Pre-Print

Which GPS variables can predict non-contact injuries in soccer players? A systematic review

Author: Dimitrios Angelidis[1]

[1]Faculty of Health, Medicine and Life Sciences, Maastricht University, The Netherlands

For correspondence: jim-3-@hotmail.com

Please cite as: Angelidis, D. (n.d.). Which GPS variables can predict non-contact injuries in soccer players? A systematic review. Retrieved from osf.io/preprints/sportrxiv/5ct84

DOI: 10.31236/osf.io/5ct84

The coordinator and the tutor of the course have read and approved this version of the review. They both agreed to the sharing of this preprint on SportRxiv.

This systematic review was produced during a student assignment for the MSc program Human Movement Science

Abstract

Background: Non-contact injuries in soccer is a big concern for soccer clubs and Global Positioning System (GPS) has recently been used to predict them. This review is aiming to find out which GPS variables can potentially predict non-contact injuries in soccer players.

Methods: PubMed and Google Scholar were chosen to find observational studies. Inclusion criteria included: soccer players and GPS usage. Total distance, high-speed running, total load, accelerations, decelerations, new body load, meters per minute, and sprinting were the identified GPS variables. Risk Ratio (RR) and Odds Ratio (OR) outcomes were computed for the most addressed variables in the studies, high-speed running and total distance, for determining the probability of the variables to predict non-contact injuries. A modified version of the Downs and Black were used to assess the methodological quality.

Results: All variables were predictors of non-contact injuries. High-speed running (RR=1.48, OR=5.58) and total distance (RR=1.64, OR=16.3) were the best predictors variables for non-contact injuries, with total load, accelerations, decelerations, new body load, meters per minute and sprinting to have positive predictions, but they were presented in fewer than two articles, and as a result, no computation of the RR and OR was done.

Limitations: They were few articles for soccer athletes, and many of these articles did not use a GPS system or did not present relevant outcomes.

Conclusion: High-speed running and total distance variables were the most addressed non-contact injuries predictors, being present in the most articles. There was a poverty of articles regarding soccer players and the use of the GPS system, posing major limitations. Findings can give a better understanding to practitioners about the variables that can potentially predict injuries and consequently try to aid the athletes to minimize injury risk.

Introduction

Monitoring loads in soccer players during training and match play is common practice in professional soccer clubs to reduce injury risk and maximize their performance (1). Training and match load are considered to be strongly associated with injuries, with professional soccer players to sustain on average 2.0 injuries per season, which causes them to miss 37 days in a 300-day season on average (2).

Injuries in professional soccer players pose a significant financial burden and can severely damage their chances of success (3). One of the most deleterious types of injuries is non-contact injuries, which have been identified to be the cause of most muscle strains, leading to 59% of all the injuries sustained in soccer (4). More specifically, non-contact injuries referred to an injury that is not a result of a hit by an opponent player, a teammate, or an object in the field. When a player undergoes a non-contact injury, they tend to be running or standing by themselves and then they will fall to the ground due to an injury to their body, usually their lower body. Accordingly, monitoring training and match loads are decisive to optimize load management and to minimize injury risk (2).

Training and match loads are generally quantified in terms of external and internal loads (5). Obtaining measures of internal load (e.g., heart rate) during competition can be impractical and often prohibited; hence practitioners tend to rely on external load measures (1). The external load refers to all player's locomotor movements and can be measured using electronic tracking systems, such as global positioning software (GPS) (6).

GPS units can be worn by each individual player on the upper back and use connections with orbiting satellites to track changes in position, allowing practitioners to track various variables such as total distance covered, peak speed and a number of accelerations/decelerations on a player by player basis (7).

The use of GPS technology to measure player's loads and intensity has become prevalent in professional soccer (8). In recent years, soccer teams have made use of GPS tracking devices to provide an objective measure of external training load (8). GPS units have been shown to be sufficiently reliable and accurate to quantify training and match loads in team sports (9) (10), with average speed, maximum/peak speed, player load, and activity at various speed zones to be some variables of the GPS that have been used in past research to analyse player game movements and have been proven valid (11).

Soccer is a very demanding sport, and soccer players are sustaining massive loads from training and games on a daily basis. Research has shown that monitoring and managing player load is an effective method of reducing non-contact injuries (12) (6). There is evidence to suggest that both low loads and excessive loads may lead to increased injury risk, and therefore practitioners have sought insight into the links between load and injury risk in various team sports (7).

Gabbet and Ullah (13) established a correlation between injury risk and high-intensity running efforts during training sessions in rugby league, whereas Nielsen et al. (14) noted that novice runners were more susceptible to injuries when weekly total distance increased by more than 30%; although these results were statistically non-significant (3). A study by Ehrmann et al. (3) has shown that 2 GPS variables, average meters per minute, and average new body load, were related to non-contact soft tissue injuries in soccer players. Colby et al. (15) found that across both seasonal phases, GPS derived load variable was shown to significantly relate to injury risk in elite Australian footballers. Nonetheless, they are some insights for team sports, but the potential link between GPS variables and non-contact injury risk in soccer players is still unclear.

Thus, the aim of this review was to identify which GPS variables can potentially predict non-contact injuries in soccer players by searching the existing published literature for observational studies.

Methods

Search strategy

Articles were systematically identified via PubMed and Google Scholar databases using the search strategy presented in Table 1. Databases were used to search for observational studies on GPS variables and non-contact injuries incidence. A distinction of the search terms taken from the research question was made. A synonyms search was conducted for the search terms using the Visualthesaurus.com and Visualwords.com websites respectively. The search took part using the Boolean operators AND/OR and the truncation* for improved search results. An advanced search builder was used for free text terms in combination with MeSH terms. The reference list of identified articles was searched for additional articles/studies using the Google Scholar database. The search string for each study characteristic (GPS, non-contact injuries, soccer) was combined in the complete search strategy. The search was developed to consider research articles published online from database inception until March 2019, when the search was conducted. The process for screening and selecting articles followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (16).

First, articles were screened through the title for any relevant information. Then, the most relevant articles were screened through the abstract to distinguish if they are eligible or not, and at the end articles included in the review were screened through the full text. Articles considered for inclusion in the review were those reported the use of the GPS system, healthy soccer players, at least one non-contact injury outcome reported, participants being in adolescence and above, articles were written in English and publication year from 2006 onwards. The hindmost inclusion criterion was chosen because the GPS system was applied in team sports only in 2006 (17). Publications were excluded if they did not report any GPS usage, no soccer players as participants, and participants who are not adolescents. The latter was used as an exclusion criterion because soccer players who are not in the adolescence were considered as kids, and as a result, it is unnatural to wear the GPS system in training sessions or games. A detailed summary of the inclusion and exclusion criteria is presented in Table 2.

Assessment of methodological quality

Methodological quality was assessed using a modified version of the Downs and Black checklist (18). This checklist was chosen because it has been validated for use with observational study designs (18) and has been previously used to assess methodological quality in systematic reviews assessing cross-sectional and longitudinal studies (19). The number of items from the original checklist can be adjusted to the needs of the systematic review, with 10-15 items used in previous systematic reviews (19). For this review, 11 items were considered relevant. Close to the 11 items, a domain about the risk of bias due to missing data was added. Each of 11 items and 1 domain question was answered with yes or no, and the answers provided the total risk of bias (high, moderate, low) (19). The checklist assessed reporting, external and internal validity bias, whereas the domain about missing data was used to assess outcomes level.

Data extraction

Data were extracted from each article by the lead author (Dimitris Angelidis). Information on the following characteristics was extracted: study design, number of participants including the level of competition, age, and the GPS system variables. The GPS system variables taken from the articles were: total distance, high-speed running, total load, accelerations, decelerations, new body load, meters per minute, and sprinting. Those variables were chosen from the articles because they demonstrated a significant probability in predicting non-contact injuries. Variables without significant results were omitted. GPS variables outcomes extracted from the studies were Risk Ratios (RR) and Odds Ratios (OR) mainly, with only two variables, new body load and meters per minute, to present alone p-values. This deviation is presented only in one study (3) and is attributed to the comparison of only two blocks (injury and season average block in one and four weeks) for the variables and as a consequence, only p-values could be used. The aftereffect was to omit p-values from calculations.

For the two most addressed variables in the articles, high-speed running (existing in five articles), and total distance (existing in three articles), the average RR and OR have been calculated by summing the RR and OR outcomes, and then divide them five times for the high-speed running and three times for the total distance. Five and three times respectively is the times those variables encountered in articles. The latter was done to present a better summary of the predictability of those variables because they were both presented in more than two articles. The rest four variables, total load, accelerations, decelerations, and sprinting had outcomes in RR and OR, but no average was calculated due to their presence in less than two articles. A Table with the GPS variables from each study was done and the consequence RR and OR outcomes for predicting non-contact injuries were presented in most of the studies, except one (3) which had only p-values to declare. Participants and studies contained the outcomes were presented as well. This approach avoided bias in the reporting of the results as there was only one responsible person for the data.

Synthesis of results

For this systematic review, a narrative synthesis of the results was used.

Table 1. Database search strategy

Search term	**Keywords**
1) GPS	GPS OR gps OR global positioning software OR global positioning system OR Geographic Information Systems[Mesh] OR external load OR external intensit* OR external work* OR workload* OR tracking system* OR distance* OR TD OR meters OR low-speed OR low-intensit* OR high-speed OR high-intensit* OR maximal-speed OR maximal-intensit* OR maximal-effort OR sprint* OR repeated sprint OR repeated high-intensity effort OR RHIE OR repeated maximal effort OR velocit* OR speed* OR accelerat* OR decelerat* OR accelerometer load* OR body load* OR player load OR total distance covered OR high-intensity running OR very-high-intensity running OR meters per minute OR new total body load
2) Non-contact injuries	injury OR non-contact injur* OR soccer/injuries [Mesh]
3) Soccer	soccer OR soccer [Mesh]

Search phase ’’GPS’’ AND ’’Non-contact injuries’’ AND ’’Soccer’’

Search string: ((((((((((((((((((((((((((((((((((((GPS) AND gps) OR global positioning software) OR global positioning system) OR external load) OR external intensit*) OR external work*) OR workload*) OR tracking system*) OR distance*) OR TD) OR meters) OR low-speed) OR low-intensit*) OR high-speed) OR high-intensit*) OR maximal-speed) OR maximal-intensit*) OR maximal-effort) OR sprint*) OR repeated sprint) OR repeated high-intensity effort) OR velocit*) OR speed*) OR accelerat*) OR decelerat*) OR accelerometer load*) OR body load*) OR player load) OR total distance covered) OR high-intensity running) OR very-high-intensity running) OR meters per minute) OR new total body load) AND injury) OR non-contact injur*) AND soccer

Table 2. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Full-text available in English	Studies with non-human subjects or with no outcome measures related to physical performance
Article is related to human physical performance	Special population, athletes with a physical or mental disability, or athletes considered to be injured or returning from injury
Healthy, able-bodied, non-injured athletes	Non-existence of the GPS as a measurement tool
Reported the using of the GPS	Participants that are kids (under 13 years old)
Participants in adolescence and above	Surveys, opinion pieces, books, periodicals, editorials, case studies, non-academic/non-peer-reviewed text, grey literature
Reported at least one measure of GPS variable	Not soccer athletes
Original research articles from PubMed and Google Scholar	Articles with injuries that are not non-contact
Soccer athletes	
Articles with all types of non-contact injuries	
Articles published from 2006 onwards	

Results

Search findings and study selection

The electronic search yielded 639 articles. An additional 2 articles from additional sources were identified as potentially relevant. A total of 4 duplicate records were removed, resulting in 635 included articles in total. A further 609 articles were excluded based on title and abstract; 26 full-text articles were screened and 20 were removed, leaving 6 articles for inclusion in the review. Reason for exclusion was no soccer players (N=10), Non-existence of the GPS as a measurement tool (N=4), Not non-contact injuries included (N=2), No relevant results (N=4). A flow diagram is presented below for a detailed overview of identification, screening, eligibility, and inclusion of the studies.

Methodological quality

The rating from the quality appraisal for each article are presented in Tables 5 and 7. The overall risk of bias was low, with three studies (3) (7) (2) to display medium risk of bias because of missing data. In line with previous literature using the Downs and Black checklist (20) (21) (22) (19), no articles were excluded on the basis of methodological quality.

Participants characteristics

Participants monitored in each study were soccer players. The sample size ranged from 19 to 41 soccer players and covered a range of playing levels. In total, all the studies (N=6) were monitored only male participants.

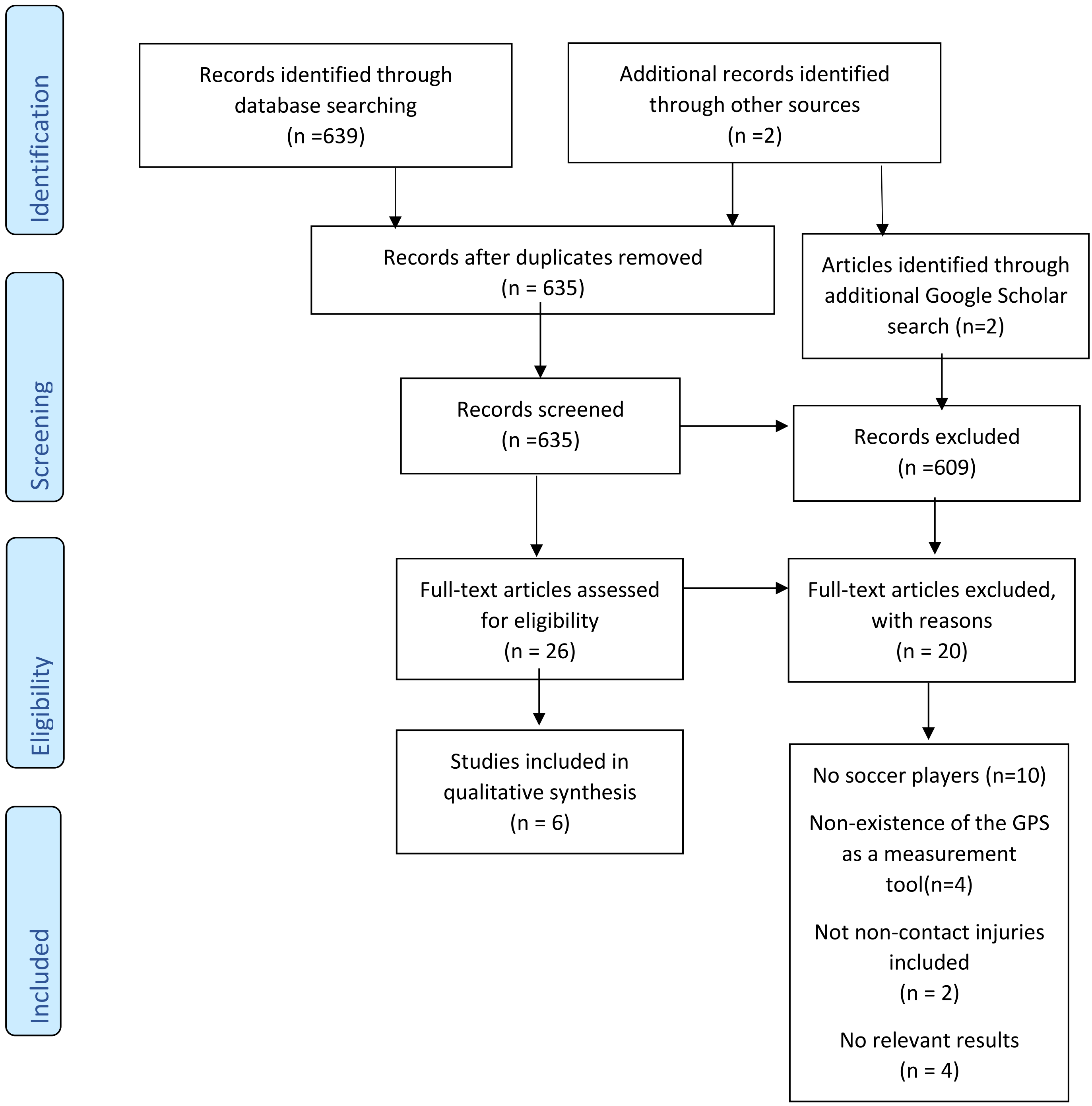
GPS variables

In the included articles the following GPS variables were extracted: total distance (N=3), new body load (N=1), meters per minutes (N=1), high-speed running (N=5), total load (N=1), accelerations (N=2), sprinting (N=2), and decelerations (N=1).

Variables outcomes predicting non-contact injuries

In a total of eight GPS variables outcomes predicting non-contact injuries, the most addressed in the articles were the high-speed running variable (N=5), followed by the total distance (N=3). The rest six variables were addressed in two and fewer studies including accelerations (N=2), sprinting (N=2), new body load (N=1), meters per minutes (N=1), total load (N=1), and decelerations (N=1). High-speed running (RR=1.48, OR=5.58) and total distance (RR=1.64, OR=16.3) were the best predictors variables of non-contact injuries. The rest of the variables can also predict non-contact injuries, but they were found in a few studies, and as a result, the RR and OR were not calculated. The detailed results are presented in Table 4.

Flow Diagram



Study characteristics

Table 3.

Authors	**Study design**	**Number of participants, sport(s), level of competition and age (mean ± SD)**	**GPS Variables**
Bowen et al. (2017) (23)	Non-RCT	32 youth elite soccer players, age 17.3±0.9 years	Total Distance (TD), High-speed Running (HSR), Total load (TL), Accelerations (ACC)
Malone et al. (2017) (24)	Observational cohort design	37 elite soccer players, age 25 ± 3 years	High-speed running (HSR) and sprinting (SPR)
Bacon et al. (2016) (25)	Non-RCT	41 professional youth soccer players, age 17.8±1.1 years	Total distance (TD) and high-speed running (HSR)
Ehrmann et al. (2016) (3)	Observational study	19 elite soccer players, age 25.7± 5.1	New body load (BL), meters per minute (MpM)
Jaspers et al. (2017) (2)	Prospective cohort study	35 professional soccer players, age 23.2±3.7 years	Total distance (TD), distance covered at high-speed running (THSR), number of accelerations (ACC), and decelerations (DEC)
Timothy I. Massard (2017) (7)	Non-RCT	33 Semi-professional soccer players, age 22.9 ± 4.1 years	High-speed running (HSR), sprinting (SPR)

All studies were used the GPS system to predict non-contact injuries

Study results

Table 4.

GPS variables	GPS variable outcomes	Number of participants(Studies)
Total distance	Risk Ratio (RR) RR=1.64, Odds Ratio (OR) =0.670 High 2-weekly Total Distance (TD) (OR)=2.25, high 1-weekly TD (OR)=1.42, medium 2-weekly TD (OR)= 1.93, and high 3-weekly TD (OR)=1.88	108(3)
New body load	Injury blocks compared with the Season Average for both 1- and 4-week blocks (*p*= 0.006 and *p*= 0.01, respectively)	19(1)
Meters per minute	Injury block compared with the Season Average for both 1- and 4-week blocks (*p*=0.008 for both comparisons)	19(1)

High-speed running	Moderate–high 4-weekly high-speed running (RR=2.14) and moderate–high speed running (RR=1.73) large weekly changes in high speed running (OR: 3.02) (OR = 0.580) Medium1-weekly high-speed running (OR: 1.56), and for a high acute: chronic workload ratios (ACWR) for high speed running (OR: 1.71) Moderate 7-day individualized high-speed running loads had a likely beneficial effect (RR=0.57)	178(5)
Total load	High 1-weekly total load (RR=2.20)	32(1)
Accelerations	When many accelerations (ACC; ≥9254) (RR=5.11)	67(2)

	Medium 4-weekly accelerations (2104–2699, OR: 0.59), and for a medium ACWR for accelerations (0.87–1.12, OR: 0.49)	
Sprinting	Large weekly changes in sprint distances (OR: 6.12)	70(2)
	Sprinting Moderate (RR=1.7) and very high arbitrary acute sprinting loads (RR=2.49)	
Decelerations	Number of decelerations for a high 2-weekly decelerations (OR: 1.49), for a high 3-weekly decelerations (OR: 1.68), and for a high 4-weekly decelerations (OR: 1.73).	35(1)

Table 5. Assessment of methodological quality using the modified Downs and Black checklist (18).

Study	**Is the hypothesis/aim/objective of the study clearly described?**	**Are the main outcomes to be measured clearly described in the introduction or methods section?**	**Are the characteristics of the subjects included in the study clearly described?**	**Are the main findings of the study clearly described?**	**Does the study provide estimates of the random variability in the data for the main outcomes?**	**Have actual probability values been reported (e.g., 0.035 rather than < 0.05) for the main outcomes except where the probability value is < 0.001?**	**Were the subjects asked to participate in the study representative of the entire population from which they were recruited?**	**Were those subjects who were prepared to participate representative of the entire population from which they were recruited?**	**If any of the results of the study were based on "data dredging," was this made clear?**	**Were the statistical tests used to assess the main outcomes appropriate?**	**Were the main outcome measures accurate (valid and reliable)?**	**Bias due to missing data**	**Description of bias**	**Overall bias**
Bowen et al.	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	YES	NO	There is no missing data	Low

Malone et al.	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO	YES	NO	There is no missing data	Low
Bacon et al.	YES	YES	YES	YES	YES	YES	YES	NO	NO	YES	YES	NO	There is no missing data	Low
Ehrmann et al.	YES	YES	YES	YES	YES	YES	NO	NO	NO	NO	YES	YES	Season data not measured	Medium
Jaspers et al.	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES	YES	Season data not measured	Medium
Timothy I. Massard	YES	NO	YES	YES	YES	YES	YES	NO	NO	YES	YES	YES	Data for goalkeepers not measured	Medium

Comparison of the studies on the outcome measures

Table 6.

Study	**GPS variables**	**Outcomes predicting non-contact injuries (RR and OR)**
Bowen et al. (2017)	Total distance, high-speed running, accelerations, total load	Total distance (RR=1.64) High-speed running distance (RR=2.14) Accelerations (RR=5.11) Total load (RR=2.20)
Malone et al. (2017)	High-speed running and sprinting	High-speed running (OR: 3.02) Sprint running distance covered (OR: 6.12)
Bacon et al. (2016)	Total distance and high-speed running	Total distance (OR: 0.670) High-speed running (OR: 0.580)
Ehrmann et al. (2016)	New body load and meters per minute	New body load (both 1- and 4-week blocks (p = 0.006 and p = 0.01, respectively) Meters per minute (1- and 4-week blocks (p = 0.008 for both comparisons)
Jaspers et al. (2017)	Total distance, distance covered at high speed, number of accelerations, and decelerations	Total distance 2-weekly TD (OR: 2.25). High1-weekly TD (OR: 1.42), for a medium2-weekly TD (OR: 1.93), and for a high 3-weekly TD (OR: 1.88) Distance covered at high speed for a medium1-weekly THSR (OR: 1.56), and for a high ACWR for THSR (OR: 1.71) Number of accelerations for a medium 4-weekly ACC (OR: 0.59), and for a medium ACWR for ACC (OR: 0.49) Number of decelerations for a high 2-weekly DEC (OR: 1.49), for a high 3-weekly DEC (OR: 1.68), and for a high 4-weekly DEC (OR: 1.73)

Timothy I. Massard (2017)	High-speed running and sprinting	High-speed running Moderate 7-day individualized HSR loads had a likely beneficial effect (RR=0.57) Sprinting Moderate (RR=1.7) and very high arbitrary acute SPR loads (RR=2.49)

Discussion

The aim of this systematic review was to identify if GPS variables can predict non-contact injuries in soccer players. After the screening of the articles, the extraction, and the interpretation of the data, eight variables have found to predict non-contact injuries; total distance, high-speed running, total load, accelerations, decelerations, new body load, meters per minute, and sprinting. The results of the variables predicting non-contact injuries have led to the fulfilment of the aim of this review.

The predictability of non-contact injuries variables was presented in RR and OR with two variables to only present p-values. High-speed running (RR=1.48, OR=5.58) was the most addressed variable existing in five studies, with total distance (RR=1.64, OR=16.3) existing in three studies. Findings from high-speed running and total distance variables showed significant predictability of non-contact injuries. RR was <1 from both variables meaning that for soccer players who had an excessive high-speed running had 1.48 times the risk to attain non-contact injury, whereas soccer players who had a high total distance had 1.64 times the risk for non-contact injury. OR were above 1 for both, meaning that they are higher odds of a non-contact injury, with high-speed running variable to have 5.58 and total distance 16.3 respectively. Those two variables showed the best predictability rates of non-contact injuries among the rest six identified in the articles.

Quality assessed was done by the modified Downs and Black checklist (18). For the most significant non-contact injuries variables predictors (high-speed running and total distance) they are two studies (7) (2) with a medium risk of bias. This result is ascribed to bias due to missing data. More thoroughly, high-speed running variable is presented in both studies with medium risk of bias out of five, while total distance variable is presented in one study out of three. The medium risk of bias due to missing data cannot be neglected. In one study (2) they are missing season data which can lead to a deviation of robust outcomes, while in the other study (7) only goalkeeper’s data are missing which is not so important because goalkeepers are not having the same amount of load as the rest soccer players. Although there was no exclusion of studies based on methodological quality, high-speed running variable might be treated with care.

High-speed running and total distance have been identified in studies as predictors of non-contact injuries. More extensively, high-speed running variable has been found to be a good predictor of non-contact injuries in soccer players (26) (27), with total distance to demonstrate similar results (6) (28). Moreover, high-speed running and total distance have been used in past research to analyse players game movement and have been proven valid (11). Taking the above into account it can be assumed that the results of this review are in conformity with other studies results.

One major limitation throughout the searching of the articles was the scarcity of articles regarding soccer players. They were many articles for team sports, but few for soccer making the search for articles even harder. The application of the GPS system in team sports was introduced only 13 years ago (17), in 2006, making the dearth of the studies even bigger. Furthermore, the GPS system is not so widely reported in research, and thus, there were some articles for soccer players, but the assessment of non-contact injuries was appraised with other methods. Another limitation was that the results were not comparable, because they were not present in all the studies included. High-speed running and total distance were present in most studies, but the rest variables were presented only in one or two articles making the comparison even harder. For this reason, only for the high-speed running and total distance the analysis took place.

The findings of this review pose significant practical applications to the practitioners. The GPS system is widely used and can assist practitioners to check player’s load from many parameters. Understanding which variables could possibly predict non-contact injuries will help them to adjust the training load for those specific variables.

Conclusion

This review was the first, in my knowledge, to provide a systematic searching for the variables which have influence in predicting non-contact injuries in soccer players. High-speed running and total distance were the variables that predicted non-contact injuries the most, with six more variables identified in the articles resulting in a bunch of variables that could be used to predict a non-contact injury. Findings can give insight for practitioners to make better and more constructive usage of the GPS system in the interest of soccer players.

Further work is recommended to improve the accuracy of the variables predicting non-contact injuries. A focus on Randomized Clinical Trials (RCTs), a bigger sample size, and a focus on team sports that GPS usage during games is allowed will make a breakthrough on the GPS system and non-contact injuries prevention.

References

1. Barrett S, Midgley A, Reeves M, Joel T, Franklin E, Heyworth R, et al. The within-match patterns of locomotor efficiency during professional soccer match play: Implications for injury risk? J Sci Med Sport. 2016 Oct;19(10):810–5.

2. Jaspers A, Kuyvenhoven JP, Staes F, Frencken WGP, Helsen WF, Brink MS. Examination of the external and internal load indicators' association with overuse injuries in professional soccer players. J Sci Med Sport. 2018 Jun;21(6):579–85.

3. Ehrmann FE, Duncan CS, Sindhusake D, Franzsen WN, Greene DA. GPS and Injury Prevention in Professional Soccer. J strength Cond Res. 2016 Feb;30(2):360–7.

4. Hawkins RD, Fuller CW. A prospective epidemiological study of injuries in four English professional football clubs. Br J Sports Med. 1999 Jun;33(3):196–203.

5. Rampinini E, Marcora SM. Physiological assessment of aerobic training in soccer AU - Impellizzeri, Franco M. J Sports Sci [Internet]. 2005 Jun 1;23(6):583–92. Available from: https://doi.org/10.1080/02640410400021278

6. Gabbett TJ. The training—injury prevention paradox: should athletes be training smarter and harder? Br J Sports Med [Internet]. 2016 Mar 1;50(5):273 LP-280. Available from: http://bjsm.bmj.com/content/50/5/273.abstract

7. Massard TI. Comparison of player-dependent and player-independent external workload thresholds to model injury risk in football . Thesis : Master of Research Acknowledgments. 2017;(September).

8. Wehbe GM, Hartwig TB, Duncan CS. Movement analysis of Australian national league soccer players using global positioning system technology. J strength Cond Res. 2014 Mar;28(3):834–42.

9. Coutts AJ, Duffield R. Validity and reliability of GPS devices for measuring movement demands of team sports. J Sci Med Sport. 2010 Jan;13(1):133–5.

10. Varley MC, Fairweather IH, Aughey RJ. Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. J Sports Sci. 2012;30(2):121–7.

11. Bauer AM, Young W, Fahrner B, Harvey J. GPS variables most related to match performance in an elite Australian football team. Int J Perform Anal Sport. 2015;15(1):187–202.

12. Gabbett TJ, Domrow N. Relationships between training load, injury, and fitness in sub-elite collision sport athletes. J Sports Sci. 2007 Nov;25(13):1507–19.

13. Gabbett T, Ullah S. RELATIONSHIP BETWEEN RUNNING LOADS AND SOFT-TISSUE INJURY IN ELITE TEAM SPORT ATHLETES. 2012;26(4).

14. Nielsen RO, Cederholm P, Buist I, Sorensen H, Lind M, Rasmussen S. Can GPS be used to detect deleterious progression in training volume among runners? J strength Cond Res. 2013 Jun;27(6):1471–8.

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 Aug;28(8):2244–52.

16. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015 Jan;4:1.

17. Aughey RJ. Applications of GPS technologies to field sports. Int J Sports Physiol Perform. 2011 Sep;6(3):295–310.

18. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health. 1998 Jun;52(6):377–84.

19. Fox JL, Stanton R, Sargent C, Wintour SA, Scanlan AT. The Association Between Training Load and Performance in Team Sports: A Systematic Review [Internet]. Vol. 48, Sports Medicine. Springer International Publishing; 2018. 2743-2774 p. Available from: https://doi.org/10.1007/s40279-018-0982-5

20. Fox AS, Bonacci J, McLean SG, Spittle M, Saunders N. What is normal? Female lower limb kinematic profiles during athletic tasks used to examine anterior cruciate ligament injury risk: a systematic review. Sports Med. 2014 Jun;44(6):815–32.

21. Heydenreich J, Kayser B, Schutz Y, Melzer K. Total Energy Expenditure, Energy Intake, and Body Composition in Endurance Athletes Across the Training Season: A Systematic Review. Sport Med - open. 2017 Dec;3(1):8.

22. Prince SA, Adamo KB, Hamel ME, Hardt J, Connor Gorber S, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. Int J Behav Nutr Phys Act. 2008 Nov;5:56.

23. Bowen L, Gross AS, Gimpel M, Li F-X. Accumulated workloads and the acute:chronic workload ratio relate to injury risk in elite youth football players. Br J Sports Med. 2017 Mar;51(5):452–9.

24. Malone S, Owen A, Mendes B, Hughes B, Collins K, Gabbett TJ. High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk? J Sci Med Sport. 2018 Mar;21(3):257–62.

25. Bacon CS, Mauger AR. Prediction of Overuse Injuries in Professional U18-U21 Footballers Using Metrics of Training Distance and Intensity. J strength Cond Res. 2017 Nov;31(11):3067–76.

26. Rossi A, Pappalardo L, Cintia P, Iaia FM, Fernandez J, Medina D. Effective injury forecasting in soccer with GPS training data and machine learning. PLoS One. 2018;13(7):e0201264.

27. Lu D, Howle K, Waterson A, Duncan C, Duffield R. Workload profiles prior to injury in professional soccer players. Sci Med Footb [Internet]. 2017 Sep 2;1(3):237–43. Available from: https://doi.org/10.1080/24733938.2017.1339120

28. Kampakis S. Predictive modelling of football injuries. 2016;(April). Available from: http://arxiv.org/abs/1609.07480

Appendix

Assessment of Methodological Quality

Questions from the modified Downs and Black checklist (18) used to evaluate methodological quality of the included articles.

Table 7.

Question no.	Question
	Reporting
1	Is the hypothesis/aim/objective of the study clearly described?
2	Are the main outcomes to be measured clearly described in the introduction or methods section?
3	Are the characteristics of the subjects included in the study clearly described?
4	Are the main findings of the study clearly described?
5	Does the study provide estimates of the random variability in the data for the main outcomes?
6	Have actual probability values been reported (e.g., 0.035 rather than < 0.05) for the main outcomes except where the prob- ability value is < 0.001?
	External validity
7	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
8	Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
	Internal validity bias
9	If any of the results of the study were based on "data dredging," was this made clear?
10	Were the statistical tests used to assess the main outcomes appropriate?
11	Were the main outcome measures accurate (valid and reliable)?