META-ANALYSIS: FATIGUE DOES NOT INCREASE LOWER-LIMB INJURY RISK

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This study sought to resolve a long-standing debate in the literature about whether or not fatigue causes lower-limb injury. For the purposes of this research, fatigue was considered chronically (time of the season) and acutely (game time). From a possible 1349 (727 after duplicated removed) articles identified that related to lower-limb musculoskeletal injuries, 15 met inclusion criteria, which provided 21 data sets. A meta-analysis on the available data sets determined that neither acute nor chronic fatigue had any influence on the likelihood of sustaining an injury to the lower limb. Additionally, this research demonstrated that injury researchers have not traditionally reported adequate details to allow secondary analysis of injury statistics. Of the 727 papers identified, over 700 failed to provide the level of detail of the injury circumstances to understand when in a season or game the injury occurred and/or where on the body the injury was sustained.

KEYWORDS: biomechanics, epidemiology, sports medicine.

INTRODUCTION: It is an apparently easy conclusion to draw that a fatigued athlete will be injured more than a non-fatigued athlete. The logic appears sound that with fatigue, muscular control that protects the joint is compromised and therefore injuries increase. The counterargument is perhaps equally logical, that a fatigued athlete moves more slowly and with less force than a non-fatigued athlete and as such the forces and moments are not high-enough to lead to injury. However, researchers do not agree about which argument is correct.

It is accepted that, when targeting known injury risk factors, injury occurrence can be decreased. For example, the inclusion of targeted injury prevention programs has previously decreased injuries by over 60% in some cases (Finch et al., 2016; Hewett, Lindenfeld, Riccobene, & Noyes, 1999). These studies though have failed to include fatigue in their programme design. As potential evidence that fatigue may influence injury risk, there is evidence from laboratory tests that lower-limb mechanics are altered when subjects are exposed to a fatiguing protocol (Cortes, Greska, Kollock, Ambegaonkar, & Onate, 2013; Savage, Lay, Wills, Lloyd, & Doyle, 2017). Unfortunately, what limits the applicability of these studies is that there was no epidemiological data to support or refute the claims made regarding injury risk. Perhaps discounting these laboratory findings, Barber-Westin and Noyes (2017) recently provided a review of laboratory-based fatigue research, drawing the conclusion that they do not lead to changes likely to increase ACL injury risk.

Although fatigue is often implicated as a factor in musculoskeletal injuries, research findings are equivocal as to whether or not this is in fact the case. For example, Okoroha et al. (2017) recently concluded that minutes played in a basketball game did not predict ACL injury. Conversely, researchers concluded that in soccer, time of the match is related to when injuries occur (Cross, Gurka, Saliba, Conaway, & Hertel, 2013; Woods et al., 2004). Noting that these studies investigated different injuries (ACL tears vs hamstring strains, respectively), the findings are in direct opposition to each other. Therefore, the aim of this research was to determine if fatigue, as it relates to time in the game and season, influences lower-limb injury occurrence.

METHODS: Following PRISMA guidelines, an extensive literature search was conducted which used keywords to identify papers that included injury data on Level I sports as defined by Daniel et al. (1994) (e.g., basketball, football, etc.). Individual searches were run for each injury type (ACL, hamstring, groin) in five databases: PUBMED, Medline, SportDiscus, CINAHL, and Ausport. Search terms were included for each injury type, injury location, and sport type. Research was not limited by date of publication, as such all original research published in English was considered for inclusion. Manual searches of databases and the literature supplemented the automated database searches. Two reviewers independently applied the selection criteria to the papers identified by the database searches. Title and abstracts were screened and articles excluded if they did not meet the inclusion criteria. Full text papers were then screened and criteria again applied independently by each reviewer. A collective decision made by both reviewers when there was disagreement. Two papers without suitable data were followed-up with the original authors, however one author no longer had access to the data and the second author did not respond. From the articles deemed suitable a meta-analysis was conducted for each injury based on time of season and time in game.

An odds ratio meta-analyses were conducted to evaluate the timing, season and game, of injury occurrence. For each of the injury areas, pooled estimates were calculated for season (first compared to second half) and match (first half vs second half, first vs second quarter, first quarter vs fourth quarter, or second to third quarters). A random effects model was used to account for the heterogeneity of the study samples.

If studies did not provide raw numbers but only figures of injury numbers, the reviewers used customized MATLAB software (GRABIT, v1.0.0.1) to digitize the figure. This allowed for the extraction of the data in a format required for subsequent analysis. Further, when data were presented as percentages or relative occurrences, reviewers converted these results to raw injury numbers. Injury timing was recorded either as within the first- or second-half of the season or game by half or quarter. When injury data were provided by month, the data were split evenly such that the first- and second-half of the season included the same number of months, if there were an odd number of months then the middle month injury numbers were halved and added to each half of the season.

RESULTS and DISCUSSION: From all searches conducted, an initial 1349 articles were identified which reduced to 727 after the exclusion of duplicate articles, which reduced further to 15 articles that provided 21 sets of data for analysis. In future scientific reports, researchers are strongly encouraged to include details of injury timing, location, and type to allow for secondary analysis of injury statistics. While the major conclusion of this research, based on secondary analysis of published data, is that fatigue (within a season or game) does not increase injury risk, further analysis by sex and sport is warranted.

The data sets that were available hinted at possible patterns of injury that differed between sex and sports. For example, Cross et al. (2013), provides support for there being sex differences in injury patterns in their investigation of hamstring injuries in soccer. Further, the research of Dallalana, Brooks, Kemp, and Williams (2007) and Brooks, Fuller, Kemp, and Reddin (2006) contradicted that of Okoroha et al. (2017) as they concluded ACL and hamstring injuries in rugby union are related to game time, whereas this was not found in NBA athletes.

Fatigue due to time in season: Based on the available data sets, comparing the first- to the second-half of the season, there were no differences in ACL, groin, or hamstring injury occurrences (ACL: OR: 1.27, CI: 0.43-3.78, Groin: OR: 1.79, CI: 0.63-5.06, Hamstring: OR: 1.16, CI: 0.88-1.53). Despite this statistical finding, careful consideration of the individual studies suggests that there may be a more complicated relationship than these findings suggest. As an example, although raw findings from Dallalana et al. (2007) and Dodson, Secrist, Bhat, Woods, and Deluca (2016) suggest injuries are more likely to occur early in the season, when co- factors such as player numbers were considered, these differences were not meaningful.

Fatigue due to time in game: Pooling available data sets, there were no differences in injury occurrence between the first- and second-halves of the game for the ACL, or hamstring (ACL: OR: 0.43, CI: 0.47-7.92, Hamstring: OR: 0.85, CI: 0.58-1.24). This was also the case when comparing the first- to the fourth-quarter (ACL: OR: 0.84, CI: 0.27-2.68, Hamstring: OR: 0.62, CI: 0.34-1.16). These findings support recent research concluding that minutes played in a basketball game did not relate to ACL injuries in National Basketball Association athletes (Okoroha et al., 2017). In opposition to these results, Dallalana et al. (2007) found the majority of all 211 knee injuries in English rugby union occurred in the second half of the game and the first quarter of matches had the lowest frequency of injuries. These opposing findings should prompt researchers to investigate the pattern of injuries across different sports to determine if fatigue has different consequences based on the sport being played. Similar to the mixed results with respect to time of the season, hamstring injury results were also mixed. Two studies reported more injuries in the second half (Brooks et al., 2006; Roe, Murphy, Gissane, & Blake, 2016), one reported more in the first half (Cross et al., 2013), and another found no difference (Ekstrand et al., 2011). Perhaps giving an insight to not only sport differences, positional differences, for some sports at least, is another area that warrants further exploration. According to Brooks et al. (2006), rugby union forwards were injured with increased frequency as the game continued. Backs, however, were more likely to be injured in the 2nd and 4th quarters of the game. Finally, providing further evidence for sex differences, Cross et al. (2013) concluded that females sustain more hamstring injuries in the second half of a soccer game for first time hamstring injuries and this is magnified for recurrent injuries.

Table 1: Odds ratio and confidence intervals for all comparisons.

INJURY	ODDS RATIO (CONFIDENCE INTERVAL)
1st vs 2nd half season	
ACL	1.27 (0.43-3.78)
Groin	1.79 (0.63-5.06)
Hamstring	1.16 (0.88-1.53)
1st vs 2nd half game	
ACL	0.43 (0.47-7.92)
Hamstring	0.85 (0.58-1.24)
1st vs 2nd quarter game	
ACL	1.92 (0.47-7.92)
Hamstring	0.77 (0.56-1.04)
1st vs 3rd quarter game	
ACL	0.59 (0.10-3.62)
Hamstring	1.03 (0.82-1.28)
1st vs 4th quarter game	
ACL	0.84 (0.27-2.68)
Hamstring	0.62 (0.34-1.16)
2nd vs 3rd quarter game	
ACL	0.36 (0.10-1.34)
Hamstring	1.33 (0.92-1.91)

CONCLUSION: Based on the available literature, the current analysis demonstrates that fatigue, with respect to time in season or time in game, likely has minimal or no influence on likelihood of injury. However, there is potentially a lot more that can be learnt within this space - future research should include more, not less, detail in published findings to enable a multifaceted investigation of ‘fatigue’ effects on injury. For example, close examination of individual studies suggests that there may be sex and sport differences in relation to how fatigue influences injury rates.

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