Fundamentals of Sports Analytics

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KEYWORDS

• Epidemiology • Study design • Analytics • Sports performance • Injury occurrence

KEY POINTS

- There are a variety of research study designs that can be used to identify risk factors for injury, including cohort, case control, and case series.
- Each has advantages and disadvantages and their use should be determined by the data available and the research question at hand.
- Sports injury surveillance systems are useful for collecting injury incidence data but have unique limitations.
- Common analytical measures used in sports injury research include injury rate, injury risk and odds, incidence rate ratio, and risk difference and can be calculated based on the study design and research question.
- There has been increased emphasis on using technology to measure athletic performance, but much is still unknown about best practices with these data.

INTRODUCTION

Analytics, in some form or another, have always been a part of sports. Basic statistics, such as the score of the game, or the number of receptions or hits, provide the basis for athletic competition. Recently, however, the importance of statistics and analytics in sports has increased, with emphasis on measures that improve the likelihood of winning or may provide an "edge" over the competition who has not yet discovered the value of these measures. These analytics include measures of sport aptitude

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(eg, strikeouts in baseball, free-throw percentage in basketball), physical location (eg, pitch location in baseball, distance run in basketball), economic value, and, most relevant to medicine, injury incidence and metrics of physical performance.

Just as measures of sport aptitude have been used in the sports setting to increase win probability, there is increasing recognition that understanding injury occurrence and identifying factors that can prevent injury can provide a team with an advantage on the field or court via implementation of data-driven injury prevention strategies. Additionally, recent advances in technology have led to an improved understanding of physical ability, functional movement, training load, and fatigue. Understanding an athlete's workload can lead to improved training that maximizes athletic performance and minimizes fatigue and injury.

The emphasis of this review is to describe measures of sports injury and fundamentals of sports injury research with a brief overview of some of the emerging measures of sports performance. First, we describe research study designs that can be used to identify risk factors for injury. Second, we discuss an important source of injury incidence data: surveillance programs. Third, we describe common measures of injury risk and association. Finally, we describe measures of physical performance and training and considerations for using these measures. This review provides sports medicine clinicians with an understanding of current research measures and considerations for designing sports injury research studies.

SPORTS INJURY RESEARCH STUDY DESIGNS

The goal of research is to answer a question about a broader population using a sample of data. Here, the population is the entire group that we want to study (eg, all adolescent boys' basketball players in the United States), and the study sample is a subset (eg, a sample of United States high school boys' basketball teams) that we actually examine to make an inference about the population of interest. Our ability to answer research questions depends on the strength of the study design, including the overall framework used, the validity of the data collected, and the rigor of the analysis and interpretation.

Evidence can be generated from both experimental and observational study designs. Experimental studies, such as randomized controlled trials, are largely considered the gold standard for evidence generation owing to the validity afforded by randomization, that is, the ability to balance participant characteristics that may affect the outcome of interest ("confounders") between groups, control treatment, or exposure delivery, and isolate treatment effects among specific populations of interest.[1–3] However, randomized controlled trials and other experimental study designs also have limitations, including high costs and time required for study completion, potential lack of real-world applicability and generalizability, a need for equipoise, and an exposure that can be ethically randomized.[1–3] Owing to these caveats, many research questions cannot be answered using experimental study designs.

Observational studies can also generate high-quality evidence when rigorous research methods are used. These studies typically fall within 3 broad study designs: cohort, case control, and case series studies (**Table 1**).[1,3] Here we provide a high-level overview of the fundamental concepts underpinning these study designs. These study designs can be used with data stemming from a variety of sources, including surveillance data, electronic medical records, administrative claims or billing information, or data specifically collected for research purposes, and the source of the data and study design are not inherently linked together, but rather separate concepts.

Cohort Studies

The basis of a cohort study involves following a group of individuals who arise from the population we want to study, some of whom are exposed to an intervention, characteristic, or experience and some of whom are unexposed. Exposure has been assigned by some nonrandom process, such as some individual choosing to wear a personal protective equipment item (eg, mouthguard), whereas others choose not to wear the item. These individuals are followed forward in time to observe an outcome of interest.[1–3] A cohort study can be initiated either prospectively or retrospectively. In a prospective study, subjects are enrolled and then followed forward in time. In a retrospective cohort study, the sample is still selected based on exposure, but the exposures are identified after the outcome event occurs, even though the exposure was recorded before the event occurring. In essence, all cohorts are prospective in time. Thus, the term "historical" cohort study is sometimes used instead of "retrospective."

In sports studies, the exposure could be anything from an athlete characteristic (eg, age, body mass index, gender, alignment, anatomic structure), to a playing condition (eg, field type, footwear, weather, sport schedule), to an intervention intended to reduce injury risk (eg, warm-up program, bracing, taping, safety equipment, rule changes), or even prior injury history or prior treatment for injury. The outcome is typically an injury, reinjury, or other adverse player health event, although the outcome could also be time lost from participation, return to sport, performance level, medical disqualification from sport, or the need for surgical intervention or other treatment.

The ultimate purpose of a cohort study is to determine whether the exposure of interest is associated with outcome occurrence.[2,3] As such, all members of the cohort must be outcome negative (free of the outcome) at the start of the follow-up period, so that temporality between the exposure and outcome occurrence is clearly defined.[1,3]

Table 1
Comparison of study design features for cohort, case control, and case series studies

Cohort	Case Control	Case Series
Anchored in time based on exposure	Anchored in time based on outcome	Descriptive based on outcome positive status
Must include both an exposed and unexposed group at the start of follow-up	Must include both an outcome positive and outcome negative group at the start of the study	Only includes an outcome positive group
Participants followed forward in time from exposure of interest to outcome	Exposure determined retrospectively after identification of outcome or no outcome	Exposures described after outcome positive group is identified
Both exposed and unexposed must be at risk for the outcome for duration of follow-up	Both exposed and unexposed must be at risk for the outcome for duration of follow-up	Only includes an outcome positive group—timing of exposure and outcome described
Cohort members must be outcome negative at the start of follow-up	Study participants must be outcome negative at the time of exposure	Study participants must be outcome positive
Study can be initiated either prospectively or retrospectively	Study can be initiated either prospectively or retrospectively	Study can be initiated either prospectively or retrospectively

Another important feature of the cohort study is "exchangeability" of the exposed and unexposed groups; the unexposed group should be similar to the exposed in all other aspects other than exposure.[3] For example, suppose we wish to assess the effect of helmets on concussion incidence. The exposed group includes football players who wear helmets, whereas the unexposed group includes tennis players who do not wear helmets. In this scenario, it would be difficult to determine whether a difference in concussion incidence was due to helmet use or due to the background difference in concussion incidence and many other characteristics that differ between football and tennis players and their respective sports.

In observational research studies, where participants are identified from a nonrandomized, real-world setting, it is often difficult to ensure that the exposed and unexposed groups are truly exchangeable.[2,3] Analytical and design methods can be used to account for potential confounders if these characteristics are enumerated and quantified. In-depth discussion of methods for adjusting for confounders is outside the scope of this review paper, but these techniques include restriction, stratification, matching, standardization, or analytical adjustment. Analytical adjustment using a statistical model is a common strategy that can be implemented if these factors are carefully considered before study initiation and the data are available.[1,3]

Case Control Studies

Similar to the cohort study, the goal of a case control study is also to determine whether the exposure of interest is associated with outcome occurrence. Case control studies, however, identify participants based on the outcome rather than the exposure, comparing individuals who are outcome positive to those who are outcome negative.[1,3] Case control studies are efficient study designs for rare events owing to the selection of cases driving the study sample. As in the cohort study, the study group for a case control study must also arise from the total population of interest.[1,3] In other words, every case control study takes place within the context of (or is "nested" in) a hypothetical cohort. After the study sample is identified, the investigator compares the prevalence of the exposure before the index date for the outcome positive and outcome negative groups.[1,3] For example, at the end of a basketball season, we may select basketball players from 1 team who sustained an ankle sprain compared with players on that team who did not sustain an ankle sprain, and then look backward in time to determine how many in each group participated in an injury prevention program during preseason.[4]

Logically, the key considerations for a cohort study that are listed, including being outcome negative at the time of exposure, exchangeability between the 2 groups (here, the outcome positive and outcome negative groups), and adjustment for confounders, also apply to case control studies. However, there are several additional considerations for case control studies, including the conscious selection of a strategy for selection of controls that is appropriate for the research question of interest.[1,3]

Controls must always arise from the source population of interest, and they can be selected using one of 3 different methods.

First, among the full study cohort (eg, all basketball players participating at the start of the season) that includes all the exposed and unexposed among the study sample, controls can be sampled from the total cohort, which would include outcome positive individuals.[1,3] This type of sampling is preferred because it represents the full cohort; however, it is typically only used if collection of data is time consuming or expensive, limiting the opportunity to perform an analysis of the full cohort. This control selection strategy is often referred to as "case cohort" sampling.

Second, control sampling can be performed from a group of outcome negative individuals who meet exchangeability criteria for the outcome positive individuals (eg, basketball players who did not sustain an ankle sprain by the end of the season).[1,3]

Third, control sampling can be performed in a prospective and dynamic fashion, such that among a group of individuals followed over time, and, when a case is identified, a control is also selected from the group at the same point in time (eg, when an ankle sprain occurs, select another basketball player playing in the same game who has not sustained ankle sprain).[1,3] With this method of sampling, it is possible that some individuals selected as controls may later become cases.[1,3] This control selection strategy is often referred to as "risk set" or "cohort nested" sampling and is conceptually closely linked to the prospective cohort study in which most of noncases are "missing by design."[4]

Regardless of how controls are sampled for a case control study, it is imperative that they be selected without respect to the exposure status (eg, controls should be taken without considering whether they participated in the prevention program during preseason). Failure to adhere to this requirement results in a biased estimate of the effect of the exposure on the outcome of interest.[1,3]

Case Series

The defining feature that differentiates a case series study from a cohort study is the lack of an outcome negative group.[5] In a case series, a group of individuals who are all outcome positive is analyzed.[5] For example, a group of injured athletes may be studied to determine the average time to return to play after the injury of interest, or a group of individuals who underwent a surgical procedure may be assessed to determine the proportion who need a revision procedure. These studies are valuable for describing the characteristics or outcomes of a group; however, it is important to note that the relationship between the characteristic, outcome, or other variable of interest and the experience that determined case series membership, cannot be assessed.[5] For example, if we study a series of soccer players who sustained an anterior cruciate ligament rupture and note that 80% of these players were participating on field turf at the time of injury, this does not suggest that field turf increases likelihood of anterior cruciate ligament rupture. To answer that question, we would need to also understand either the distribution of field turf participation for all soccer players or for a sample of uninjured soccer players. Nevertheless, this type of descriptive study is often the first step in hypothesis generation that can motivate performing a future in-depth investigation into an association.

SPORTS INJURY SURVEILLANCE

As noted, the data for all these study designs can be derived from a variety of sources. One common source of these data are sports injury surveillance systems. Sports injury surveillance systems can examine trends in sports injuries over time and measure the impact of interventions aimed to reduce sports injuries. Injury surveillance is the "ongoing and systematic collection" of injury data.[6,7] Surveillance systems exist in a variety of settings to collect a multitude of data, including hospital admissions and mortality, and many sports injury surveillance systems have been established at the high school,[8–10] collegiate,[11] and professional[12–14] levels. In addition to descriptive data, surveillance systems can be used as the source of cases and controls in case control studies. Surveillance systems can also be used for cohort studies, either retrospective in nature using data already collected, or they can be used to track outcomes among subjects enrolled prospectively into a study.

Injury surveillance is most commonly used for assessing the incidence of various conditions in different sports settings and addressing trends over time. These assessments can be used to demonstrate the need for research on a particular injury type, sport, or play. Among clinicians, measurements of injury incidence are used to justify their roles and help to determine resource allocation of clinical services and equipment.[15] These assessments are also used to justify the implementation of an intervention or rule change by governing bodies.[11] Once the intervention or rule change is implemented, injury surveillance can determine the impact of the intervention on injury occurrence by continuously monitoring injury rates over time or retrospectively assessing injury rates preimplementation and postimplementation.[16]

Although there are many uses and strengths of sports injury surveillance, there are also limitations and considerations for using surveillance data to answer sports injury research questions (**Table 2**). Sports injury surveillance is instrumental in establishing the "who, what, when, and where" of sports injuries. However, to capture large volumes of data, data collection processes are often streamlined and focus on breadth rather than depth. Therefore, etiology, especially at the individual level, is difficult to establish. Unlike a traditional prospective cohort study, individuals do not typically have baseline measurements and may not be followed over time. Rather, data are collected at a population level and focus on the injuries and the circumstances surrounding the injuries, often with only group-level measurements of time at risk.

Some existing sports injury surveillance systems have data available for release to external researchers for peer-reviewed publications. These include the Consumer Product Safety Commission's National Electronic Injury Surveillance System,[17] the NCAA Injury Surveillance Program,[11] and the National Athletic Treatment, Injury and Outcomes Network.[10] Whether using an existing sports injury surveillance system to answer a new research question or implementing your own sports injury surveillance system, it is important to consider a number of factors that influence the way data from these systems are interpreted. These include the following factors.

- *Definition of the injury*: How is an "injury" defined? Must the injury be related to a sports activity? Are both time loss and non–time loss injuries included? Are multiple injuries from the same injury event included? Some examples of injury definitions are included in **Table 3**.

Table 2
Strengths and limitations of sports injury surveillance

Strengths	Limitations
Establishes extent of the injury problem, including incidence and severity[16]	Many etiologic factors not captured, especially at the individual level
Consistent data collection over time to capture trends	Difficult to adapt data collection for changes in clinical practice or sport play without affecting time trends
Intervention effectiveness can be determined	Data collection often not specific to particular injuries, sports, or plays (breadth prioritized over depth)
Data can be captured using means integrated with clinical documentation (easy data collection)	Research definitions for variables not always used; consistency of data collection across sites unknown
Population-level estimates derived	Individuals usually not followed longitudinally; traditional cohort study analyses may be inappropriate

Table 3
Possible definitions of "injury" in sports injury surveillance systems

Full Definition	Short Definition
Any injury or physical complaint sustained by a player that affects or limits participation in any aspect of sport-related activity[14]	Impeded participation
An injury that occurred as a result of participation in an organized practice or competition, required attention from an AT or physician, and resulted in restriction of the student–athlete's participation for ≥1 d beyond the day of injury[8,11]	Medically attended, ≥1 d time lost
Any injury that was evaluated or treated (or both) by an AT or physician, regardless of time lost[11]	All medically attended
Any injury that prevents a player from taking a full part in all training and competition play activities typically planned for that day for a period of >24 h from midnight at the end of the day the injury was sustained[18]	Medically attended, >1 d time lost
All injuries resulting in a player missing ≥1 competitive competition[18]	Prevented participation in a competition
Any physical or medical condition that causes a player to miss a competition in the regular season or finals (playoffs)[12]	Prevented participation in a competition (regular/postseason)

Abbreviation: AT, athletic trainer.

- *Data source*: Are the data collected from a clinical system (eg, integration with an electronic medical record) or from a separate system designed for research purposes? Is the data collector a clinician (eg, athletic trainer) or someone trained to perform research studies? How are the data collectors trained? What is the likelihood of missing data and how are these data handled?
- *Population and sample*: Is this a sample or a census? If a sample of the population is taken, how was this sample taken; was it a simple random sample (teams/schools are selected using a some form of random process and have a predetermined fixed probability of being selected), a stratified random sample (same as a simple random sample, except the probability of selection varies based on some larger group of which they are a part; eg, geographic region, size, league), or a convenience sample (any team/school that volunteers to participate is included)?
- *Denominator*: How is time at risk captured? Is it at the individual level or the population level? Is it by hours or minutes of play or unit-based (eg, athlete–exposure)?

There is no right or wrong answer for many of these questions, but each has implications for how data should be analyzed and interpreted.

COMMON MEASURES OF INJURY OCCURRENCE AND ASSOCIATION WITH RISK

Injury Rate

The most frequently used metric of injury occurrence in sports injury research is a rate, which describes the number of injuries divided by the total time that the study population was at risk for injury.[19] An athlete–exposure (AE) denominator is one of the most commonly used measures of time at risk in the literature, with this metric representing one athlete participating in one athletic event, such as a practice, game, or conditioning session.[19,20]

$$\text{Rate} = \frac{\sum \text{injuries}}{\sum \text{AEs}}$$

The resulting interpretation of the incidence rate is, "*X* number of injuries are expected to occur for every *X* number of AEs."

Aside from an AE denominator, there are multiple other metrics that can be used to describe the time that athletes are at risk for injury, which are summarized in **Table 4**. The choice of a denominator depends on the research question of interest and the preferred method of describing and communicating injury occurrence, as well as availability of data. In many cases, the most granular information on participation is preferred (eg, player–minute of participation) because these data provide the most accurate description of time at risk; however, these data are rarely available across all settings (eg, both practices and games). Subsequently, the strengths and limitations of the denominator of choice should always be considered and summarized when presenting results.

The primary benefit of calculating an injury rate versus another injury occurrence metric is the ability to account for varying time at risk for injury between players, teams, or other groups.[19] For example, when comparing game injuries among first string versus second string players, second string players are likely to have a lower injury risk per game than first string players because they play for less time in each game. Accounting for the difference in minutes played between first and second string players by calculating a rate per player–minute creates more comparable groups in terms of time at risk when assessing injury occurrence. An additional benefit of the rate metric is the ability to allow for inclusion of all injuries, including multiple injuries to the same athlete, in the numerator.[19] Athletes reenter the pool of time at risk as soon as they are once again eligible to sustain an injury.

With the ability to measure all injuries, including multiple injuries to the same athlete, this brings up additional considerations for defining recurrent injuries,

Table 4
Rate denominators for sports injury studies

Denominator	Assumptions
Team—season	Across all teams participating, the baseline risk for injury is the same across a season; Can include injuries that occur in any setting (eg, practices, games, training) in the numerator
Team—games	Across all teams participating, the baseline risk for injury is the same across a game; should only include injuries that occur in a game in the numerator
Player—season	Across all players participating, the baseline risk for injury is the same across a season; can include injuries that occur in any setting (eg, practices, games, training) in the numerator
Player—games	Across all players participating, the baseline risk for injury is the same across a game; should only include injuries that occur in a game in the numerator
Player—minutes or player—plays	Assumes players are only at risk for injury while they are actively participating; should only include injuries that occur while participation is measured
Athlete—exposure (1 athlete participating in 1 athletic practice, competition, or training session)	Similar to player—games, assumes the baseline risk for injury is the same across each athletic session; can include injuries that occur in any setting (eg, practices, games, training) in the numerator

new/subsequent injuries, or exacerbations of a previous injury. Generally, a subsequent injury is any injury that occurs after a first injury, irrespective of whether it is related to earlier injury occurrences. A recurrent injury is another injury of the same type at the same location, and an exacerbation is a reinjury before resolution of the prior injury.[21,22] Finch and Cook's[21] subsequent injury categorization model had become a standard for use in classifying these injuries, providing even more detailed definitions of subsequent injuries, broken down into 10 categories. In many cases, however, the information needed for using the subsequent injury categorization model is not available, and researchers must rely on the clinical judgment of data collectors.

Injury Risk and Odds

Although injury rates are most commonly used to describe and compare injury occurrence, injury risk provides a metric that is more easily interpreted and communicated to stakeholders who are not scientists or data analysts (eg, players, coaches, administrators, general public).[19] Injury risk is the average probability across all athletes that an athlete will sustain an injury over a specific time period of participation.[20] In sports, injury risk is most frequently used to describe the number of athletes who sustain at least one injury over the course of a season of participation:

$$\text{Injury Risk for a Season} = \frac{\text{Number of injured athletes in a season}}{\text{Number of athletes at risk of being injured in a season}}$$

This metric can also be used to describe the risk of injury in any given game, assuming that all athletes on the team are at risk for injury for the entire game, regardless of their actual participation time. Injury risk is a more intuitive concept to grasp than injury rate because it is bounded by 0 and 1 and can be expressed as a percentage[19]; however, the calculation of risk also requires that the athlete is both observed for the full time period and at risk for injury during the full time period.[1,3] Additionally, multiple injuries to the same athlete during the same risk period (eg, 1 season or 1 game) are not included in the numerator, because the numerator counts injured athletes (not injuries). Differences in playing time or, in the case of risk across a season, number of events in which the athlete participated, are also not accounted for in the denominator used in injury risk. In addition, calculation of risk assumes that all athletes analyzed have a comparable baseline risk for injury over the time period of interest. This assumption should be carefully considered when using risk metrics, because the validity of the assumption may be questioned for certain comparisons, such as first string versus second string players. Nevertheless, calculating percentages of athletes who sustain an injury over a sports season is important for understanding and comparing the burden of sports injuries.

Similarly, the odds of injury, which is a function of risk, is another metric that can be used to describe injury occurrence.

$$\text{Injury odds for a season} = \frac{\text{Risk}}{(1 - \text{Risk})}$$

$$= \frac{\dfrac{\text{Number of injured athletes in a season}}{\text{Number of athletes at risk of being injured in a season}}}{\left(1 - \dfrac{\text{Number of injured athletes in a season}}{\text{Number of athletes at risk of being injured in a season}}\right)}$$

Similar to risk, calculating odds requires that the athlete is both observed for the full time period and at risk for injury during the full time period; however, odds are bounded by 0 and ∞, rather than 0 and 1.[1,3] Calculation of risk is typically preferred over odds, because risk is more intuitive and odds tend to be more extreme than risk.[3]

Measures of Association

Measures of association can be used to compare injury rates, risks, and odds between 2 groups of interest, such as the exposed and unexposed in cohort studies or the cases and controls in case control studies. These measures are used to identify factors associated with increased or decreased injury incidence. A ratio measure is calculated by taking the measure of occurrence in the exposed or cases and dividing by the measure of occurrence in the unexposed or controls. As an example calculation, an incidence rate ratio (IRR) is calculated as follows.

$$\text{IRR} = \frac{\text{Rate}_{\text{exposed}}}{\text{Rate}_{\text{unexposed}}} = \frac{\frac{\sum \text{injuries}}{\sum \text{AEs}}_{\text{exposed}}}{\frac{\sum \text{injuries}}{\sum \text{AEs}}_{\text{Unexposed}}}$$

For ratio measures, if no association exists between the exposure and the outcome, the resulting point estimate will be approximately 1, or a null association.[1,3] The point estimate from a ratio measure is interpreted as, "the risk/rate/odds of injury among the exposed/cases is *x* times the risk/rate/odds of injury among the unexposed/controls."

Comparable ratio measures can be computed for odds and risk. Notably, the odds ratio is the only measure of association that can be calculated directly from case control studies, because the calculation of a rate ratio or risk ratio requires information about the denominator or total study population at risk.[1] In a case control study, a sample of controls is selected from the study population at risk instead. However, depending on the sampling strategy used for control selection, the odds ratio may approximate the risk or rate ratio. A case control study that uses case cohort sampling estimates a risk ratio, whereas case control study that uses risk set sampling estimates a rate ratio.

Ratios provide relative measures of association between 2 groups. Difference measures, on the other hand, provide absolute measures of association. A rate or risk difference can be calculated by taking the rate or risk in the exposed and subtracting the rate or risk in the unexposed. As an example calculation, a risk difference (RD) is calculated as follows.

$$\begin{aligned}\text{RD} &= \text{Risk}_{\text{exposed}} - \text{Risk}_{\text{unexposed}} \\ &= \frac{\text{Number of injured athletes in a season}}{\text{Number of athletes at risk of being injured in a season}}_{\text{exposed}} \\ &\quad - \frac{\text{Number of injured athletes in a season}}{\text{Number of athletes at risk of being injured in a season}}_{\text{unexposed}}\end{aligned}$$

If no difference exists, the resulting point estimate will be approximately 0, or a null association.[1,3] The point estimate from a difference measure is interpreted as, "the risk/rate of injury among the exposed is *x* percentage points greater/less than the risk/rate of injury among the unexposed." The advantage of the rate/risk difference over the rate/risk ratio is that it includes information about the scale of injury incidence, which is not represented in ratio measures. For example, a spine fracture may be 10 times as likely in one group than another; however, the incidence of spine fractures

may be very low in both groups, which is important to know.[20] The risk difference provides this information, whereas the risk ratio does not.

When calculating these measures of injury occurrence and association from data, it is important to remember that these estimates are only as good as the sample from which they were calculated. In the case of rare events, it can be challenging to calculate stable estimates owing to small sample sizes and large standard errors. This factor should be considered in the study design phase and when interpreting results from analysis of small samples. Exact statistics are a class of statistics that are often more appropriate than regular (so-called "large sample") statistics when sample sizes are small. Exact statistics are particularly useful when the counts in some cells of analysis tables are very low (eg, $\leq$3).

MEASURES OF PHYSICAL PERFORMANCE AND TRAINING

Recent advances in technology have led to an increase in "wearable technologies" and the use of computer and video to measure functional movement. The goal of many of these technologies is to measure physical ability, workload, and fatigue in the hopes of predicting and implementing measures to mitigate injury. Given their relative recentness in the sports literature, especially in sports injury research, it is important to consider how to best use these measures in study designs and consider what these devices and metrics are actually measuring.

One of the most commonly used measures of training and workload are wearable global positioning software (GPS) devices, which track an athlete's heart rate, distance run, and intensity of work (time spent and distance run at different levels), among other things.[23] The goal is to use these measures to determine the amount of stress on the body, such that performance is maximized but risk of overtraining is minimized. These measures have been studied in research as both exposures (predictors of injury) and outcomes (as surrogates for fatigue and other performance measures).[24–27] This measure provides an objective counterpart to previously used subjective measures of training and effort, such as the rating of perceived exertion scale,[28] which has been associated with injury.[29] A particular area of emphasis has been acute workload (usually measured within the course of single conditioning session or competition or days) compared with chronic workload (usually measured over the course of weeks or an entire season) and the effect of the ratio of these measures on injury.[30,31] Evidence shows that moderate workloads, as well as a moderate acute:chronic workload ratio is protective of injury, and the ratio of acute:chronic workload may be more predictive of injury than workloads themselves, although much of this work has been done using subjective measures.[30,32–34]

In addition to measuring workload, these technologies can be used to measure exposure for risks and rates. If an athlete logs time on a GPS device, then the researcher knows that he or she participated in athletic activity for that day. This provides an athlete–exposure count, but it also allows for more detailed exposure measurement, such as player–minutes.

Subjective measures of functional movement, such as the Landing Error Scoring System and Balance Error Scoring System have long existed to predict injury or measure possible deficits in movement after injury.[35,36] Additionally, technology using force plates has been used to measure movement and balance. More recently, however, these measures have been integrated with video systems for motion capture. This includes formal systems designed for motion capture, as well as adaptations of existing video game systems for the purposes of measuring physical performance and functional movement.[37,38] These tools have been used to both predict injury and capture deficits in physical performance after injury.

STUDY DESIGN CONSIDERATIONS FOR MEASURES OF PHYSICAL PERFORMANCE

Although many of these measures of physical performance and training have been used in clinical situations and by coaches, especially strength and conditioning coaches, their use in research is still limited. Most studies have been done to validate the measures as predictors of injury or determine how the findings associate with other known measures of the same constructs. As use of these metrics become more widespread, researchers must consider study design implications. For example:

- Are these measures the exposure of interest or the outcome of interest? That is, is training load or functional movement leading to injury or game performance outcomes, or are other factors leading to training load or functional movement?
- Are the devices used measuring the construct of interest? And, more important, what is the construct of interest and why?
- How are these data aggregated across a game, season, or career? Are the average values most meaningful, or is the change in value over time more meaningful? How is a continuous stream of data analyzed and interpreted?
- What is the best way to measure "training load" or "fatigue"? As mentioned, recent research has examined whether acute, chronic or the ratio of acute:-chronic workload is most relevant. In addition to this, the definition of "acute" versus "chronic" varies across research studies. The GPS devices also provide a wide range of measures, including heart rate, distance run, to time in certain heart rate zones, number of sprints, and so on. Choosing the best measure is difficult and may depend on the research question. If all are used in separate analyses, researchers should consider the implications of performing so many comparisons surrounding the same research question.
- These data are often collected multiple times across the course of the season, often daily, on the same research subjects. As such, methods that account for multiple observations per subject, such as mixed models, should be used to ensure that assumptions of statistical independence associated with traditional statistical techniques are not violated.

SUMMARY

Although sports analytics have long been a part of sport, their use continues to grow, with emphasis on measuring sports injury and physical aptitude. Most existing epidemiologic and research study designs can be used in the sports setting, but there are special considerations that researchers must take and clinicians reading sports research studies should consider. In particular, researchers should carefully choose what measures of injury occurrence they plan to measure and how these data will be collected, what study design makes the most sense for the research question at hand, and how measures such as "recurrent injury" and "workload" will be defined. With these considerations in mind, a high-quality research study can provide valuable insights into injury prevention and management.

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