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Can the workload–injury relationship be moderated by improved strength, speed and repeated-sprint qualities?

Shane Malone[a,b,*], Brian Hughes[b], Dominic A. Doran[a], Kieran Collins[a], Tim J. Gabbett[c,d]

[a] The Tom Reilly Building, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, UK
[b] Gaelic Sport Research Centre, Department of Science, Institute of Technology Tallaght Dublin, Ireland
[c] Gabbett Performance Solutions, Australia
[d] Institute for Resilient Regions, University of Southern Queensland, Australia

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ABSTRACT

Objectives: The aim of this study was to investigate potential moderators (i.e. lower body strength, repeated-sprint ability [RSA] and maximal velocity) of injury risk within a team-sport cohort.
Design: Observational cohort study.
Methods: Forty male amateur hurling players (age: 26.2 ± 4.4 year, height: 184.2 ± 7.1 cm, mass: 82.6 ± 4.7 kg) were recruited. During a two-year period, workload (session RPE × duration), injury and physical qualities were assessed. Specific physical qualities assessed were a three-repetition maximum Trapbar deadlift, 6 × 35-m repeated-sprint (RSA) and 5-, 10- and 20-m sprint time. All derived workload and physical quality measures were modelled against injury data using regression analysis. Odds ratios (OR) were reported against a reference group.
Results: Moderate weekly loads between ≥1400 AU and ≤1900 AU were protective against injury during both the pre-season (OR: 0.44, 95% CI: 0.18–0.66) and in-season periods (OR: 0.59, 95% CI: 0.37–0.82) compared to a low load reference group (≤1200 AU). When strength was considered as a moderator of injury risk, stronger athletes were better able to tolerate the given workload at a reduced risk. Stronger athletes were also better able to tolerate larger week-to-week changes (>550–1000 AU) in workload than weaker athletes (OR = 2.54–4.52). Athletes who were slower over 5-m (OR: 3.11, 95% CI: 2.33–3.87), 10-m (OR: 3.45, 95% CI: 2.11–4.13) and 20-m (OR: 3.12, 95% CI: 2.11–4.13) were at increased risk of injury compared to faster athletes. When repeated-sprint total time (RSA_t) was considered as a moderator of injury risk at a given workload (≥1750 AU), athletes with better RSA_t were at reduced risk compared to those with poor RSA_t (OR: 5.55, 95%: 3.98–7.94).
Conclusions: These findings demonstrate that well-developed lower-body strength, RSA and speed are associated with better tolerance to higher workloads and reduced risk of injury in team-sport athletes.

1. Introduction

The process of planning appropriate workloads is a cross-discipline effort involving management, strength and conditioning and medical staff encompassing an ever evolving and holistic process.[1] Adequate workloads are required to improve player's physical and performance qualities[2,3] however, there is a balance to be considered between improving fitness and increasing player fatigue.[4] The evolving nature of team based sports has resulted in an increased interest in monitoring player activities quantitatively on a daily and weekly basis.[5] As such the prescription of appropriate training loads requires careful consideration by all stakeholders to best maximise performance levels while minimising the negative (injury) effects of the prescribed load.[5] While several studies have documented the relationship between specific elements of training load and injury[6,7] in team sport players, very few have investigated potential mediators and moderators of injury risk within these cohorts.

The process leading to a specific injury occurrence is multifactorial, and thus attributing injuries to single risk factors is a gross simplification of the injury process.[8,9] Therefore, the interpretation of the workload–injury relationship can never be completed in isolation.[10] Instead, it is important for practitioners to understand the specific mechanisms such as workload spikes, physical qualities, playing experience, and previous injury that may increase (or decrease) the likelihood of injury.[10,11] Furthermore, it is important

* Corresponding author.
E-mail address: shane.malone@mymail.ittdublin.ie (S. Malone).

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that the characteristics that make athletes more robust or more susceptible to injury at any given workload are better understood. To date, few studies investigated which factors potentially *mediate* or *moderate* the workload–injury relationship.[10] Specifically, it is known in rugby league that rapid increases in running workloads, indicated by a high acute:chronic workload ratio, *mediated* the risk for non-contact injuries.[12] However, in Gaelic football and soccer players, high aerobic fitness *moderated* the risk for non-contact injuries.[2,11]

Recently, workload–injury investigations have examined absolute weekly workloads (1–4 weekly) and acute workloads relative to chronic workloads (acute:chronic workload).[2,6] Previously higher workloads have been reported to have either positive or negative influences on injury risk.[7,11] Specifically, compared with players who had a low chronic workload, players with a high chronic workload were more resistant to injury with moderate-low through moderate-high (0.85–1.35) acute:chronic workload ratios and less resistant to injury when subjected to 'spikes' in acute workload.[12] In addition, higher chronic workloads combined with well-developed aerobic fitness can moderate subsequent injury risk.[3,11] Indeed, Gaelic football players with higher chronic loads were able to complete maximal velocity running exposures at lower risk than players with lower chronic loads.[11] High training loads, designed to develop physical qualities, are thought to be critical to prepare players for competition. Ultimately there is the need to understand which physical qualities best protect players during these periods of increased load.[1] To date, speed, lower-body strength, and repeated-sprint ability (RSA) have not been investigated as potential moderators of injury risk.[10] There is a need for practitioners to understand the mediators and moderators of injury risk within team sport athletes. At present, very few studies[3,6] have analysed multiple physical qualities and determined how these qualities subsequently impact the workload–injury relationship. As such, the purpose of the current investigation was to examine the relationship between training load, physical qualities and injury in team sport players.

2. Methods

Forty amateur male hurling players (age = 26.2 ± 4.4 years, height = 182.2 ± 7.1 cm, mass = 81.3 ± 3.7 kg) with a median of 5 years (range 1–12 years) playing experience from a single team were recruited for this study. The human research ethics committee of the local institution approved the study and participants gave informed written consent prior to the observational period.

All time-loss injuries were recorded using a bespoke database for data collection. All injuries that prevented a player from taking full part in all training and match-play activities typically planned for that day, and prevented participation for a period greater than 24 h were recorded. The current definition mirrors that employed by Brooks et al.[13] and conforms to the consensus time-loss injury definitions proposed for team sport athletes.[14,15] All injuries were classified as being low severity (1–3 missed training sessions); moderate severity (player was unavailable for 1–2 weeks); or high severity (player missed 3 or more weeks). Injuries were also categorised for injury type (description), body site (injury location) and mechanism.[16]

Data were collected from 241 pitch and gym based training sessions across a two-year period. Each player participated in 2–3 pitch based training sessions depending on the week of the season. During the pre-season, training sessions typically had elements of position-specific fitness work in addition to technical and tactical elements. As the season progressed there was a focus towards increased technical and tactical work. This resulted in a reduction of fitness-specific elements. The pitch based training sessions were supplemented by 1–2 gym-based, strength training sessions per week depending on the phase of the season. The duration of the pitch based training sessions was typically between 60 and 110 min depending on session goals. The typical gym-based session was 60–80 min with both upper and lower body exercises completed within the program.

The intensity of all training sessions (including rehabilitation sessions) and match-play were estimated using the modified Borg CR-10 rate of perceived exertion (RPE) scale, with ratings obtained from each individual player immediately after the completion of each training session and match.[2,3] Each player had the scale explained to them before the start of the season and players were asked to report their RPE for each session confidentially without knowledge of other players' ratings.[16] Session-RPE in arbitrary units (AU) for each player was then derived by multiplying RPE and session duration (min). Session-RPE (s-RPE) has previously been shown to be a valid method for estimating exercise intensity.[17] The collection of s-RPE also allowed for the quantification of the following training load measures, 1 week rolling through 4 week rolling load, acute:chronic workload ratio (ACWR; 1-week:4-week) and absolute change in workload (the previous to current week).[2,8] A weekly cycle of training load was defined from Sunday to Sunday, this allowed for match-play events to be calculated within a week of training load. A one-week acute load comparison to four-week chronic load period is suited to Gaelic sports such as hurling given that most training programs are designed by coaches around 4-week cycles during the season due to limited match-play events during the seasonal period.

The physical qualities of players were assessed by conditioning staff during each phase of each season across a two-day testing period with 24-h between testing days. Specifically, during the observational period the conditioning staff assessed maximal lower body strength (3 RM Trapbar deadlift), maximal linear speed across 5-, 10-, and 20-m and repeated-sprint ability (RSA). On day one of testing maximum lower body strength was assessed using a 3-repetition maximum (RM) Trapbar deadlift exercise performed using a free-weight barbell. After warming up with progressively heavier loads, the athlete attempted their self-selected 3RM. The intraclass correlation coefficient (ICC) for test retest reliability and typical error of measurement (TEM) for the 3RM Trapbar deadlift were 0.93 and 2.3%, respectively. The final weight lifted was then referenced to players' body mass to provide relative lower body strength. After a one-hour recovery period, players linear sprint speed was assessed using a 5-, 10- and 20-m sprint. Players sprinted from a standing start. Players were instructed to run as quickly as possible along the 20-m distance. Speed was measured to the nearest 0.01 s, with the fastest value obtained from 2 trials used as the speed score. For the 5-, 10- and 20-m sprint tests, the ICC for test-retest reliability were 0.95, 0.96 and 0.97, respectively, and the TEM were 1.8%, 1.6% and 1.2%, respectively. On day two of the assessment, a RSA test was conducted using six repeated 35-m shuttles with 10 s of passive recovery between efforts.[18] Players sprinted from a standing start and were instructed to sprint as fast as they could for each repeated effort with total sprint time (RSA_t; s) recorded. The ICC for test-retest reliability was 0.95, for RSA_t and TEM was 1.2%. Both linear running tests were monitored with a photocell timing gate system (Witty, Mircrogate, Bolzano, Italy).

Data were analysed in SPSS Version 22.0 (IBM Corporation, New York, USA). A chi-squared analysis was used to compare the frequency of injuries at different workloads and physical qualities across the seasonal phases. Based on the total injuries and sessions completed the calculated statistical power to establish the association between workload, physical qualities and soft-tissue injury was 83%. Weekly load exposure values, physical qualities and all injury data (injury vs. no injury) including subsequent week injuries, were then modelled using a second order polynomial regression. Data were divided into quartile ranges, with a given workload and physical quality range being used as a reference analysis grouping. Odds ratios (OR) were calculated to determine the injury risk at a given cumulative workload (1, 2, 3 and 4-weekly cumulative), ACWR and for absolute change in workload (the previous to current week). Correlation coefficients between the training load measures, alongside variance inflation factors (VIF), were used to detect multicollinearity between the predictor variables. A VIF of ≥10 was deemed indicative of substantial multicollinearity.[19] Within our model, all load measures provided a VIF of ≤10 therefore providing acceptable levels of multicollinearity. When an OR was greater than 1, an increased risk of injury was reported (i.e., OR = 1.50 is indicative of a 50% increased risk) and vice versa.

3. Results

In total, 93 time-loss injuries were reported across the two-seasons. Overall the most common site of injury was the thigh (35%), the knee (11%) and the ankle (17%) with pelvis/groin injuries accounting for 14% of overall injuries. The performance profile of the investigated cohort are shown in Supplementary Table 1. The typical one weekly through to four weekly loads and ACWR as potential risk factors associated within injury are shown in Supplementary Fig. 1 and Supplementary Table 2 respectively. Moderate weekly loads between ≥1400 AU and ≤1900 AU were shown to protect players during both the pre-season (OR: 0.44, 95% CI: 0.18–0.66) and in-season periods (OR: 0.59, 95% CI: 0.37–0.82) compared to a low weekly load group of ≤1200 AU. There were consistent trends for moderate loads to offer reduced odds of injury for 2-weekly, 3-weekly and 4-weekly loads across both the pre-season and in-season phases. Large absolute weekly changes in load (≥1000 AU) were shown to increase the odds of injury compared to smaller weekly changes in load during the pre-season (OR: 5.58, 95% CI: 3.19–7.32) and in-season (OR: 4.98, 95% CI: 2.33–5.36) phases. An ACWR between 0.90 and 1.30 was shown to offer protective effects, with the ratio explaining 60% of the variance associated with likelihood of subsequent injury (Supplementary Fig. 1). When relative strength was considered independent of other factors, players who had higher relative strength qualities were at reduced risk of injury compared to their lower relative strength counterparts (Fig. 1). When strength was assessed as a moderator on injury risk at a given weekly workload (≥1750 AU), stronger athletes were better able to tolerate the given workload at a reduced risk (Table 1). Stronger athletes were also better able to tolerate larger week to week changes (>550–1000 AU) in workload than weaker athletes (OR = 2.54–4.52). When a given ACWR and strength were considered, stronger athletes were shown to tolerate spikes in workload better than weaker athletes (OR: 1.33–5.10). Faster athletes over 5-, 10-, and 20-m had lower injury risk than slower athletes (Fig. 1). When speed qualities were considered as a moderator at a given weekly workload (≥1750 AU), athletes who were slower over 5-m (OR: 3.11, 95% CI: 2.33–3.87), 10-m (OR: 3.45, 95% CI: 2.71–4.12) and 20-m (OR: 3.12, 95% CI: 2.11–4.13) were at increased risk compared to the faster athlete reference group. Additionally, slower 5-m (OR: 3.98, 95% CI: 2.34–4.55), 10-m (OR: 2.78, 95% CI: 1.32–3.14) and 20-m (OR: 4.55, 95% CI: 2.12–4.98) athletes had increased injury risk when the weekly ACWR was ≥1.25 (Table 2). Athletes with better RSA_t had lower risk than players with slower RSA_t, when considered independently of all other variables (Fig. 1). When RSA_t was considered as a moderator of injury risk at a given workload (≥1750 AU), athletes with better RSA_t had lower risk than players with slower RSA_t (OR: 5.55, 95%: 3.98–7.94). Athletes with slower RSA had higher odds of injury and were unable to tolerate larger week to week changes (>550–1000 AU) in workload

Table 1
Relative lower body strength (kg kg^{-1}) as a risk factor for injury above certain training and game load values. Data presented as OR (95% CI) when compared to a reference group.

Load calculation	OR	95% confidence interval		p-value
In-season	Exp (B)	Lower	Upper	
Cumulative load (sum)				
1 weekly				
>1750 AU				
3.0 (Reference)	1.00			
2.5 to 2.9	1.51	1.03	2.29	0.459
1.7 to 2.4	2.08	1.22	3.93	0.045
1.0 to 1.7	4.53	3.98	5.50	0.033
Absolute change (±)				
Previous to current week				
>550 AU–1000 AU				
3.0 (Reference)	1.00			
2.5–2.9	2.54	1.04	2.97	0.487
1.7–2.4	3.53	2.66	3.88	0.011
1.0–1.7	4.52	3.98	4.92	0.023
Acute:chronic workload (AU)				
>1.25 AU				
3.0 (Reference)	1.00			
2.5–2.9	1.33	1.10	2.59	0.032
1.7–2.4	2.48	1.33	3.87	0.004
1.0–1.7	5.10	3.98	6.10	0.003

Table 2
Speed over 5-,10- and 20-m (s) as a risk factor for injury above certain training and game load values. Data presented as OR (95% CI) when compared to a reference group.

Load calculation	OR	95% confidence interval		p-value
In-season	Exp (B)	Lower	Upper	
Cumulative load (sum)				
1 weekly				
>1750 AU				
5-m				
0.88 (Reference)	1.00			
0.88–0.92	1.23	1.01	2.01	0.041
0.92–0.95	1.45	1.22	2.11	0.023
>0.95	3.11	2.23	3.87	0.001
10-m				
1.75 (Reference)	1.00			
1.75–1.78	2.45	1.98	3.33	0.012
1.78–1.83	1.98	1.11	2.11	0.045
>1.83	3.45	2.71	4.12	0.004
20-m				
2.85 (Reference)	1.00			
2.85–2.89	1.77	1.14	2.13	0.049
2.89–3.01	1.98	1.45	3.11	0.034
>3.01	3.12	2.11	4.13	0.004
Acute:chronic workload (AU)				
>1.25 AU				
5-m				
0.88 (Reference)	1.00			
0.88–0.92	2.11	1.45	3.23	0.042
0.92–0.95	3.23	2.11	4.12	0.004
>0.95	3.98	2.34	4.55	0.003
10-m				
1.75 (Reference)	1.00			
1.75–1.78	1.87	1.34	2.54	0.05
1.78–1.83	2.11	1.45	3.11	0.041
>1.83	2.78	1.32	3.14	0.034
20-m				
2.85 (Reference)	1.00			
2.85–2.89	2.11	1.76	3.12	0.044
2.89–3.01	3.12	2.87	4.11	0.023
>3.01	4.55	2.12	4.98	0.005

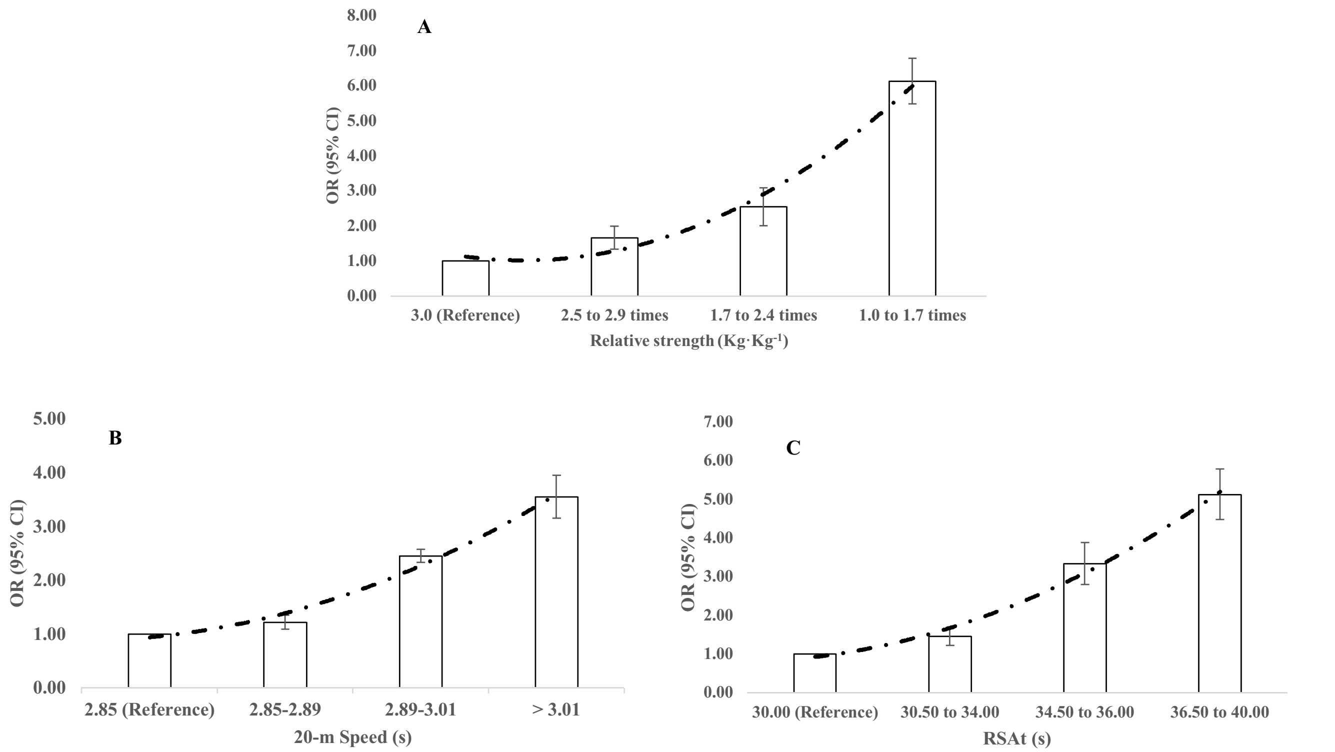

Fig. 1. Relative strength (a), speed over 20-m (b) and RSA_t (c) as risk factors for injury independent of other factors. Data presented as OR (95% CI) when compared to a reference group.

than athletes with better RSA_t (OR = 2.54–6.52), with similar trends reported for a given ACWR (Supplementary Table 2).

4. Discussion

This study investigated the association between measures of training load, physical qualities and injury risk in team sport (i.e. hurling) players. Our data highlights that moderate weekly loading offers a protective effect for team sport athletes. In agreement with previous literature[2,8] we have shown that the ACWR has an association with injury risk with the ratio explaining 60% of the variance in injury risk within the current cohort. Furthermore, we have identified greater relative lower body strength, faster speed and repeated-sprint ability as potential moderators of subsequent injury risk. Specifically, when considered both independently and at specific absolute workloads, relatively stronger athletes were at reduced risk of injury compared to their weaker counterparts. Similarly, we found that faster athletes over 5-m, 10-m and 20-m were at lower risk of injury than their slower counterparts. Finally, our data highlights the need to consider the repeated-sprint abilities of team sport athletes given the observed relationship between faster RSA_t and reduced injury risk in this cohort.

Our findings agree with the previously observed association between weekly training loads and injury risk in team sport athletes.[2,3] Interestingly, we consistently observed that moderate weekly loads offered protective effects for athletes across both the pre-season and in-season phases. In agreement with previous studies,[7,16] higher weekly workloads resulted in increased risk of injury for players. Players who exerted moderate weekly loads of between ≥1400 AU to ≤1900 AU had lower injury risk than players who exerted lower loads, with this finding observed during both the pre-season (OR: 0.44, 95% CI: 0.18–0.66) and in-season periods (OR: 0.59, 95% CI: 0.37–0.82). In line with previous literature on the workload–injury association,[3,10] larger absolute weekly changes in load (≥1000 AU) were shown to increase the odds of injury compared to smaller weekly changes in load during both the pre-season (OR: 5.58, 95% CI: 3.19–7.32) and in-season (OR: 4.98, 95% CI: 2.33–5.36) phases. These results highlight the need to appropriately load players from week to week to ensure improved physical capacities which in turn have been shown to protect against injury within team sport athletes.[3,10]

Interestingly we observed that moderate loading patterns protected players from injury both in pre-season and in-season. This finding is in contrast to previous findings where higher workloads have been associated with lower injury risk.[11,12] One potential explanation for this finding may be directly related to training time with players only training two to three times per week, with it difficult for players to attain higher loads due to limited training time. Ultimately, coaches and medical staff need to work holistically to effectively improve physical capacities while reducing the injury risk of players,[1,8] particularly during the pre-season phase where within many team sports there is a specific focus on improving the fitness levels of players which often involves higher training loads. While moderate loads and U-shaped curves (i.e. lower and higher loading patterns increasing risk of injury) have been previously noted within the literature[11] there is a fine balance to be struck by coaches. Ultimately coaches will need to maintain adequate chronic loads while manipulating acute loads to ensure improved fitness and reduced injury risk.[8] This can be achieved by maintaining an ACWR of between 0.90 and 1.30. Interestingly, in the current investigation, the ACWR explained 60% of the variance associated with likelihood of subsequent injury compared to 52% in previous literature.[8] However, practitioners need to be aware that several limitations have been suggested when using a s-RPE derived. The ACWR will be subject to statistical scaling across all metrics with which practitioners utilize. Furthermore, sRPE is unlikely to be sensitive to the subtle changes in high-speed running movements of match-play and training which have been shown to be important within the injury-workload paradigm.[11] Therefore, a coach's injury prevention and monitoring philosophy should not be limited to the monitoring of a single training load variable. As such understanding an athlete's physical qualities in addition to their sporting and individual needs, is fundamental to ensure athletes are healthy across a competitive season. Furthermore, the ACWR-injury relationship will ultimately differ between sporting codes and cohorts.

Our data highlights for the first time that relative strength can moderate injury risk for team sport athletes. Specifically, stronger athletes were better equipped to tolerate larger week to week changes in workload along with higher absolute workloads. Interestingly, athletes with a higher relative strength were also shown to tolerate spikes in workload better than weaker athletes (OR: 1.33–5.10). The current data is of practical significance to the workload–injury literature as it highlights the necessity for conditioning and medical staff to appropriately load athletes within the gym to provide them with the required strength and robustness to tolerate pitch and match-based loads. Previously, adequate strength profiles have been associated with improved flexibility, running economy, maximal aerobic speed, rate of force development, change of direction, jumping, and maximal speed,[20] all of which are associated with improved ability to perform repeated intense exercise, a key component of team sport competition. Therefore, coaches should be aware that improved strength will reduce subsequent injury risk while also potentially improving athletic performance.[20]

The current investigation has observed that faster players over 5-, 10-, and 20-m were at reduced risk of subsequent injury. The current data provides important considerations for coaches given that anecdotally, exposure to maximal velocity is feared amongst many practitioners despite this quality being considered to be critical for performance. Well-developed maximal velocity running abilities are required of players during competition to beat opposition players to possession and gain an advantage in attacking and defensive situations.[21] In order to optimally prepare players for these maximal velocities and high-speed elements of match-play, players require regular exposure to periods of high-speed running during training environments.[3,11] Recent evidence suggests that lower limb injuries are associated with excessive high-speed running exposure.[22] However, the risk appears to be reduced when players have well-developed aerobic fitness and chronic workloads.[2,11] Future research should aim to assess the preventative nature of specific speed training methodologies to allow medical and conditioning staff to select the most appropriate training method to enhance performance and reduce injury risk. Overall, the current findings add further support to the notion of maximal velocity providing a protective effect against injury. Coaches may aim to improve speed and thus reduce injury risk through the application of training methodologies such as very heavy sled based training.[23] Previous literature has shown the positive impact that the application of 80% body mass load through sled based training can have on athlete's speed across distances of 5-m and 20-m respectively in team sport athletes.[23]

We show for the first time that an athlete's ability to repeat maximal efforts over a short period of time can protect them from subsequent injury risk. This would appear intuitive given that during both training and match environments athletes can engage in movements that require them to repeatedly produce maximal or near maximal efforts (i.e. sprints), interspersed with brief recovery intervals consisting of complete rest or low- to moderate-intensity activity.[18] While recently the external validity of these tests has been questioned in team-sport environments,[24] we have observed that those athletes with better RSA_t were at reduced risk compared to athletes with slower RSA_t (OR: 5.55, 95%: 3.98–7.94). Therefore, it would appear that improving a player's ability to tolerate repeated exposures to maximal sprinting can in turn reduce their subsequent injury risk. As such while these events may be rare within match-play, these tests offer medical staff the ability to stratify athletes into higher and lower risk groups based on their repeated-sprint ability across a shortened period of time.

Factors in addition to weekly training loads and physical qualities such as previous injury, age,[25] perceived muscle soreness, fatigue, mood, sleep ratings and psychological stressors,[26] are likely to impact upon an individual's injury risk, however these were not accounted for in the current analysis. Although sRPE has been shown to provide a valid indication of internal training load, it may underestimate the average intensity of resistance exercise,[27] with fatigue potentially confounding the relationship between RPE and relative intensity.[28] Although strength training sessions in the current study comprised a limited amount of the global total training load, it is possible that the total training load experienced by players may be slightly underestimated due to the mismatch between perceived and actual resistance training intensity. Unfortunately, it was not possible to describe the external and internal training loads of specific session types within the current study. Additionally, there is a need to assess the utility of external:internal load ratios as a potential metric for injury risk assessment given the known relationship between these ratios and fitness in team sport athletes.[29,30] Finally, the model developed within the current investigation will be best suited to the population from which it is derived. Therefore, since this study involves a single team across a two-season period, it is difficult to translate these findings to other teams across different training environments. Therefore, we recommend cross-sport and cross-team analysis of testing and training load data to better understand the potential moderators of the workload–injury relationship.

5. Conclusion

In conclusion, the present findings demonstrate that well-developed lower body strength, RSA and speed were associated with better tolerance to higher workloads and reduced odds of injury within team-sport athletes. When compared to a lower performance group those with greater strength, and faster speed and RSA were consistently at reduced risk of injury. Coaches should aim to expose players to training regimens that aim to improve these physical qualities to best moderate injury risk within their own specific cohort of players. Given that the current investigation was completed with an amateur cohort (i.e. 2–3 days training per week), our findings are likely to be relevant to coaches and practitioners of sub-elite athletes.

Practical applications

- Speed, repeated-sprint ability and maximal strength are physical qualities that stratify injury risk.
- Coaches should be aware that improved strength, repeated-sprint ability and speed will reduce subsequent injury risk while also potentially improving athletic performance and therefore should aim to develop training scenarios that allow these qualities to be trained consistently.
- We consistently observed that moderate weekly loads offered protective effects for athletes across both the pre-season and in-season phases.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.01.010.

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