the strongest risk factor (IRR, 2.23) for injury but also that the relationship was exponential rather than linear. These findings are important because subsequent injury risk substantially increases as more injuries are incurred throughout the season, and therefore injury prevention measures should accommodate this relationship. Increased preventative measures (eg, workload management) should be highly considered for those players who have sustained multiple injuries throughout a season.

Numerous studies have investigated the influence of match congestion on injury.[5,10-12] Our investigation took a unique approach by examining overall session congestion and match congestion. Interestingly, we found overall session congestion, but not match congestion, to be significantly associated with noncontact injury risk. Further, our results indicate that having >1 day off from training and matches in a 7-day period may be beneficial in reducing injury risk. Previous works investigating calendar congestion have been inconsistent. Dellal et al[21] observed that training injuries during congested time periods were either unaltered or reduced, which is credited to a decreased training load during highly congested periods. Several studies have approached this question by dichotomizing between match recovery periods to assess relative risk, with some finding no differences between match recovery periods (<3 days vs >4 days)[5,12] and others finding significantly higher injury rates with less recovery time (<3 days[11,21] or <4 days[5,22] vs >6 days). Conflicting findings are likely the result of contextual factors, such as individual team periodization structures and coaching philosophies, or differences in analytical approaches taken. Our results indicate that session congestion, rather than match congestion, significantly affects injury rates in collegiate soccer and is therefore a critical factor to consider. Prescribing more rest or recovery sessions to counterbalance the highly congested match schedule in NCAA Division I soccer may be an important strategy for improving an athlete's risk profile throughout a season.

Workload Factors

Our findings are consistent with several others who found low chronic workload[15,38] and "spikes" in workload to be associated with increased injury risk.[15,29,39] Figure 3 (C and D) displays a clear negative, linear relationship between chronic workloads (ie, 28-day rolling sum) and injury likelihood for both TD and HSD. Attaining and maintaining high chronic workloads appears to be protective of injury, while low chronic workloads are typically associated with increased injury risk.[38] However, it is important to note that not all studies support this, as McCall et al[46] found no association between injury risk and chronic load in a study of 5 professional soccer teams.

While most evidence suggests chronic workloads are negatively associated with injury incidence, it is likely that injury risk is affected by complex interactions between acute and chronic loads. Our findings suggest that injury risk is elevated when acute loads are below (ACWR, <1) and exponentially increase when well above chronic baselines (ACWR, >2) for TD (Figure 3A) and HSD (Figure 3B). Interestingly, injury risk was lower throughout a wider range of workload ratios than has been previously shown based on data from cricket, Australian football, and rugby leagues (ACWR, 0.8-1.5).[30] These differences are likely attributed to a number of differences in analytical methods between our research and others. First, this study investigated daily workload ratio and injury risk in the subsequent session instead of using average weekly ratios based on rolling means to assess injury risk in the subsequent week. Further, when Carey et al[9] split ACWR-injury analysis by session type (ie, match vs training), they found noncontact injury likelihood to be lower throughout a wider range of workload ratios when training injuries were considered compared with match injuries, with a less steep curve at increased workload ratios. Because physical and cognitive stresses are generally higher during a match compared with training, it makes sense that injury likelihood would also be elevated during a match compared with training when athletes are exposed at increased workload ratios. Our results support previous contentions that injury risk is associated with changes in workload relative to an athlete's chronic baseline.[9,16,30] Additionally, the flatness of our ACWR-injury curve throughout a wider range of workload ratios than previously shown may be a result of the inclusion of both training and match injuries.

In addition to acute and chronic workloads, we also investigated the association between workload monotony and injury risk, which has been previously linked with overtraining syndrome and increased illness.[26] This link has been supported by Brink et al,[8] who found that an increase in monotony was significantly related to an increase in injury odds (OR, 2.59; 95% CI, 1.22-1.50). Our research further supports these findings, highlighting monotony as an important workload metric to consider when prescribing training. These findings are important for coaches because workload metrics such as chronic workload, ACWR, and monotony can be directly influenced by the workload periodization structure used and thus are not as reliant on an athlete's compliance in comparison with other preventative measures (eg, sleep strategies, recovery modalities). Ensuring that higher chronic loads are sustained, while introducing adequate load variability and minimizing acute spikes or lulls in load, is a practical consideration for reducing injury risk when prescribing training.

Sleep Factors

Survey-based research on the adolescent athlete's sleep behavior indicates that chronic lack of sleep is associated with injury risk.[48,57] Research by Milewski et al[48] found sleep duration to be a predictor of injury risk in adolescent athletes, with athletes who slept <8 hours per night being 1.7 times (95% CI, 1.0-3.0; P = .04) more likely to incur an injury compared with athletes sleeping >8 hours. Additionally, von Rosen and colleagues[57] found that getting ≥8 hours of sleep during weekdays reduced the odds of injury for adolescent athletes by 61% (OR, 0.39; 95% CI, 0.16-0.99). In contrast, we did not find an association between chronic sleep behavior and the odds of sustaining an injury over the course of a collegiate soccer season for a range of sleep duration and sleep quality measures. Interestingly, a case study on 3 injuries in 1 elite soccer athlete indicates that sleep latency and efficiency 1 night before and 1 week before injury may be compromised in elite male soccer players.[50] In the current study, we investigated this relationship with 91 separate noncontact injuries and found no disruption in sleep duration or quality in the night preceding injury or an average of 3 and 7 nights preceding injury compared with an athlete's chronic baseline sleep average. In contrast to the findings of Nédélec et al,[50] our results suggest sleep disruption acutely preceding an injury may not be a normal occurrence. However, to investigate a potential lag effect of poor sleep characteristics, we also assessed whether poor sleep in a week may be related to increased injury in the subsequent week. Indeed, we found aspects of sleep quality but not sleep duration to be associated with injury risk during the following week. These findings have important implications for the coach and practitioner. Our results indicate that although poor sleep may not directly influence injury risk in the subsequent few days, having a poor week of sleep may negatively influence an athlete's injury risk profile the following week. Sleep hygiene strategies should be routinely implemented rather than at select instances (eg, before or after matches), as there may be a lag effect whereby poor average weekly sleep negatively influences injury risk in the subsequent week. Additionally, sleep hygiene strategies focused on creating an environment conducive to falling asleep and promoting optimal sleep quality, in addition to efforts to extend sleep duration, may be more effective in reducing injury risk.

Limitations

Although several injury risk factors were assessed independently in this investigation, the degree of interaction between identified injury risk factors remains unclear. One of our limitations is that complex interactions are occurring between factors (eg, preseason is associated with lower chronic loads, higher ACWR, and higher training monotony), which cannot be captured by this univariate approach. These interactions can be described as mediating and moderating effects, which have been discussed by Windt et al[59] in the context of injury cause. Although identifying complex interactions between risk factors was beyond the aim of this preliminary investigation, these associations certainly exist, and several have been pointed out here. Further investigations examining the effect of a number of workload, sleep, and contextual factor interactions on injury risk are needed.

Some previous risk factor studies have elected to use more conservative injury classifications such as noncontact injuries leading to time loss[46] or even use more conservative classifications such as injuries leading to matches missed. There is an inherent paradox whereby the use of conservative injury definitions may enhance the consistency of the injury record between studies (eg, matches missed) but incompletely capture the injury burden in sports. We elected to include all noncontact injuries, regardless of time loss, which could be viewed as a limitation. It is, however, the authors' contention that all injuries, regardless of time loss, have the potential to negatively affect individual and team performance and therefore deserve consideration when investigating factors contributing to injury and ultimately designing preventative strategies. Additionally, in investigating the association between previous injury and subsequent injury risk, we investigate athletes' risk of injury based on any previous injury and do not account for the site or nature of injury. This is a relevant limitation because athletes may be experiencing recurrent injuries to the same site or may be incurring injuries as a result of mechanical alterations in gait from a previous injury. The propensity for incurring injury after a past injury is indeed complex and warrants detailed investigation of both recurrent injury risk and the risk that interaction between a previous injury and altered gait may have on future injury.

While this study was novel in that the same player tracking system was used for all teams involved and objective measures of workload were recorded for all participants, the investigation focused only on measures of external workload volume (TD) and intensity (total HSD). Previous research has shown that injury is associated with subjective measures of internal workload (ie, session rating of perceived exertion [sRPE]).[31,37] Additionally, subjective sRPE and objective internal workloads (ie, duration of time at heart rate >70% maximum heart rate) have been shown to vary based on a number of contextual factors (eg, season phase and days relative to a match) in NCAA Division I soccer and therefore may also be linked to injury risk.[17] We postulate that investigating internal workloads; accelerometry measures such as accelerations, decelerations, and collisions; and relevant markers of fatigue may offer additional insight into the relationship between workload and injury.

A further limitation of this study is the lack of objective measurement of sleep or of activity during sleep. While several subjective sleep assessment tools have been validated and are widely used in sports,[13] there are several limitations inherent to subjective assessment of sleep. First, subjective measures rely on the assumption that participants are fully aware of when they fall asleep and wake up, with research indicating that individuals tend to overestimate the amount of sleep they get.[43] This has important implications for sleep-injury relationships investigated in this study in that, while items of the KSD have been shown to be correlated with objective measures of sleep, we cannot be certain of the accuracy of the recorded sleep data. Another limitation specific to our research is the lack of control of when participants reported their sleep after waking, in which recall accuracy can be negatively affected as time extends from initial waking (ie, recall bias). However, it is relevant to note that these issues are not isolated to subjective measures, as actigraphy also tends to overestimate sleep duration,[42] often lacks external validation, and can be difficult to implement on a larger scale (eg, technology and software licensure cost, data accessibility, and management). Future research utilizing complementary methods of sleep assessment (ie, objective and subjective tools) can help better define sleep accuracy (eg, sleep/wake patterns, aspects of sleep quality[27]), allowing the assessment of sleep-injury relationships to be more robust.

CONCLUSION

This investigation identified 9 separate noncontact injury risk factors in collegiate soccer, which include relative workloads (ACWR), chronic workloads, workload monotony, season type, session type, days relative to a match, session congestion, sleep latency, and sleep quality. Athletes were at higher risk for noncontact injury during the preseason compared with in-season and postseason, during matches compared with training, and when only 1 day of rest occurred in the previous 7 days compared with >1 day, and injury rates peaked when training occurred 4 days before a match. Further, injury risk increased exponentially with increases in noncontact injury throughout the season. Chronic sleep behavior was not associated with noncontact injury during the season, and sleep was not altered the night before or an average of 3 nights or 7 nights before an injury. Weekly fluctuations in perceived sleep quality were, however, informative of injury risk in the subsequent week, suggesting that an athlete's sleep the week before may be influencing subsequent injury risk. Several athlete and schedule-specific contextual factors combined with characteristics of workload and weekly sleep behavior are significantly associated with injury in collegiate soccer.

CLINICAL RELEVANCE

Multiteam prospective cohort studies involving objective and subjective monitoring allow for the identification of multiple injury risk factors in sports, which can be used to guide injury prevention strategies on both a team (eg, scheduling of training and rest days) and individual (eg, player workload periodization) level. Maintaining higher chronic loading, lowering training monotony (increasing training variability), and minimizing acute spikes or lulls in loading are all practical load management considerations for reducing injury risk. Our finding of a significant association between session congestion but not match congestion and injury highlights an important modifiable risk factor in collegiate soccer. From a scheduling perspective, injury risk may be reduced by prescribing >1 day off from on-field team sessions (ie, match and training) in a 7-day period. Replacing training sessions with rest and recovery, particularly during match-dense periods, is an easily implemented strategy for reducing injury risk. While it is widely understood that injury rates are higher in matches, coaches should be aware that injury rates during training have a nonlinear relationship with days relative to a match, with injury rates peaking when training occurs 4 days removed from a match. Further, our results indicate subjective sleep quality rather than quantity is associated with injury and negative alterations in sleep in the previous week may be influencing injury likelihood. Sleep hygiene strategies may consider focusing on improving sleep quality rather than sleep quantity to reduce injury likelihood. Further, efforts to mitigate injury risk may be bolstered by monitoring aspects of sleep quality, so that extended periods of poor sleep may be identified and recovery or load management strategies can be implemented. Developing a multifactorial view is vital for context when trying to understand complex phenomena such as injury and to develop both team and individual injury prevention practices.

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REFERENCES

1. Akerstedt T, Hume K, Minors D, Waterhouse J. The meaning of good sleep: a longitudinal study of polysomnography and subjective sleep quality. *J Sleep Res*. 1994;3(3):152-158. doi:10.1111/j.1365-2869.1994.tb00122
2. Åkerstedt T, Hume K, Minors D, Waterhouse J. The subjective meaning of good sleep, an intraindividual approach using the Karolinska Sleep Diary. *Percept Mot Skills*. 1994;79(1):287-296. doi:10.2466/pms.1994.79.1.287
3. Anderson L, Orme P, Michele RD, et al. Quantification of seasonal-long physical load in soccer players with different starting status from the English Premier League: implications for maintaining squad physical fitness. *Int J Sports Physiol Perform*. 2016;11(8):1038-1046. doi:10.1123/ijspp.2015-0672
4. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med*. 2004;32(1)(suppl):5S-16S. doi:10.1177/0363546503258912
5. Bengtsson H, Ekstrand J, Hägglund M. Muscle injury rates in professional football increase with fixture congestion: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med*. 2013;47(12):743-747. doi:10.1136/bjsports-2013-092383
6. Benjamin CL, Adams WM, Curtis RM, Sekiguchi Y, Giersch GEW, Casa DJ. Early morning training impacts previous night's sleep in NCAA Division I cross country runners. *Women Sport Phys Act J*. 2019;28(1):27-33. doi:10.1123/wspaj.2018-0050
7. Bittencourt NFN, Meeuwisse WH, Mendonça LD, Nettel-Aguirre A, Ocarino JM, Fonseca ST. Complex systems approach for sports

injuries: moving from risk factor identification to injury pattern recognition—narrative review and new concept. *Br J Sports Med*. 2016;50(21):1309-1314. doi:10.1136/bjsports-2015-095850

8. Brink MS, Visscher C, Arends S, Zwerver J, Post WJ, Lemmink KA. Monitoring stress and recovery: new insights for the prevention of injuries and illnesses in elite youth soccer players. *Br J Sports Med*. 2010;44(11):809-815. doi:10.1136/bjsm.2009.069476
9. Carey DL, Blanch P, Ong KL, Crossley KM, Crow J, Morris ME. Training loads and injury risk in Australian football—differing acute:chronic workload ratios influence match injury risk. *Br J Sports Med*. 2017;51(16):1215-1220. doi:10.1136/bjsports-2016-096309
10. 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. doi:10.1055/s-0031-1283190
11. Carling C, McCall A, Le Gall F, Dupont G. The impact of short periods of match congestion on injury risk and patterns in an elite football club. *Br J Sports Med*. 2016;50(12):764-768. doi:10.1136/bjsports-2015-095501
12. Carling C, Orhant E, LeGall F. Match injuries in professional soccer: inter-seasonal variation and effects of competition type, match congestion and positional role. *Int J Sports Med*. 2010;31(4):271-276. doi:10.1055/s-0029-1243646
13. Claudino JG, Gabbett TJ, de Sá Souza H, et al. Which parameters to use for sleep quality monitoring in team sport athletes? A systematic review and meta-analysis. *BMJ Open Sport Exerc Med*. 2019;5(1):e000475. doi:10.1136/bmjsem-2018-000475
14. Cnaan A, Laird NM, Slasor P. Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data. *Stat Med*. 1997;16(20):2349-2380.
15. Colby MJ, Dawson B, Heasman J, Rogalski B, Gabbett TJ. Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *J Strength Cond Res*. 2014;28(8):2244-2252. doi:10.1519/JSC.0000000000000362
16. Colby MJ, Dawson B, Peeling P, et al. Multivariate modelling of subjective and objective monitoring data improve the detection of noncontact injury risk in elite Australian footballers. *J Sci Med Sport*. 2017;20(12):1068-1074. doi:10.1016/j.jsams.2017.05.010
17. Curtis RM, Huggins RA, Benjamin CL, et al. Contextual factors influencing external and internal training loads in collegiate men's soccer. *J Strength Cond Res*. 2020;34(2):374-381. doi:10.1519/JSC.0000000000003361
18. Curtis RM, Huggins RA, Benjamin CL, et al. Seasonal accumulated workloads in collegiate men's soccer: a comparison of starters and reserves. *J Strength Cond Res*. Published online August 23, 2019. doi:10.1519/JSC.0000000000003257
19. Curtis RM, Huggins RA, Looney DP, et al. Match demands of National Collegiate Athletic Association Division I men's soccer: *J Strength Cond Res*. 2018;32(10):2907-2917. doi:10.1519/JSC.0000000000002719
20. Datalys Center, Inc. NCAA Injury Surveillance Program. Accessed March 8, 2021. https://www.datalyscenter.org/ncaa-Injury-surveillance-program/
21. Dellal A, Lago-Peñas C, Rey E, Chamari K, Orhant E. The effects of a congested fixture period on physical performance, technical activity and injury rate during matches in a professional soccer team. *Br J Sports Med*. 2015;49(6):390-394. doi:10.1136/bjsports-2012-091290
22. Dupont G, Nedelec M, McCall A, McCormack D, Berthoin S, Wisløff U. Effect of 2 soccer matches in a week on physical performance and injury rate. *Am J Sports Med*. 2010;38(9):1752-1758. doi:10.1177/0363546510361236
23. Dvorak J, Junge A, Chomiak J, et al. Risk factor analysis for injuries in football players. Possibilities for a prevention program. *Am J Sports Med*. 2000;28(5)(suppl):S69-S74. doi:10.1177/28.suppl_5.s-69
24. Ekstrand J. Preventing injuries in professional football: thinking bigger and working together. *Br J Sports Med*. 2016;50(12):709-710. doi:10.1136/bjsports-2016-096333
25. Eliakim E, Doron O, Meckel Y, Nemet D, Eliakim A. Pre-season fitness level and injury rate in professional soccer - a prospective study. *Sports Med Int Open*. 2018;2(3):E84-E90. doi:10.1055/a-0631-9346
26. Foster C. Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exerc*. 1998;30(7):1164-1168.
27. Fullagar HHK, Skorski S, Duffield R, Hammes D, Coutts AJ, Meyer T. Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports Med*. 2014;45(2):161-186. doi:10.1007/s40279-014-0260-0
28. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Clin J Sport Med*. 2006;16(2):97-106.
29. Gabbett TJ. The development and application of an injury prediction model for noncontact, soft-tissue injuries in elite collision sport athletes. *J Strength Cond Res*. 2010;24(10):2593-2603. doi:10.1519/JSC.0b013e3181f19da4
30. Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? *Br J Sports Med*. 2016;50(5):273-280. doi:10.1136/bjsports-2015-095788
31. Gabbett TJ, Jenkins DG. Relationship between training load and injury in professional rugby league players. *J Sci Med Sport*. 2011;14(3):204-209. doi:10.1016/j.jsams.2010.12.002
32. Gabbett TJ, Ullah S. Relationship between running loads and soft-tissue injury in elite team sport athletes. *J Strength Cond Res*. 2012;26(4):953-960. doi:10.1519/JSC.0b013e3182302023
33. Giersch GEW, Huggins RA, Benjamin CL, et al. Validity and reliability of a shirt-based integrated GPS sensor: 2759 Board #42 June 1 2: 00 PM - 3: 30 PM. *Med Sci Sports Exerc*. 2018;50(5)(suppl):673. doi:10.1249/01.mss.0000538219.84744.41
34. Hägglund M, Waldén M, Ekstrand J. Exposure and injury risk in Swedish elite football: a comparison between seasons 1982 and 2001. *Scand J Med Sci Sports*. 2003;13(6):364-370.
35. Hägglund M, Waldén M, Ekstrand J. Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. *Br J Sports Med*. 2006;40(9):767-772. doi:10.1136/bjsm.2006.026609
36. Hägglund M, Waldén M, Magnusson H, Kristenson K, Bengtsson H, Ekstrand J. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med*. 2013;47(12):738-742. doi:10.1136/bjsports-2013-092215
37. Hulin BT, Gabbett TJ, Blanch P, Chapman P, Bailey D, Orchard JW. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med*. 2014;48(8):708-712. doi:10.1136/bjsports-2013-092524
38. Hulin BT, Gabbett TJ, Caputi P, Lawson DW, Sampson JA. Low chronic workload and the acute:chronic workload ratio are more predictive of injury than between-match recovery time: a two-season prospective cohort study in elite rugby league players. *Br J Sports Med*. 2016;50(16):1008-1012. doi:10.1136/bjsports-2015-095364
39. Hulin BT, Gabbett TJ, Lawson DW, Caputi P, Sampson JA. The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. *Br J Sports Med*. 2016;50(4):231-236. doi:10.1136/bjsports-2015-094817
40. Jennings D, Cormack S, Coutts AJ, Boyd L, Aughey RJ. The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *Int J Sports Physiol Perform*. 2010;5(3):328-341.
41. Junge A, Dvorak J. Influence of definition and data collection on the incidence of injuries in football. *Am J Sports Med*. 2000;28(5)(suppl):S40-S46. doi:10.1177/28.suppl_5.s-40
42. Krystal AD, Edinger JD. Measuring sleep quality. *Sleep Med*. 2008;9(suppl 1):S10-S17. doi:10.1016/S138w9-9457(08)70011-X
43. Lauderdale DS, Knutson KL, Yan LL, Liu K, Rathouz PJ. Sleep duration: how well do self-reports reflect objective measures? The CARDIA Sleep Study. *Epidemiology*. 2008;19(6):838-845. doi:10.1097/EDE.0b013e318187a7b0

44. Laux P, Krumm B, Diers M, Flor H. Recovery-stress balance and injury risk in professional football players: a prospective study. *J Sports Sci*. 2015;33(20):2140-2148. doi:10.1080/02640414.2015.1064538
45. Malone JJ, Di Michele R, Morgans R, Burgess D, Morton JP, Drust B. Seasonal training-load quantification in elite English Premier League soccer players. *Int J Sports Physiol Perform*. 2015;10(4):489-497. doi:10.1123/ijspp.2014-0352
46. McCall A, Dupont G, Ekstrand J. Internal workload and non-contact injury: a one-season study of five teams from the UEFA Elite Club Injury Study. *Br J Sports Med*. 2018;52(23):1517-1522. doi:10.1136/bjsports-2017-098473
47. Meeuwisse WH, Tyreman H, Hagel B, Emery C. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clin J Sport Med*. 2007;17(3):215-219. doi:10.1097/JSM.0b013e3180592a48
48. Milewski MD, Skaggs DL, Bishop GA, et al. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. *J Pediatr Orthop*. 2014;34(2):129-133. doi:10.1097/BPO.0000000000000151
49. Murray NB, Gabbett TJ, Townshend AD, Blanch P. Calculating acute:chronic workload ratios using exponentially weighted moving averages provides a more sensitive indicator of injury likelihood than rolling averages. *Br J Sports Med*. 2017;51(9):749-754. doi:10.1136/bjsports-2016-097152
50. Nédélec M, Leduc C, Dawson B, Guilhem G, Dupont G. Case study: sleep and injury in elite soccer—a mixed method approach. *J Strength Cond Res*. 2019;33(11):3085-3091. doi:10.1519/JSC.0000000000002251
51. Pfirrmann D, Herbst M, Ingelfinger P, Simon P, Tug S. Analysis of injury incidences in male professional adult and elite youth soccer players: a systematic review. *J Athl Train*. 2016;51(5):410-424. doi:10.4085/1062-6050-51.6.03
52. Reilly T. *The Science of Training—Soccer: A Scientific Approach to Developing Strength, Speed and Endurance*. Routledge; 2007.
53. Roos KG, Wasserman EB, Dalton SL, et al. Epidemiology of 3825 injuries sustained in six seasons of National Collegiate Athletic Association men's and women's soccer (2009/2010–2014/2015). *Br J Sports Med*. 2017;51(13):1029-1034. doi:10.1136/bjsports-2015-095718
54. Saxon L, Finch C, Bass S. Sports participation, sports injuries and osteoarthritis: implications for prevention. *Sports Med*. 1999;28(2):123-135.
55. Thorborg K, Krommes KK, Esteve E, Clausen MB, Bartels EM, Rathleff MS. Effect of specific exercise-based football injury prevention programmes on the overall injury rate in football: a systematic review and meta-analysis of the FIFA 11 and 11+ programmes. *Br J Sports Med*. 2017;51(7):562-571. doi:10.1136/bjsports-2016-097066
56. van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Med*. 1992;14(2):82-99.
57. von Rosen P, Heijne AILM, Frohm A. Injuries and associated risk factors among adolescent elite orienteerers: a 26-week prospective registration study. *J Athl Train*. 2016;51(4):321-328. doi:10.4085/1062-6050-51.5.01
58. Windt J, Gabbett TJ. How do training and competition workloads relate to injury? The workload-injury aetiology model. *Br J Sports Med*. 2017;51(5):428-435. doi:10.1136/bjsports-2016-096040
59. Windt J, Zumbo BD, Sporer B, MacDonald K, Gabbett TJ. Why do workload spikes cause injuries, and which athletes are at higher risk? Mediators and moderators in workload-injury investigations. *Br J Sports Med*. 2017;51(13):993-994. doi:10.1136/bjsports-2016-097255