Statement on methods in sport injury research from the 1st METHODS MATTER Meeting, Copenhagen, 2019

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ABSTRACT

High quality sports injury research can facilitate sports injury prevention and treatment. There is scope to improve how our field applies best practice methods—methods matter (greatly!). The 1st METHODS MATTER Meeting, held in January 2019 in Copenhagen, Denmark, was the forum for an international group of researchers with expertise in research methods to discuss sports injury methods. We discussed important epidemiological and statistical topics within the field of sports injury research. With this opinion document, we provide the main take-home messages that emerged from the meeting.

OPINIONS FROM THE MEETING

Meeting participants agreed that the definition of sports injury depends on the research question and context. It was considered essential to be explicit about the goal of the research effort and to use frameworks to illustrate the assumptions that underpin measurement and the analytical strategy. Complex systems were discussed to illustrate how potential risk factors can interact in a non-linear way. This approach is often a useful alternative to identifying single risk factors. Investigating changes in exposure status over time is important when analysing sport injury aetiology, and analysing recurrent injury, subsequent injury or injury exacerbation remains challenging. The choice of statistical model should consider the research question, injury measure (eg, prevalence, incidence), type and granularity of injury data (categorical or continuous) and study design.

THE FUTURE

Multidisciplinary collaboration will be a cornerstone for future high-quality sports injury research. Working outside professional silos in a diverse, multidisciplinary team benefits the research process from the formulation of research questions and designs to the statistical analyses and dissemination of study results in implementation contexts.

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INTRODUCTION

Sports injury researchers have powerful statistical software packages at their disposal to help answer increasingly sophisticated questions posed by coaches, clinicians and athletes. New statistical approaches, aetiological and causal frameworks, and complex systems theory continue to be developed and refined—a gift and a challenge in equal measure. This ongoing development of methodological approaches allows for high-quality analyses that advance the broad field of sports injury research to improve clinical care, injury treatment and injury prevention.[1]

Two decades ago, in general medical journals, the proportion of published articles with questionable application of statistical methods reportedly ranged from 39% to 90%.[2] Researchers made so many basic statistical errors that the late Professor Douglas Altman, a former Director of the Centre for Statistics in Medicine in Oxford, declared that the level of inappropriate use of statistical techniques in biomedical research was a scandal.[3] In the future, it is therefore essential that similar or even worse findings than those in biomedical research two decades ago are not repeated in the present sports injury research context. After all, methods matter![1]

"How often do we discuss epidemiology, causality and statistical sciences in sports injury research?", you may ask. To the best of our knowledge, no specific community or forum exists on epidemiology or statistics in sports injury research. Training new researchers to conduct methodologically robust sports injury research is often limited and inadequate, and researchers—both experienced and inexperienced—often employ traditional methods that may not be ideal for their type of data and research question. This limited focus on methodology inspired the first METHODS MATTER Meeting for a group of representative researchers. The goal was to discuss epidemiological and statistical topics within the field of sports injury research. With this opinion document, we provide readers of sports injury research with a summary of discussions and the main take-home messages that emerged from the 1st METHODS MATTER Meeting. An overview of these take-home messages is provided in table 1.

METHODS

The 1st METHODS MATTER Meeting was held in Copenhagen, Denmark on 29 and 30 January 2019. Thirty-one researchers from 13 countries were invited and 25 researchers from 11 countries attended. The agenda consisted of six pre-selected topics: (1) injury definition; (2) sports injury data and statistical modelling; (3) complex systems thinking and computational modelling; (4) longitudinal data analyses; (5) recurrent and subsequent injuries; and (6) causality.

In each session, the key elements were introduced by two or three presentations, after which a discussion followed on the content of the presentations and other topics that emerged (for the meeting invitation, title of presentations and book of abstracts see the online supplementary file). Each session-specific discussion was guided by a scientific facilitator and a moderator. The facilitator was a content expert who ensured that everyone had a chance to contribute to the discussion. The facilitator encouraged discussions around the table and aimed to provide a

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Table 1 Take-home messages and recommendations from the 1st Methods Matter Meeting

Topic	Opinions and recommendations
No universal sports injury definition is necessary	1. There is no need for a single universally accepted definition of sports injury 2. Choosing an injury definition is a balancing act between a range of factors, such as level of pain/injury severity, number of cases, research question and ease of reporting. As these factors are often competing, we encourage researchers to match their choice of definition to the study purpose, setting and design
Be explicit about the goal of your research: are you describing, predicting or drawing a causal inference?	3. Be explicit about the research goal (eg, description, prediction or causal inference) 4. To ensure that sports injury researchers report the goal of their research in their publications, we recommend coordinated action by sports science and medicine journals. For instance, the author guidelines could state that authors should explicitly describe their research goal 5. Define the terms used in research (eg, prediction, causation). Standard language that clinicians and researchers understand will improve evidence transparency and quality
Frameworks can guide researchers	6. Clearly outline your assumptions. Specifying your theoretical framework and/or drawing a causal diagram when dealing with a causal question is generally very helpful to the reader
Analysing longitudinal data	7. As sports injury occurrence is likely a highly dynamic process, investigating changes over time is important. Consequently, sports injury researchers are recommended to embrace the options that longitudinal data offer
Which statistical approach should I choose?	8. The choice of the statistical analytical approach depends on various factors including, but not limited to, research question, injury measure (eg, prevalence, incidence), type of injury data (categorical or numerical/continuous) and study design
Dealing with recurrent or subsequent injury	9. There is no consensus on what constitutes a 'healed' injury. 1. There is no consensus on the recommended statistical approach to analyse recurrent injury data, subsequent injury data or data on injury exacerbation 10. As no consensus on what constitutes a recurrent injury, subsequent injury or injury exacerbation exist, classifications of recurrent injury, subsequent injury and injury exacerbation should be clearly defined in each manuscript
Sports injuries are complex and contextual	12. Researchers require at least a basic understanding of what complex systems entail and how to interpret the results to better use complex system analysis in sports science 13. Statistical modelling and systems-based modelling approaches that recognise non-linear complex interactions complement traditional biostatistical and epidemiological methods 11. Approaches that combine qualitative and quantitative methods may help investigators better understand how non-linear complex interactions underpin most sports injuries
Need for multidisciplinary teams and collaborations	15. Collaboration bridges gaps between statisticians, epidemiologists, sports injury researchers, athletes and clinical experts 16. Involve statisticians, epidemiologists and practitioners early when designing a study, not after data have been collected 17. Working in diverse multidisciplinary teams should help to better formulate research questions, identify an appropriate study design, ensure appropriate and legally acceptable data acquisition, conduct correct statistical analyses, make proper interpretation of study results and disseminate them in suitable implementation contexts 12. Stakeholders in sports injury research are encouraged to intensify their investments in statistical, epidemiological and methodological education in our field, such as multisite and interdisciplinary collaborations, training reviewers, providing online opportunities, exchanging trainees, developing (and extending) guidelines and including methods content in regular scientific meetings

concise 2-minute summary at the end of each session. The moderator kept time.

After the meeting, each facilitator drafted a summary of their session and this was circulated to the presenters and moderator associated with that topic for review. Authors RON and EV merged the six documents and drafted the introduction, methods and conclusion, which were then distributed to all authors for a first round of feedback. After revisions, the full-text manuscript was circulated twice for final comments and suggestions for improvement prior to submission.

The attendees agreed on certain issues (eg, an injury definition depends on a range of factors) and were challenged by other issues (eg, how to best analyse recurrent events). Consequently, this manuscript should not be regarded as a consensus statement. We hope it will serve as a tool for sports science researchers dealing with the complexity of sports injury epidemiology, causality, sports biostatistics and other methodological issues.

Our views and take-home messages are presented under the following eight headings: (1) No universal sports injury definition is necessary. (2) Be explicit about the goal of your research: are you describing, predicting or drawing a causal inference? (3) Frameworks can guide researchers. (4) Analysing longitudinal data. (5) Which statistical model should I choose? (6) Dealing with recurrent or subsequent injury. (7) Complex systems. (8) Need for multidisciplinary collaborations.

NO UNIVERSAL SPORTS INJURY DEFINITION IS NECESSARY

Injury consensus statements across sports use different definitions of sport injury,[4–12] in part because the definition depends on the context.[13–15] Researchers planning a sports injury study need to consider a range of operational injury definitions. These can be roughly divided into broad categories with respect to time loss from sports, such as 'any physical complaint', which includes non-time loss injuries, and more narrow definitions (eg, 'unavailable for competition'). Studies that use a broader definition often have greater statistical power because more injuries are captured. However, collecting detailed injury data using a broad definition may be resource-demanding, require criteria that are more subjective, and capture a number of injuries with minimal consequences (eg, cuts and bruises). In contrast, narrow definitions are generally based on more objective criteria and filter out less severe cases. Associations may exist for a broader definition when none exist for a narrow definition, or vice versa.

Traditionally, measures such as prevalence proportion or incidence rate are reported in sports injury studies.[16] At the METHODS MATTER Meeting, we discussed the outcomes 'injury severity' and 'injury burden'.[17 18] Currently, there is no consensus on the definition of injury burden or on how to operationalise burden in statistical analyses. Creating a composite burden score (eg,

the severity score from the Oslo Sports Trauma Research Centre questionnaire) from different outcome measures to collapse a complex phenomenon into one number should be considered with caution. This approach risks omitting important information (eg, the difference between prevention and treatment). Still, the idea of injury burden is appealing, as it aims to provide more information on the consequences of an injury beyond the classical measures of prevalence and incidence.

Recording sports injury events in practice is also contingent on who identifies the event (ie, whether it is researchers, athletes, coaches and managers, clinicians or combinations of these). For instance, loyalty or toughness may encourage athletes, coaches and medical staff to downplay injury symptoms or hasten return-to-sport.

The choice of sports injury definition should also be guided by the research question. For example, studies of workload and injury risk have typically recorded only non-contact injuries, based on an assumption that workload is unrelated to contact injuries.[19] On the other hand, studies of overuse injuries in general require broad definitions, as athletes often continue to participate in training and competition despite being injured.[20 21] In addition, we need to consider how to capture a sports injury when it originates from sport, from an activity of daily living or from a combination of the two. A continued discussion on these (and other) aspects related to injury definitions is needed.

BE EXPLICIT ABOUT THE GOAL OF YOUR RESEARCH: ARE YOU DESCRIBING, PREDICTING OR DRAWING A CAUSAL INFERENCE?

In causal inference, "… being explicit about the goal of the analysis is a prerequisite for good science",[22] and we recommend the practice for sports injury researchers as well. For such clarification, a 3-fold classification of the research goal, which was published recently,[23] may be used:

1. Description: for instance, describe injury risk or rate over time in a group of athletes.
2. Prediction: for instance, examine which athletes are more likely to sustain injury than others; in plain language, this translates to identifying/predicting 'who' is at high risk of getting injured.
3. Causal inference: for instance, examine the causal effect of an exposure on sports injury; in layman's terms, this translates to examining 'why' or 'how' an injury occurs using intrinsic and extrinsic causes of injury.

When identifying the research goal, it is important to understand that every true causal factor (if it is well measured) is a predictor (although sometimes a weak one), but not every predictor is a causal factor.[24 25] As an example, American football players wearing a shirt with an animal logo had a lower risk of concussion than players who wore shirts without an animal logo.[26] Here, the 'who' question (prediction) was addressed through an animal logo variable that is not a causal factor (most likely, changing one's jersey will not change risk of concussion).

If the sports injury researcher is aiming to investigate the causal effect of body weight (or another causal question) on sports injury occurrence, he or she is dealing with a 'why' question. In this case, concepts such as confounding, effect-measure modification, and mediation should be given careful attention and consideration, as the aetiology of sports injury is likely to be multifactorial.[27] If the goal is prediction, attention to subgroup differences may be needed, depending on the research question of interest.

At the METHODS MATTER Meeting, there was discussion about whether the terms 'why' and 'how' cover the same concept. We did not reach agreement. Clinicians, coaches and athletes should be aware that some sports injury researchers use the 'why' and 'how' terms interchangeably. Some may consider 'why' and 'how' to cover different aspects (eg, aetiology and mechanisms, respectively),[28] and others may avoid using the terms altogether.

FRAMEWORKS CAN GUIDE RESEARCHERS

Researchers should be encouraged to disclose the underlying assumptions of their analyses. Sports injury frameworks help to illustrate the assumptions underpinning 'who' or 'why'-related questions. The fundamental rationale and theoretical basis that a sports injury occurs if the load applied to a body structure exceeds its capacity to withstand the load[29] led to different frameworks about the causal relationship between workload and injury, with slightly different assumptions.[28 30–33] For example, a dynamic model of aetiology in sport injury was presented in 2007, in which the authors argued that "exposure is a combination of both possessing a risk factor and then participating (to a greater or lesser degree) with the risk factor".[34]

In a sports injury setting, if the aim is to assess causality, directed acyclic graphs (DAGs) and other causal diagrams can help illustrate which variables to include and adjust for in a statistical analysis. It has been recommended that sports injury researchers include DAGs in their publications.[35 36] Directed acyclic graphs are useful to understand when to adjust for confounding variables,[37 38] when an effect is mediated through another variable, and when adjusting for a variable introduces new bias rather than minimising bias. This is important when trying to investigate the average/direct/indirect/total causal effect of a certain causal factor in sports injury occurrence.[39 40] For additional information on DAGs, we refer readers to other published literature.[35]

ANALYSING LONGITUDINAL DATA

Longitudinal data may be viewed as multiple records (eg, injury status) on one or more athletes over time. New technologies make access to such data easier, but they carry the price of in-depth considerations when analysing the data.[41] Irrespective of the size of the data set, researchers must ensure that they collect appropriate data (in an appropriate manner) to answer specific and clear research questions, and that they employ correct statistical tools to handle such data.[42] Athletes often change their training schedule and characteristics. In the 1970s, general methodologists of science insisted that it was impossible to measure how health-related exposures and outcomes changed over time.[43] Researchers interested in the study of change were encouraged to frame their questions in other ways.[43] Later, this was identified as poor advice.[43]

As sports injury occurrence is a highly dynamic process,[27] investigating changes over time is important. Consequently, sports injury researchers are recommended to embrace the options that longitudinal data offer. For instance, longitudinal data permit the calculation of metrics that quantify absolute or relative changes in training load.[44 45] When studying change over time, time-varying exposures (eg, change in training load) and time-varying outcomes (eg, change in injury status) are two essential concepts.[46] The open question remains: Which approach is suitable for which question and data? There are many options (eg, time-to-event methods,[45] g-methods,[47] survival trees,[48] classification and regression trees

with repeated events,[49] and generalised linear mixed models[50]). The most suitable approach for the research question should be given greater consideration in sports injury research in the future. At best, sports injury epidemiologists and sports biostatisticians should be included when deciding on the analytical approach.[42]

Although the advantage of large-scale longitudinal data must be highlighted, these data also carry challenges, including (1) handling dependencies in these data due to the repeated measures on each individual; (2) missing data, which are often substantial in these studies; (3) censoring;[45] (4) competing risk;[44] and (5) understanding the complexity of the statistical analyses required to take full advantage of the many opportunities longitudinal data provide. Ignoring these challenges when fitting models may lead to biased estimates and misinterpretation of results.[42 44–46]

WHICH STATISTICAL APPROACH SHOULD I CHOOSE?

Injury data are often classified as a dichotomous outcome (ie, an athlete is either injured or not injured) or as different categorical states that each athlete can inhabit over time. However, other ways of collecting and handling injury data exist, as (1) athletes often move between various states of injury severity, (2) athletes can have more than one injury or (3) researchers are interested in other injury-related outcomes. This reality may be better reflected in injury data of greater detail and granularity, which can end up being categorical or numerical.[44] The type and granularity of injury data has a substantial impact when choosing the statistical approach. For instance, log-binomial regression or logistic regression requires a dichotomous injury outcome, whereas linear regression requires numerical/continuous data. In addition to the type of injury data, the type of injury outcome measures (eg, prevalence proportion or incidence rate) also has implications when choosing statistical models as well.

Different statistical approaches continue to be integrated in the field, including data imputation, time-to-event analysis, longitudinal data and clustered data, among others. Machine learning approaches to data, of which prediction is the main goal, are also being considered.[23 51 52] Whether the analyses of interest are descriptive or inferential (the latter can be subdivided into prediction or causal inference), authors should use appropriate terms, concepts and methods accordingly.[25] Study design and outcomes of interest will play an important role in deciding the appropriate analytical approaches beyond the classical regression techniques.

A common analytical approach is the generalised linear model.[53] This approach requires independence between observations of the injury outcome. However, these assumptions may be violated in some situations, such as clustered studies (outcomes of individuals within a cluster may be more similar than those of individuals between clusters) or longitudinal studies (repeated measures of the same athletes are analogous to clustering in an individual). Ignoring non-independence of data when fitting the model may lead to incorrect estimation of standard errors and erroneous conclusions often due to overstated statistical significance. The two following techniques are often used to account for correlated data of any type: (1) adding a 'random effect' to account for clustering (eg, generalised linear *mixed* models, frailty models), or (2) incorporating a correlation structure for the observations (eg, generalised estimating equations (GEE)).

There is a special interest in recurrent event data. The simplest approach to analysis in this setting is to count the events observed within a given period. These counts are usually assumed to follow a Poisson distribution.[54] Where the variance of the counts (rates) is not the same as the mean (ie, data do not follow a Poisson distribution), a quasi-Poisson or a negative binomial distribution is an alternative choice.[55 56] Another way of looking at recurrent event data is to model the time to event. In this case, the time to event of all individuals may not be fully observed, as this may be subject to censoring (eg, drop out from the study before complete follow-up).

Analysing data in a 'competing risk' setting (when other outcomes may preclude the outcome of primary interest and/or change the probability of the outcome of interest) may be important, as athletes may sustain multiple injuries over time.[44 57] Some suggested methods to analyse data in the face of these challenges include competing risk models,[44 57] multistate models[57] and recurrent event models with a time-dependent covariate.[58–60]

DEALING WITH RECURRENT OR SUBSEQUENT INJURY

There is wide recognition that a subsequent injury can be correlated to a previous injury. When analysing subsequent injury, the terms 'repeat', 'recurrent', 'exacerbation' or 'multiple' are often used interchangeably. To avoid confusion, authors should clearly define their terminology in each manuscript. For example, the answer to "when is an injury considered healed?" depends on the research question, and multistate models might provide a framework for researchers and clinicians to help decide on the appropriate categorisation.[61] Importantly, models and frameworks should be transparent, valid and demonstrate clinical utility for the end user. Here, valid and reliable assessment of injury data over time is important. Momentary assessment was discussed as a tool to record information on recurrent injury, including occurrence day and recovery day (however defined).[62–67]

Competing risks and analysis of recurrent events are major challenges in sports injury research,[57 68–70] and there is considerable uncertainty about how to handle these. Methods like the Aalen–Johansen estimator could be a useful alternative to the Kaplan–Meier estimator in survival analyses when dealing with competing risks.[44] Extra precaution should be taken when analysing small data sets, as these may introduce additional bias and overfitting.

SPORTS INJURIES ARE COMPLEX AND CONTEXTUAL

As with most health conditions, it is likely that linear and non-linear complex interactions underpin most sports injuries.[30 71 72] A complex systems approach to sports injuries tries to understand how relationships between the multitude of direct and indirect risk factors result in different paths to being injured.[30 73 74] Further, athletes act within an ecological context where other determinants of risk may be important to take into account. For instance, the finding that the quality of communication between medical staff and team managers in professional soccer clubs was correlated with injury rates expands the understanding of injury mechanisms because failed communication could lead to inappropriate workloads for some athletes.[75 76] The outcomes of studies performed in the ecological context can immediately be used for sports safety promotion interventions and programmes.[77] To further improve consistency and relevance in recommendations, research approaches that include complex systems models or are ecological are needed to effectively engage stakeholders and qualitatively derive relevant questions to measure quantitatively.

NEED FOR MULTIDISCIPLINARY TEAMS AND COLLABORATIONS

The presentations and discussions at the MMETHODS MATTER Meeting from various methodology-oriented peers were sometimes contentious but occurred in a relaxed and friendly atmosphere, where open critique was encouraged. To reduce the risk of having the use of statistical techniques in sports injury research referred to as a scandal,[3] we discussed the next steps. Here are three considerations regarding multidisciplinary collaborations:

- Collaboration is key to bridging gaps between statisticians, researchers and clinical content experts. Developing objectives, design, data acquisition, analyses, interpretation and dissemination in the most appropriate implementation context requires collaborative approaches.
- Different presentations of the same research project to different statisticians, data scientists or injury methodologists will often be met with different recommendations regarding methods.
- Researchers must collaborate more with the statistical community and invest in statistical education in our field (eg, multicentre and interdisciplinary collaborations, reviewer training, online opportunities, trainee exchanges, guidelines, methodological content in meetings).

The next steps in collaboration include ongoing contribution to educational editorials and reviews to accompany those previously published in *Journal of Orthopaedic & Sports Physical Therapy*, *British Journal of Sports Medicine* and other journals.[1 16 32 36 44 45 78–84]

CONCLUSION

The general sentiment at the METHODS MATTER Meeting was that defining sports injury depends on the research question and context. It is essential that researchers are explicit about the goal of any research effort (eg, description, prediction and causal inference) and that they use frameworks to illustrate assumptions underpinning the analytical strategy. Modelling of complex systems was brought forward to illustrate how the description of interaction between risk factors can be an alternative to identifying isolated risk factors.

Investigating changes in exposure status over time is important when analysing sports injury aetiology, even though analysing recurrent injury, subsequent injury or injury exacerbation remains challenging. Finally, the choice of statistical model should consider the research question, injury measure (eg, prevalence, incidence), type of injury data (categorical or continuous) and study design. The view at the meeting was that multidisciplinary collaboration will be the cornerstone for future high-quality sports injury science. Working beyond professional silos in a diverse, multidisciplinary team benefits the research process. It promotes better research questions, more appropriate study design and more rigorous statistical analysis. Collaboration also promotes dissemination of study results—a step towards implementation!

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