Sports injury prevention is complex: We need to invest in better processes, not singular solutions.

Running heading: Re-emphasising the process-driven nature of injury prevention

Review Article

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Abstract

In recent years an understanding has developed that sports injuries are the emergent outcomes of complex, dynamic systems. Thus, the importance of local contextual factors on injury outcomes is increasingly being acknowledged. These realisations place injury prevention research at a crossroads. Currently, injury prevention researchers develop universally applicable injury prevention solutions, but the adoption of these solutions in practice is low. This occurs because implementation contexts are both unique and dynamic in nature, and as a result singular, static solutions are often incompatible. In contrast, practitioners address injury prevention through iterative cycles of trial and error, aiming to optimise the injury prevention process within their own unique contexts. The purpose of this critical review is to draw attention to the misalignment between research and practice-based approaches to injury prevention. In light of this, we propose alternative research approaches that acknowledge the process-driven nature of injury prevention in practice. We propose that a core focus of sport injury prevention research should be to provide practitioners with useful and relevant information to support their decision-making around their localised injury prevention practice. Through this approach injury prevention research ceases to be about what works, and begins to engage with understanding what works in what contexts and why?

Key points

- The contexts in which injury prevention interventions are applied are unique and continuously evolving, and as such transferability of interventions between contexts is always uncertain. Injury prevention interventions must be adaptable to be compatible with these dynamic settings.
- The only way to manage contextual uncertainty is to engage in an iterative process of intervention modification in response to emergent injury outcomes.
- Injury prevention researchers should support this process by providing information on what interventions are efficacious in specific contexts, using empirical evidence to support or challenge theoretical reasoning.

1. Introduction

Sports injury prevention recognises that a change is needed. It is becoming apparent that in a range of sports settings, injury outcomes are not improving, despite considerable effort from both researchers and practitioners [1,2]. A realisation is dawning that injury and its prevention are complex [3,4], and that we need to look to different 'ways of knowing' to better understand the implications thereof [5]. It is becoming increasingly apparent that we need to explore beyond generic 'risk factors' and 'injury mechanisms', and understand the complex interactions of a range of contextual factors that influence injury. Practitioners and researchers often adopt a reductionist approach because it lends to simplicity and causal inference in decision-making [6], but in reality this approach does not fit with the complex nature of the problem [4]. Considering the implications of complexity thinking provides an opportunity to challenge whether conventional research approaches are appropriate, particularly when the needs of practitioners are considered. In this critical review, we question the *outcomes-based* nature of sports injury prevention research and re-emphasise that the *process-driven* nature of injury prevention needs to be a primary consideration in injury prevention research. In particular, we advocate that it is necessary to construct iterative research cycles to ensure that injury prevention interventions that are dynamic and can be successfully applied in broadly different contexts and are able to adapt as these contexts evolve [7].

2. Approach to the problem

The aim of this review was to critically assess the prevailing approaches to injury prevention research. This assessment aimed to challenge whether these approaches align with current conceptual understanding of the nature of injury and it's prevention. Where misalignment was present, solutions and innovation were sought from other areas of research that have dealt with similarly complex problems, with aim of leveraging these solutions to positively influence sports injury prevention research. This research was undertaken to provide the theoretical grounding for a league wide injury surveillance and injury prevention project embedded within a professional sports league. The authors are professional sport scientists with >15 years collective experience working in professional sports environments.

The critical review was developed through a number of distinct stages. The starting point was to review the history and evolution of injury prevention research approaches over time. Secondly, investigation was conducted into the practical challenges to the adoption of these research interventions in practice, providing new interpretation of the existing data where possible. Finally, conceptual development of novel solutions to

adoption and implementation challenges were sought, with a particular emphasis placed on identifying strategies that have been effective in different fields with similarly complex challenges. At each stage of development, relevant publications were initially identified through searches of academic data bases (Pubmed, SPORTDiscus, Google Scholar) using relevant search descriptors (e.g. sport AND injur* AND prevent* OR reduc*). To this end, we sought to identify the most significant items in the field of contemporary thinking within injury prevention research, rather than perform a fully systematic search and exhaustive search, as per established critical review methodology [8]. Therefore, articles were screened for both relevance and relative impact (assessed by citation count over time). These articles were read in full by the first author, and the reference lists were searched to identify further relevant articles. At each stage of the research process, meetings were held among the writing team to discuss the collected material. These meetings lead to the identification of further relevant literature from the authors' libraries and lead to further database searches. This process continued in an iterative fashion until no new themes emerged from the discussions and the writing team reached consensus on the interpretation of the material.

3. The growing importance of context in injury prevention research

Sports injury prevention research aims to devise interventions that reduce the occurrence of injury within the target population. For the purposes of this review interventions are defined as any action, activity or process specifically implemented with the intention of reducing injury, and may include strategies such as neuromuscular training, technique adjustments or education programs. The development of these interventions has a clearly described pathway that has evolved over time to reflect increased understanding of the challenges of injury prevention research. Initially, van Mechelen et al. (1992) described the *sequence of prevention* [9], a process that was primarily focused on determining the *efficacy* of injury prevention interventions - whether the interventions 'work' or not. Yet, asking 'can this intervention work' can be likened to asking "can this football team win?" – the implied premise is inherently flawed because this cannot be a yes or no question in all contexts and in perpetuity, the answer must always be: 'it depends' [10].

Moving towards increased acknowledgment of the influence of context, Finch (2006) developed the *translating research into injury prevention practice* (TRIPP) framework [10]. In this framework, intervention developers aim to describe the context within which the intervention should 'work' (TRIPP stage 5), before assessing the intervention in context (TRIPP stage 6). The TRIPP framework therefore assesses intervention *effectiveness* –

answering the question ‘does this intervention work in context?’ [10]. However, a weakness of this framework is that the intervention is designed under ideal conditions prior to describing and understanding the implementation context. More recently, researchers have noted the necessity to understand and consider both the context [11] and needs of end-users (athletes, coaches, physiotherapists, doctors etc.) [12,13], as starting points within the research process. Indeed, as Bolling et al. (2018) observed, the quality of the “feedstock”, in this case the description of the intervention context, determines the quality of the final product [11].

The realisation of the importance of context in injury prevention leads to two key problems for researchers:

1) Implementation contexts are not interchangeable

   The injury outcomes of a particular individual or team emerge from the complex interactions between people, the physical environment and the social environment [3]. Injury prevention settings are affected by historical, political, social, economic, scientific, cultural, and organizational factors which all interact with each other. These interactions can be described by a socioecological framework that considers the athlete (e.g., genotype, injury history, training history, stress), the team (e.g., tactics, player interactions, coach interactions), the league, the sport, the governing body, and the society within which these factors exist and interact to create injury outcomes [11]. Recognising that intervention contexts arise from the interaction of multiple components that influence each other in unpredictable ways is problematic for the generalizability of injury prevention interventions because while some contexts are similar, no two can be exactly the same. The argument that every context is unique and interventions cannot be generalised should not be overstated because it is clear that some interventions are highly resilient to contextual variation [14]. However, this does not negate the fact that the transferability of interventions to new contexts is always uncertain [15].

2) The dynamic nature of the injury prevention context

   The contexts for injury prevention interventions are rapidly changing. For example, in professional football, high speed running distance has increased by 30% over the past 7 years, while in rugby union the size of youth international players increased dramatically in a 13-year period [16]. In addition, sports governing bodies regularly change the rules of competition [17]. Furthermore, changes in coaching and playing staff within organisations result in constant changes to team tactics, and playing and training approaches which can have profound effects on the physical demands to which athletes are exposed. Changes in staff may also introduce different leadership styles and communication preferences with

coaching and support teams that can further affect injury outcomes [18,19]. Therefore, any static injury prevention intervention will be problematic, because the context it was designed for will rapidly evolve. Injury prevention processes therefore need to be agile to respond to changes in the implementation context.

When these factors are considered, it is not surprising that injury prevention interventions often have variable outcomes, demonstrating effectiveness in in some contexts, and being ineffective in others [20]. This may explain why injury prevention programs that have been proven to be efficacious are often poorly adopted in practice [21-23]. The practitioners involved do not have sufficient evidence to understand whether a particular intervention is likely to be effective in their own context. Within the social sciences, researchers make use of realist evaluation to understand complex social interventions, and do so by asking "What works, for whom, in what circumstances, in what respects and why?" [7]. This approach accepts that the emergent outcomes of interventions in complex systems result from the interaction between the intervention mechanism and the context within which it is applied. Understanding these interactions requires different types of evidence from that typically provided by traditional injury prevention research approaches.

It has been demonstrated that researchers and sporting federations have different research priorities [24,25]. Researchers are primarily concerned with injury surveillance, determining injury mechanisms and developing preventative interventions, while sporting federations are more concerned with better understanding intervention implementation [24,25]. While this information highlights a misalignment between the goals of researchers and sports federations, the ultimate end-users of injury prevention research are practitioners who are responsible for implementing injury prevention practices in their own contexts [25, 26]. For the purposes of this critical review, we consider practitioners to be the coaches, strength and conditioning coaches, medical and support staff responsible for advocating and effecting injury prevention practices in sporting contexts. These practitioners are the key implementers of injury prevention practice [26], and as such it is important to consider whether injury prevention research meets their needs, and be critical of approaches that do not.

4. Traditional injury prevention research methods do not align with the injury prevention process

Historically, sports injury prevention research has taken its lead from established practices in clinical, public health and medical research. Within these fields of research there is an established hierarchy of methodological

quality that prioritizes efficacy studies in the form of randomized controlled trials (RCTs), and meta-analyses of these trials, above other types of research evidence [27,28]. In practice settings, professionals are then encouraged to utilize 'evidence-based practice' to provide the best service for their clients [6,29,30]. Evidence-based practice requires practitioners to use research evidence in conjunction with their professional expertise and knowledge of the constraints of the environment to make treatment decisions [31].

Sports injury prevention research has similarly inherited many of the problems inherent in the translation of this type of evidence into practice – the so-called "research-practice gap" [32,33]. One of the key causes of the research-practice gap is the uni-directionality of research [34,35], where academic researchers provide solutions that are efficacious under ideal conditions to practitioners who are expected to implement them in a broad range of real-world settings. One of the challenges of evidence-based practice is that practitioners working in different contexts may have very different levels of professional experience and expertise (e.g. full-time professional coach vs. a part-time volunteer community coach) that will effect the way in which they interpret and implement research evidence. Inexperienced practitioners may appreciate 'plug and play' interventions that are specific to their context, and may struggle to adapt interventions in the face of resource and environmental challenges. On the other hand, practitioners with high levels of expertise may be able to interpret and adapt interventions to suit their resources and environment, but will find the need to maintain intervention fidelity constraining. Inevitably, any singular intervention will not satisfy the needs of all practitioners, creating mistrust that academic knowledge can offer anything of relevance to practice situations [36]. To address these challenges, researchers could try to produce adaptable interventions that are usable across a continuum of expertise, describing interventions with highly structured, recipe-like applications on one end of the spectrum, and articulatable core intervention components [37] on the other, but this level of sophistication would require ongoing process evaluation research [38]. Unfortunately, in the field of sports injury prevention in many cases intervention development stops following the establishment of intervention efficacy.

Conducting a RCT for sports injury prevention is the equivalent of completing steps 3 and 4 of van Mechelen's sequence of prevention. In recent years there has been a move towards assessing injury prevention interventions in more ecological settings [15,39]. While this shift towards ecological evaluation of interventions is welcome, problems with the generalizability of these interventions to other settings remain. Through these approaches, researchers tend to develop singular and 'final' injury prevention products with the intention of implementing

them in a broad range of settings with minimal adaptation. This assumes that the injury problem can be solved, as if it were an equation [40]. This approach has to lead to interventions that are demonstrably effective, but have disappointing impact due to poor adoption and adherence among end users [21-23]. This is likely because practitioners adopt an entirely different approach to injury prevention.

An alternative to traditional top-down research is the concept of 'practice-based evidence', an approach that accepts that the real world is messy and complicated, but provides a deep understanding of the challenges faced by those delivering injury interventions. Practice-based research acknowledges that efficacy or effectiveness is only one of many pieces of information required to ensure successful intervention implementation [41,42].

In applied settings, the complex nature of injury occurrence means that practitioners will never be able to prevent all injuries and thus will never be able to 'solve' the injury problem. Instead, they assess constraints and risk factors present within their particular context, and make expertise-based judgments regarding the interventions that are most likely to be effective [43,44]. These interventions cannot be assessed as 'right or wrong' and are instead interpreted as 'better or worse' based on the contextual constraints, the level of investment required and positive and negative outcomes achieved [40]. The nature of the injury problem also means that a final solution can never be achieved, but better solutions are always possible [40]. As such, practitioners observe the effects of their injury prevention efforts, make further expertise-based judgments on what is effective or not, adjust their injury prevention strategy, and repeat the cycle in an effort to continually improve. Through these iterative feedback cycles, practitioners develop increasingly better understanding of what injury prevention approaches are most effective in their own context.

An extended example of the conflicts between the traditional approach to injury prevention research and the needs of injury prevention practitioners can be given using the FIFA 11+ injury prevention program. The 'efficacy' of the FIFA 11+ program was established by three successful ecological RCTs in young (13-17 years) amateur Norwegian females [45], young (14-19 years) amateur Nigerian males [46] and adult American collegiate males [47]. One conflicting study showed no effect of the FIFA 11+ intervention on injury rates in veteran (>32 years) German male footballers [48]. Other study types (observational cohort studies) have shown equivocal results [49,50]. Based on this evidence (and meta-analysis corroborating these findings [51]), FIFA (soccer's world governing body) and many national member associations (e.g. Deutscher Fussball-Bund, The German Football

Association) have expended significant resources implementing this program worldwide [52]. However, in practice, uptake and compliance with the FIFA 11+ program has been disappointing [22,53-55]. We would like to make the point that the results of traditional injury prevention research do not provide the information that practitioners need when making decisions about injury prevention implementation. Among other types of information (Table 1), it is particularly important for practitioners to know the following in order to confidently implement an intervention -

1. What are the core intervention components?

   Researchers expect injury prevention interventions to be universally applied as they were designed, maintaining intervention fidelity—the degree to which an experimental manipulation has been implemented as intended [56]. However, as discussed, these interventions are not always a good fit across a broad range of implementation contexts. As a result, practitioners frequently modify interventions to 'fit' within their context [55], but cannot be sure that these modifications do not reduce effectiveness. The term core components to refers to the essential functions or principles, and associated elements and intervention activities that are judged necessary to produce desired outcomes [37]. Identifying the core components of interventions would assist practitioners to understand which program or practice elements are "essential" and which ones can be modified without jeopardizing outcomes. This is now accepted practice within public health settings where complex interventions can be tailored to suit specific intervention contexts [38]. Identifying and validating core components is not a simple task, it requires research over time and replications across multiple sites [37] requiring researchers to remain invested in the research process long after that efficacy of the initial intervention is described. As a practical example, researchers recently showed that performing part 2 (strength, plyometrics, balance) of the FIFA 11+ after practice rather than in the warm up improved compliance and reduced injury burden [57]. This demonstrates that interventions can still be improved after their effectiveness has been established by continuing research to determine what makes them effective.

2. In what contexts was the intervention successful?

   The RCTs that established the efficacy of the FIFA 11+ [45-47] did not describe or control for

training history, injury history, training load or physical characteristics of the participants, all of which can influence the risk of injury. They also did not describe the range of responses. It is likely that within the FIFA 11+ RCTs some teams have experienced high injury rates despite using the 11+, and others experienced low injury rates in the absence of the 11+. Since the contexts in which the FIFA 11+ is most effective are not clearly described it is impossible for practitioners to understand whether the intervention would be effective in their context.

For example, high levels of strength and neuromuscular control are known to be beneficial for both performance and injury prevention [20,58,59], yet neither were controlled for in the FIFA 11+ RCTs. This makes it difficult to interpret whether the 11+ is effective because it improves participant strength, participant neuromuscular control or because of some other mechanism. It is also impossible to know whether the FIFA 11+ remains effective for players who undertake regular neuromuscular and/or strength training, or if it is effective because it provides a proxy for this type of training in groups without access. Practitioners whose teams already engage in regular neuromuscular and/or strength training have no evidence that incorporating the FIFA 11+ will provide any additional benefit.

3. How does the intervention interact with other interventions?

Due to the requirement for RCTs to be rigorously controlled in their execution, RCTs are typically carried out under 'ideal conditions' so that the effect of a particular intervention can be determined. In contrast, practitioners working at the 'coalface' tend to 'overdetermine' [60] their injury prevention strategies by implementing multiple prevention approaches simultaneously (e.g., preventative exercises, training load management, squad rotation, recovery activities) [43,44,54,61-63]. Furthermore, practitioners often consider multiple risk factors (age, previous injury, training load, fascicle length etc.) [65] and attempt to individualise injury prevention interventions based on these [44,65]. The strict experimental structure of RCTs makes it impossible for this type of research to explain how an intervention might interact with other prudent preventative measures.

4. What is the minimum investment necessary for the intervention to be effective?

Understanding the dose–response nature of training and recovery strategies is arguably one of the most important considerations for successful implementation. In order to demonstrate effectiveness, injury prevention researchers may design interventions that are highly demanding of practitioners and/or athletes. This investment can be characterised in terms of time, resources, training load and acute fatigue response. While it is clear that some level of investment will be required to induce a response (e.g. improved strength, improved landing mechanics, reduced fatigue), the cost of this investment needs to be considered. Recently, Fuller (2019) provided an assessment of time invested in injury interventions versus injury days averted demonstrating that most injury prevention interventions do not provide adequate return on investment [66].

In order to determine cost and benefit, practitioners need to understand what the smallest investment likely to obtain an injury reduction might be. For example, it is regularly reported that compliance is essential for the FIFA 11+ to be effective [50,67], but the minimum effective dose [68] has not yet been established. Players are simply instructed to perform the 11+ "before every training session (at least twice per week)" (http://www.f-marc.com/11plus/11plus/). For a team that trains 46 weeks per year, this is onerous and repetitive, and probably drives poor compliance. Practitioners would benefit from knowing whether performing the program less often would be equally effective. It has been demonstrated that hamstring injury prevention can be achieved with a lower volume of Nordic curls than the FIFA 11+ prescribes [69], so it makes sense for practitioners to align with this rather than stick rigidly to the intervention structure.

There is also an argument that for any intervention to be efficient, it should be a replacement of previously existing practice, rather than simply an addition to the current investment. In this sense, an intervention would only be viewed as worthwhile if it: a) improves or maintains the current level of an outcome (e.g., hamstring strength, injury rates, etc.) with substantially reduced investment, or b) substantially improves the current level of an outcome with similar or less investment. This philosophy is common in the evaluation of fitness interventions [70] but is seldom a consideration in the appraisal of an injury prevention programmes.

5. Does the intervention remain effective long-term?

> Most neuromuscular training programs show large improvements in the initial stages of exposure, but diminishing returns over time [71]. It is well established that regular variation in training stimulus is necessary to drive physiological adaptation [72]. All of the RCTs that established the effectiveness of the FIFA 11+ were single season observations. No evidence is available to show whether the program remains effective in subsequent seasons or whether it is subject to diminishing returns.

In short, the current approach to injury prevention research satisfies the needs of injury prevention researchers, but not the end users who are individuals, teams and organisations aiming to reduce injury in their own unique contexts. Is it any wonder that under these conditions, practitioners choose to use their practice-based experience and professional judgement [73] to select and implement bespoke injury prevention interventions, rather than maintaining the fidelity of empirically validated interventions [21-23]? As recently reported, coaches often do not adopt injury prevention programs because they "do not offer a relative advantage over coaches' existing practices." [74]

* * * Table 1 near here * * *

Before the implementation of any intervention is seriously considered, the following three questions should have been answered – 'Can it work? Does it work? Is it worth it? [75]. The first two questions relate to efficacy and effectiveness, and can be answered with the evidence of clinical and ecological controlled trials respectively. These research approaches have high internal validity, but low external validity indicating that the results are highly reproducible, but may not be readily transferred to other contexts [42]. The third question relates to efficiency – whether the effect of the intervention justifies the effort or resource it consumes. This type of question can only be answered through practice-based research and is invaluable to practitioners due to higher levels of external validity [42]. It needs to be recognised that while RCTs remain an essential to the development of injury prevention interventions, they should not be the final step in the research pathway. Increased focus on the production of practice-based evidence will lead to improved better adaptation of that evidence into the real world.

5. Applying implementation science

In response to the poor uptake of traditionally designed injury prevention interventions in practice, a new branch

of injury prevention research has emerged referred to as "implementation science" [76]. The thrust of this field of investigation has been to better understand the barriers to injury prevention program implementation and develop methods to overcome these [22]. Proposed solutions to the implementation problem include further studies to assess intervention adherence [77], coach education programs [74], improved communication strategies [78], increased injury prevention advocacy [53], intervention mapping [13,39] and the establishment of knowledge transfer groups [79]. In addition, economic arguments have been used to drive mandatory implementation by national governing bodies [80]. Implementation science has made meaningful contributions in other fields [81].

While any efforts to improve the translation of research into practice are welcomed, implementation scientists must carefully consider whether the intervention warrants these efforts. If there is a mismatch between the characteristics and resources required by an intervention and those available in the applied setting, no amount of implementation science will overcome this problem [82]. Using the principles of evidence-based practice, in cases where the intervention and environment are incongruent practitioners must use their professional expertise to modify the intervention or select other interventions that are more appropriate (Figure 1). To extend an analogy from a recent publication on this topic [11], if the injury prevention intervention is represented by a Formula 1 car and the intervention context represented by a bumpy country road that the vehicle is ill-designed for, then many implementation science interventions represent an attempt to rebuild the road, rather than to redesign the car.

* * * Figure 1 near here * * *

In situations where the intervention and implementation setting are well suited to each other, implementation science strategies may be highly successful in driving uptake and adoption. For example, Wilke et al. (2018) demonstrated that German football coaches rated the suitability and feasibility of the FIFA 11+ as high within their contexts [78]. In this situation, the major barrier to implementation was awareness of the program and the authors recommended improved communication strategies [78]. On the other hand, in a study of high school soccer and basketball coaches in the USA, the coaches reported that injury prevention interventions were not compatible with the coaches' needs, and difficult to implement in their settings [74]. The authors in this case concluded that improved dissemination on its own would not improve compliance and that issues of compatibility would need to be addressed.

It should be noted that there are a number of important implementation science applications that can take place prior to intervention design that can overcome many of the lack of fit problems described [12,13,79,83,84]. However, even with the best intentions to design contextually relevant interventions, no single solution can possibly be optimal in all situations. Without adaptability built into the interventions implementation scientists will inevitably fail to satisfy all stakeholders.

6. Learning from other industries – success in complex markets

In order to better navigate the challenges of designing injury prevention interventions suitable for a diverse range of real-world contexts, researchers may be able to learn from other industries. In particular, the software development industry places a premium on producing effective product solutions that are rapidly adopted within unpredictable and complex markets. These products may be either bespoke applications for individual users and companies, or mass-market products for broad public use. Central to product development in this context is the need for prototyping.

A prototype is an early sample, model, or release built to test a concept or process or to act as a product to be replicated or learned from [85]. Within software production, it is generally accepted that following product development, the product will still contain a number of known or unknown 'bugs'. This early release product is often referred to as a *beta* version. Despite being imperfect, the *beta* version of the software is released on a small scale to selected users to test and provide feedback, facilitating general improvement to the product before general release. This demonstrates that developers find it impossible to completely describe the complexity of the market environment, and as a result choose to cast uncertainty as inherent in product development. As real-world positive and negative outcomes emerge, these insights inform adaptation, and product design improves in an iterative fashion while the product evolves [86]. A prototyping approach has been previously proposed for the development of sports injury prevention interventions, with the developers noting the need to 'obtain feedback from early implementers' prior to finalising the intervention [83].

In the software industry, the prototyping process has been so effective that a number of notable developers have chosen to never release 'final' versions of their software, preferring to establish 'perpetual *beta*' versions that allow for continuous refinement of the product [87]. Similarly, the field of business management has broadly embraced the principle of 'continuous improvement' [88] or 'Kaizen' [89], a process based model that aims to improve business practices through ongoing iterative PDCA (plan, do, check, adjust) cycles.

As an endorsement of the relevance of the iterative development cycles for injury prevention, a recent commentary on the implications of complexity theory for implementation science noted that "tailored solutions and iterative processes" are essential for the transfer of research evidence into practice [90]. Indeed iterative research cycles have also been proposed by Pawson and Tilley (1997) as essential for increasing understanding of complex problems, and by Tugwell et al (1985) for the evaluation of health interventions [7,91].

It is important to emphasise at this point that conventional approaches to injury prevention were initially described as ongoing, iterative feedback loops [9,10]. As originally envisaged, the efficacy of injury interventions should be repeatedly and continuously assessed through multiple iterations of the sequence of prevention. These repeated cycles of observation are necessary because the introduction of the injury intervention changes the complex system (which itself is constantly evolving), resulting in foreseen and unforeseen consequences [3]. As these real-world outcomes emerge, they provide information that should lead to increased understanding and inform further improvement to the intervention. The conventional approach thus provides clear and compelling steps to effectively addressing complex injury problems. Unfortunately, due to the *outcomes-based* nature of research, these iterative cycles are rarely completed.

It is ironic that a prototyping process was used in the development of the FIFA 11+. Its predecessor, the FIFA 11, was demonstrated to be ineffective in both youth female [92] and senior male [93] populations. Despite these disappointing initial results, these early studies informed later versions of the intervention leading to higher exercise volumes and the inclusion of exercise progressions [51]. However, it seems that once the intervention was shown to be effective, this was presented as a singular, final solution and no further improvements were attempted.

7. Moving forward: Sports injury prevention as a process

Sports injury prevention research needs to move past the idea of finding singular, final 'solutions' to injury problems. In order to be relevant, injury prevention solutions must be adaptable to a range of contexts, and have the ability to evolve as these contexts change over time. When treating complex medical conditions like cancer, medical professionals aim to tailor treatments to be the most suitable for the individual [94]. Why do we then think that a singular sports injury prevention solution will work for all people in all contexts? Injury prevention

research must stop asking ‘What interventions work?’ and start asking ‘What interventions work in which contexts, and why?’. Learning why particular interventions are or are not successful in particular contexts enhances both understanding of the intervention mechanism and of the contextual factors that contributed to the success or failure.

This article was written with the intention of reminding injury prevention researchers of the process-driven nature of injury prevention. Understanding injury prevention as a process requires researchers to set up iterative and ongoing feedback loops that embrace learning from previous intervention cycles. This approach (designated the team-sport injury prevention [TIP] cycle) is aligned with the actual processes that team sports medical practitioners engage in [44], and has been shown to be effective in injury reduction [43,95]. A pertinent example of this approach is the success of the RugbySmart campaign in New Zealand, which has recently noted that conducting research on program effectiveness and using this information to modify the program and responding to facilitator and participant feedback were essential to that program’s success [95].

Coordinating this approach across multiple research sites would provide knowledge of the effectiveness of interventions across a range of contexts. This approach is illustrated in Figure 2. In this process approach, the intervention is not cast as a final solution, but rather as a step in the ‘product development’ pathway. Each iteration of the intervention cycle leads to improved understanding of the problem and informs future prevention efforts. When the intervention cycle is implemented in new contexts, further information regarding the core intervention components and degrees of freedom available for adaptation of the intervention emerge, informing further adaptations to improve efficacy in context. Through this approach, injury prevention research becomes less about whether an individual intervention ‘works’ or not, but more about how well it works within a system or process, whether it can be improved, and how. The product of this process based approach is a continually evolving and adaptable intervention that can be confidently articulated to be effective in a range of contexts.

* * * Figure 2 near here * * *

8. Harnessing the process model for research

This section discusses approaches that could be used to operationalize the process model for injury prevention in research. On the smallest scale, it should be recognised that there is value in single team practice-based research,

particularly if this can be conducted longitudinally over multiple seasons. This approach allows for the description of specific intervention contexts [11], the implementation of bespoke pilot interventions within these contexts, and meaningful interpretation of the successes or failures of these interventions. This research should not aim to overly regulate interventions, or to sanitise the context, but must rather observe and describe interventions in context as they evolve and adapt. It is in this space where practitioners have the opportunity to address the research-practice gap by providing much needed practice-based evidence to supplement the evidence base. Practice-based researchers (practitioners with research training) have an important role to play in this process because they are uniquely placed to understand the needs of end-users and the necessary research processes [12]. One challenge to this type of research is that many experts working in practice do not have the time to document and report their developing understanding of effective injury prevention in their own context. One potential solution to this problem is the emergence of a quick review online practitioner journal where case studies can be easily published (https://sportperfsci.com).

On a larger scale, league wide injury surveillance is becoming common in many sports [96] (e.g. England's Professional Rugby Injury Surveillance Project, and the UEFA's Elite Clubs Injury Study). Typically, these epidemiological data report the average injury incidence and burden in a sample population, but do not explore what is happening in teams or organisations that are well above or well below the mean. Applying a "bright spots" approach where *observable exceptions* that *produce results above the norm with only the same kinds of resource* [97] are investigated to understand why they are successful can be a powerful tool for injury prevention research. Qualitative research could describe the processes that teams and organisations who are successful in injury prevention adopt, explaining how these results are achieved and why they are efficacious in those settings. This type of research has clearly enhanced medical practice in a number of areas [98], and could be similarly effective in encouraging improved practice in sports injury prevention.

These co-ordinated league-wide surveillance projects also present opportunities to leverage research approaches from clinical and public health structures that have addressed similarly complex problems. In particular, practical clinical trials [99], and community-based participatory research (CBPR) [100] are approaches which could be fruitful areas for research that is useful to practitioners.

Practical clinical trials deliberately compare alternative interventions in diverse contexts to provide data that inform decision making for end users. This research approach has been demonstrated to provide rapid and contextually relevant research outcomes for practitioners [101] but requires significant resource to complete.

Community-based participatory research relies on the development of collaborative partnerships that equitably and actively involve community partners (in this case sports teams) in all aspects of the research process. Since teams are likely to benefit from reduced injury burden, it may be possible to include a number of teams in the iterative process of data collection, intervention development, and evaluation, provided that interventions are adaptable to the team context and adequate support is provided [102]. The principles of CBPR include the following [100]:

a. Build on strengths and resources within the community
b. Integrate knowledge and action for mutual benefit of all partners, which draws attention to local social, cultural, and political issues
c. Promote a co-learning and empowering process between the research team and community collaborators, which can anticipate and bridge gaps between program design and eventual adoption settings/populations
d. Use a cyclical and iterative intervention development and evaluation process that allows integration of new knowledge
e. Address health from both positive and ecological perspectives, identifying factors across multiple levels that influence study outcomes
f. Disseminate findings and knowledge gained to all partners, so that no one member of the team has "ownership" of the outcome data or its interpretation
g. Facilitate collaborative, equitable involvement of all partners in all phases of the research.

The CBPR approach allows for interventions to be applied in multiple settings, and allows for practitioners within those settings to use their experience and expertise to make appropriate modification to the intervention to ensure its 'fit' within that context. This approach recognises the expertise of practitioners working in these environments who integrate the best currently available scientific evidence with professional expertise and experience to produce pragmatic solutions for their context [64,83], thus diminishing the gap between researchers and practitioners.

In conjunction with both these research approaches, it would be useful to conduct process evaluation research in parallel [67]. While practical clinical trials and CBPR will provide information on what interventions work best in different contexts, process evaluation research is likely to provide valuable information regarding what was actually done in each setting (fidelity), likely mechanisms of effect and how contextual factors affect implementation. Again, this information is highly aligned with the needs of practitioners who are responsible for making decisions regarding the implementation of injury prevention measures.

9. Conclusion

Sports injury prevention research needs to move past the idea of finding singular, final 'solutions' to injury problems, and acknowledge that multiple, evolving initiatives are viable across complex contexts. Intervention developers must adopt iterative feedback processes that embrace uncertainty and hold space for the evolution of interventions in context. In this way, sports injury prevention *as a process* has real-world responsiveness, and requires a different framing. The outcome, then, does not lie in definitive solutions, but rather in what we can learn from the process of intervention. This places the focus sharply on understanding the *process* of (ongoing) intervention, rather than measuring the (final) *outcome* product.

References

1. Rafferty J, Ranson C, Oatley G, Mostafa M, Mathema P, Crick T, et al. On average, a professional rugby union player is more likely than not to sustain a concussion after 25 matches. Br J Sports Med. 2018; https://doi.org/10.1136/bjsports-2017-098417

2. Ekstrand J, Waldén M, Hägglund M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. Br J Sports Med. 2016;50:731-7.

3. Bekker S, Clark AM. Bringing complexity to sports injury prevention research: from simplification to explanation. Br J Sports Med. 2016;50:1489-1490.

4. Bittencourt NFN, Meeuwisse WH, Mendonça LD, Nettel-Aguirre A, Ocarino JM, Fonseca ST. Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition narrative review and new concept. Br Journal Sports Med. 2016;50:1309-1314.

5. Slade SC, Patel S, Underwood M, Keating JL. Rigorous qualitative research in sports, exercise and musculoskeletal medicine journals is important and relevant. Br J Sports Med. 2017;52:1409-10.

6. Jeffreys I. Evidence based practice in strength and conditioning - reality or fantasy. Professional Strength and Conditioning. 2015;39:7-14.

7. Pawson R, Tilley N. Realistic Evaluation. Los Angeles: Sage, 1997.

8. Grant MJ, Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Information & Libraries Journal, 2009;26:91-108.

9. Van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. Sports Med. 1992;14:82-99

10. Finch C. A new framework for research leading to sports injury prevention. J Sci Med Sport. 2006;9:3-9.

11. Bolling C, van Mechelen W, Pasman HR, Verhagen E. Context matters: revisiting the first step of the 'sequence of prevention' of sports injuries. Sports Med. 2018; https://doi.org/10.1007/s40279-018-0953-x

12. Jones B, Till K, Emmonds S, Hendricks S, Mackreth P, Darrall-Jones J, et al. Accessing off-field brains in sport; an applied research model to develop practice. Br J Sports Med. 2017; https://doi.org/10.1136/bjsports-2016-097082

13. Donaldson A, Finch CF. Planning for implementation and translation: seek first to understand the end-users' perspectives. Br J Sports Med. 2012;46:306-7.

14. Donnell-Fink LA, Klara K, Collins JE, Yang HY, Goczalk MG, Katz JN, et al. Effectiveness of knee injury and anterior cruciate ligament tear prevention programs: a meta-analysis. PLoS One. 2015;10:e0144063 https://doi.org/10.1371/journal.pone.0144063

15. Evans RE, Craig P, Hoddinott P, Littlecott H, Moore L, Murphy S, et al. When and how do 'effective' interventions need to be adapted and/or re-evaluated in new contexts? The need for guidance. J Epidemiol Community Health. 2019; https://doi.org/10.1136/jech-2018-210840

16. Lombard WP, Durandt JJ, Masimla H, Green M, Lambert MI. Changes in body size and physical characteristics of South African under-20 rugby union players over a 13-year period. J Strength Cond Res. 2015;29:980-8.

17. Tucker R, Raftery M, Kemp S, Brown J, Fuller G, Hester B, et al. Risk factors for head injury events in professional rugby union: a video analysis of 464 head injury events to inform proposed injury prevention strategies. Br J Sports Med. 2017;51:1152-1157.

18. Ekstrand J, Lundqvist D, Lagerbäck L, Vouillamoz M, Papadimitiou N, Karlsson J. Is there a correlation between coaches' leadership styles and injuries in elite football teams? A study of 36 elite teams in 17 countries. Br J Sports Med. 2018;52:527-531.

19. Ekstrand J, Lundqvist D, Davison M, D'Hooghe M, Pensgaard AM. Communication quality between the medical team and the head coach/manager is associated with injury burden and player availability in elite football clubs. Br J Sports Med. 2019;53:304-308

20. Lauersen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. Br J Sports Med. 2014;48:871-7.

21. Bahr R, Thorborg K, Ekstrand J. Evidence-based hamstring injury prevention is not adopted by the majority of Champions League or Norwegian Premier League football teams: the Nordic Hamstring survey. Br J Sports Med. 2015;49:1466-71.

22. O'Brien J, Young W, Finch CF. The delivery of injury prevention exercise programmes in professional youth soccer: Comparison to the FIFA 11. J Sci Med Sport. 2017;20:26-31.

23. Read PJ, Oliver JL, De Ste Croix MBA, Myer GD, Lloyd RS. An audit of injuries in six English professional soccer academies. J Sports Sci. 2018;36:1542-1548.

24. Finch CF, Talpey S, Bradshaw A, Soligard T, Engebretsen L. Research priorities of international sporting federations and the IOC research centres. BMJ Open Sport Exerc Med. 2016;2:e000168 https://doi.org/10.1136/bmjsem-2016-000168

25. Finch CF. Whose research agenda is it? Reconciling the views of researchers and sports stakeholders. Br J Sports Med. 2017;51:3-4.

26. O'Brien J, Finch CF. Injury prevention exercise programs for professional soccer: understanding the perceptions of the end-users. Clin J Sport Med. 2017;27:1-9.

27. Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults--The Evidence Report. National Institutes of Health. Obes Res. 1998;6 Suppl 2:51S-209S

28. MRC Health Services and Public Health Research Board. A Framework for development and evaluation of RCTs for Complex Interventions to Improve Health. April, 2000.

29. English KL, Amonette WE, Graham M, Spiering BA. What is "evidence-based" strength and conditioning? Strength Cond J. 2012;34:19.

30. Scurlock-Evans L, Upton P, Upton D. Evidence-based practice in physiotherapy: a systematic review of barriers, enablers and interventions. Physiotherapy. 2014;100:208-19.

31. Straus SE, Glasziou P, Richardson WS, Haynes RB. Evidence-based medicine: how to practice and teach EBM. 5th ed. China: Elsevier, 2018.

32. Lenfant C. Clinical research to clinical practice - lost in translation? N Engl J Med. 2003;349:868-74.

33. Rolfe G. The theory-practice gap in nursing: from research-based practice to practitioner-based research. J Adv Nurs. 1998;28:672-9.

34. Bishop D. An applied research model for the sport sciences. Sports Med. 2008;38:253-63.

35. Pryjmachuk S. A nursing perspective on the interrelationships between theory, research and practice. J Adv Nurs. 1996;23:679-84.

36. Schön DA. The reflective practitioner: how professionals think in action. London: Temple Smith; 1983.

37. Blase K, Fixsen D. Core Intervention Components: Identifying and Operationalizing What Makes Programs Work. ASPE Research Brief. *US Department of Health and Human Services*. 2013

38. Moore GF, Audrey S, Barker M, Bond L, Bonell C, Hardeman W, et al. Process evaluation of complex interventions: Medical Research Council guidance. BMJ. 2015;350:h1258 https://doi.org/10.1136/bmj.h1258

39. Finch CF. No longer lost in translation: the art and science of sports injury prevention implementation research. Br J Sports Med. 2011;45:1253-7.

40. Rittel HWJ, Webber MM. 1973, Dilemmas in a general theory of planning, Policy Sciences. 1973;4:155-169.

41. Ammerman A, Smith TW, Calancie L. Practice-based evidence in public health: improving reach, relevance, and results. Ann Rev Public Health. 2014;35:47-63.

42. Green LW. Closing the chasm between research and practice: evidence of and for change. Health Promot J of Austr. 2014;25: 25-29.

43. Tee JC, Bekker S, Collins R, Klingbiel J, van Rooyen I, van Wyk D, et al. The efficacy of an iterative "sequence of prevention" approach to injury prevention by a multidisciplinary team in professional rugby union. J Sci Med Sport. 2018;21:899-904.

44. O'Brien J, Finch CF, Pruna R, McCall A. A new model for injury prevention in team sports: the Team-sport Injury Prevention (TIP) cycle. Science and Medicine in Football. 2018; https://doi.org/10.1080/24733938.2018.1512752

45. Soligard T, Myklebust G, Steffen K, Holme I, Silvers H, Bizzini M, et al. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. BMJ. 2008;337:a2469.

46. Owoeye OB, Akinbo SR, Tella BA, Olawale OA. Efficacy of the FIFA 11+ Warm-Up Programme in male youth football: a cluster randomised controlled trial. J Sports Sci Med. 2014;13:321-8.
47. Silvers-Granelli H, Mandelbaum B, Adeniji O, Insler S, Bizzini M, Pohlig R, et al. Efficacy of the FIFA 11+ Injury Prevention Program in the Collegiate Male Soccer Player. Am J Sports Med. 2015;43:2628-37.
48. Hammes D, Aus der Fünten K, Kaiser S, Frisen E, Bizzini M, Meyer T. Injury prevention in male veteran football players - a randomised controlled trial using "FIFA 11+". J Sports Sci. 2015;33:873-81.
49. Grooms DR, Palmer T, Onate JA, Myer GD, Grindstaff T. Soccer-specific warm-up and lower extremity injury rates in collegiate male soccer players. J Athl Train. 2013;48:782-9.
50. Soligard T, Nilstad A, Steffen K, Myklebust G, Holme I, Dvorak J, et al. Compliance with a comprehensive warm-up programme to prevent injuries in youth football. Br J Sports Med. 2010;44:787-93.
51. Thorborg K, Krommes KK, Esteve E, Clausen MB, Bartels EM, Rathleff MS. Effect of specific exercise-based football injury prevention programmes on the overall injury rate in football: a systematic review and meta-analysis of the FIFA 11 and 11+ programmes. Br J Sports Med. 2017;51:562-571.
52. Bizzini M, Dvorak J. FIFA 11+: an effective programme to prevent football injuries in various player groups worldwide-a narrative review. Br J Sports Med. 2015;49:577-9.
53. Owoeye OBA, Akinbo SRA, Olawale OA, Tella BA, Ibeabuchi NM. Injury prevention in football: Knowledge and behaviour of players and availability of medical care in a Nigerian youth football league. S Afr J Sports Med. 2013;25:77-80.
54. Meurer MC, Silva MF, Baroni BM. Strategies for injury prevention in Brazilian football: Perceptions of physiotherapists and practices of premier league teams. Phys Ther Sport. 2017;28:1-8.
55. O'Brien J, Young W, Finch CF. The use and modification of injury prevention exercises by professional youth soccer teams. Scand J Med Sci Sports. 2017;27:1337-1346.
56. Taylor KL, Weston M, Batterham AM. Evaluating intervention fidelity: an example from a high-intensity interval training study. PLoS One. 2015;10:e0125166 https://doi.org/10.1371/journal.pone.0125166
57. Whalan M, Lovell R, Steele JR, Sampson JA. Rescheduling Part 2 of the 11+ reduces injury burden and increases compliance in semi-professional football. Scand J Sci Med Sports. 2019; doi: 10.1111/sms.13532
58. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. Sports Med. 2016;46:1419-49.

59. Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo AJ, McLean SG, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. Am J Sports Med. 2005;33:492-501.

60. Grenny J, Patterson K, Maxfield D, McMillan R, Switzler A. Influencer: the New Science of Leading Change. 2nd ed. New York: McGraw-Hill Publishing; 2013.

61. Wilke J, Niederer D, Vogt L, Banzer W. Head coaches' attitudes towards injury prevention and use of related methods in professional basketball: A survey. Phys Ther Sport. 2018;32:133-139.

62. Read PJ, Jimenez P, Oliver JL, Lloyd RS. Injury prevention in male youth soccer: Current practices and perceptions of practitioners working at elite English academies. J Sports Sci. 2018;36:1423-31.

63. McCall A, Carling C, Nedelec M, Davison M, Le Gall F, Berthoin S, et al. Risk factors, testing and preventative strategies for non-contact injuries in professional football: current perceptions and practices of 44 teams from various premier leagues. Br J Sports Med. 2014;48:1352-7.

64. Buchheit M, Eirale C, Simpson BM, Lacome M. Injury rate and prevention in elite football: let us first search within our own hearts. Br J Sports Med. 2018; https://doi.org/10.1136/bjsports-2018-099267

65. Roe M, Malone S, Blake C, Collins K, Gissane C, Büttner F, et al. A six stage operational framework for individualising injury risk management in sport. Inj Epidemiol. 2017;4:26.

66. Fuller CW. Assessing the return on investment of injury prevention procedures in professional football. Sports Med. 2019; https://doi.org/10.1007/s40279-019-01083-z

67. Steffen K, Emery CA, Romiti M, Kang J, Bizzini M, Dvorak J, et al. High adherence to a neuromuscular injury prevention programme (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players: a cluster randomised trial. Br J Sports Med. 2013;47:794-802.

68. Bickel CS, Cross JM, Bamman MM. Exercise dosing to retain resistance training adaptations in young and older adults. Med Sci Sports Exerc. 2011;43:1177-87.

69. van der Horst N, Smits DW, Petersen J, Goedhart EA, Backx FJ. The preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer players: a randomized controlled trial. Am J Sports Med. 2015;43:1316-23.

70. Macpherson TW, Weston M. The effect of low-volume sprint interval training on the development and subsequent maintenance of aerobic fitness in soccer players. Int J Sports Physiol Perform. 2015;10:332-8.

71. Harries SK, Lubans DR, Callister R. Systematic review and meta-analysis of linear and undulating periodized resistance training programs on muscular strength. J Strength Cond Res. 2015;29:1113-25.

72. Issurin VB. New horizons for the methodology and physiology of training periodization. Sports Med. 2010;40:189-206.

73. Ardern CL, Dupont G, Impellizzeri FM, O'Driscoll G, Reurink G, Lewin C, et al. Unravelling confusion in sports medicine and sports science practice: a systematic approach to using the best of research and practice-based evidence to make a quality decision. Br J Sports Med. 2019;53:50-56.

74. Norcross MF, Johnson ST, Bovbjerg VE, Koester MC, Hoffman MA. Factors influencing high school coaches' adoption of injury prevention programs. J Sci Med Sport. 2016;19:299-304.

75. Haynes B. Can it work? Does it work? Is it worth it? The testing of healthcare interventions is evolving. BMJ. 1999;319:652-3.

76. Donaldson A, Finch CF. Applying implementation science to sports injury prevention. Br J Sports Med. 2013;47:473-5.

77. Owoeye OBA, McKay CD, Verhagen EALM, Emery CA. Advancing adherence research in sport injury prevention. Br J Sports Med. 2018;52:1078-79.

78. Wilke J, Niederer D, Vogt L, Banzer W. Is the message getting through? Awareness and use of the 11+ injury prevention programme in amateur level football clubs. PLoS One. 2018;13:e0195998 https://doi.org/10.1371/journal.pone.0195998

79. Verhagen E, Voogt N, Bruinsma A, Finch CF. A knowledge transfer scheme to bridge the gap between science and practice: an integration of existing research frameworks into a tool for practice. Br J Sports Med. 2014;48:698-701.

80. Rössler R, Verhagen E, Rommers N, Dvorak J, Junge A, Lichtenstein E, et al. Comparison of the '11+ Kids' injury prevention programme and a regular warmup in children's football (soccer): a cost effectiveness analysis. Br J Sports Med. 2019;53:309-14.

81. Owen N, Glanz K, Sallis JF, Kelder SH. Evidence-based approaches to dissemination and diffusion of physical activity interventions. Am J Prev Med. 2006;31:S35-44.

82. Glasgow RE, Emmons KM. How can we increase translation of research into practice? Types of evidence needed. Annu Rev Public Health. 2007;28:413-33.

83. Donaldson A, Lloyd DG, Gabbe BJ, Cook J, Young W, White P, et al. Scientific evidence is just the starting point: A generalizable process for developing sports injury prevention interventions. J of Sport Health Sci 2016;5:334-341.

84. Hanson D, Allegrante JP, Sleet DA, Finch CF. Research alone is not sufficient to prevent sports injury. Br J Sports Med. 2014:48:682-4.

85. Blackwell A, Manar E. "Prototype". UXL Encyclopedia of Science. 3rd ed. UXL, 2015.

86. Dow SP, Glassco A, Kass J, Schwarz M, Schwartz DL, Klemmer SR. Parallel prototyping leads to better design results, more divergence, and increased self-efficacy. ACM Transactions on Computer-Human Interaction. 2010;17:1-24.

87. Constantinides E, Fountain SJ. Web 2.0: Conceptual foundations and marketing issues. Journal of Direct, Data and Digital Marketing Practice. 2008;9:231-244.

88. Fryer KJ, Antony J, Douglas A. Critical success factors of continuous improvement in the public sector: a literature review and some key findings. *The TQM Magazine*, 2007;19:497-517.

89. Masaaki I. Kaizen: The key to Japan's competitive success. 1986. *New York, ltd: McGraw-Hill*.

90. Braithwaite J, Churruca K, Long JC, Ellis LA, Herkes J. When complexity science meets implementation science: a theoretical and empirical analysis of systems change. BMC Med. 2018;16:63 https://doi.org/10.1186/s12916-018-1057-z

91. Tugwell P, Bennett KJ, Sackett DL, Haynes RB. The measurement iterative loop: a framework for the critical appraisal of need, benefits and costs of health interventions. Journal of chronic diseases. 1985;38,339-351.

92. Steffen K, Myklebust G, Olsen OE, Holme I, Bahr R. Preventing injuries in female youth football--a cluster-randomized controlled trial. Scand J Med Sci Sports. 2008;18:605-14.

93. van Beijsterveldt AM, van de Port IG, Krist MR, Schmikli SL, Stubbe JH, Frederiks JE, et al. Effectiveness of an injury prevention programme for adult male amateur soccer players: a cluster-randomised controlled trial. Br J Sports Med. 2012;46:1114-8.

94. McDermott U, Settleman J. Personalized cancer therapy with selective kinase inhibitors: an emerging paradigm in medical oncology. J Clin Oncol. 2009;27:5650-9.

95. Quarrie K, Gianotti S, Murphy I, Harold P, Salmon D, Harawira J. RugbySmart: Challenges and lessons from the implementation of a nationwide sports injury prevention partnership program. Sports Med. 2019; https://doi.org/10.1007/s40279-019-01177-8

96. Ekegren CL, Gabbe BJ, Finch CF. Sports injury surveillance systems: a review of methods and data quality. Sports Med. 2016;46:49-65.

97. Pascale RT, Sternin J, Sternin M. The power of positive deviance: how unlikely innovators solve the world's toughest problems. Boston, Mass.: Harvard Business Press; 2010.
98. Ziebland S, Locock L, Fitzpatrick R, Stokes T, Robert G, O'Flynn N, et al. Informing the development of NICE (National Institute for Health and Care Excellence) quality standards through secondary analysis of qualitative narrative interviews on patients' experiences. Southampton (UK): NIHR Journals Library; November, 2014.
99. Tunis SR, Stryer DB, Clancy CM. Practical clinical trials: increasing the value of clinical research for decision making in clinical and health policy. JAMA. 2003;290:1624-32.
100. Israel BA, Schulz AJ, Parker EA, Becker AB. Review of community-based research: assessing partnership approaches to improve public health. Annu Rev Public Health. 1998;19:173-202.
101. Glasgow RE, Kessler RS, Ory MG, Roby D, Gorin SS, Krist A. Conducting rapid, relevant research: lessons learned from the My Own Health Report project. Am J Prev Med. 2014;47:212-9.
102. Ekegren CL, Donaldson A, Gabbe BJ, Finch CF. Implementing injury surveillance systems alongside injury prevention programs: evaluation of an online surveillance system in a community setting. *Injury epidemiology*, 2014;1:19

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Compliance with Ethical Standards

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Conflict of interests

Jason Tee, Ben Jones and Shaun McLaren declare that they have no conflicts of interest relevant to the content of this review.

Figures

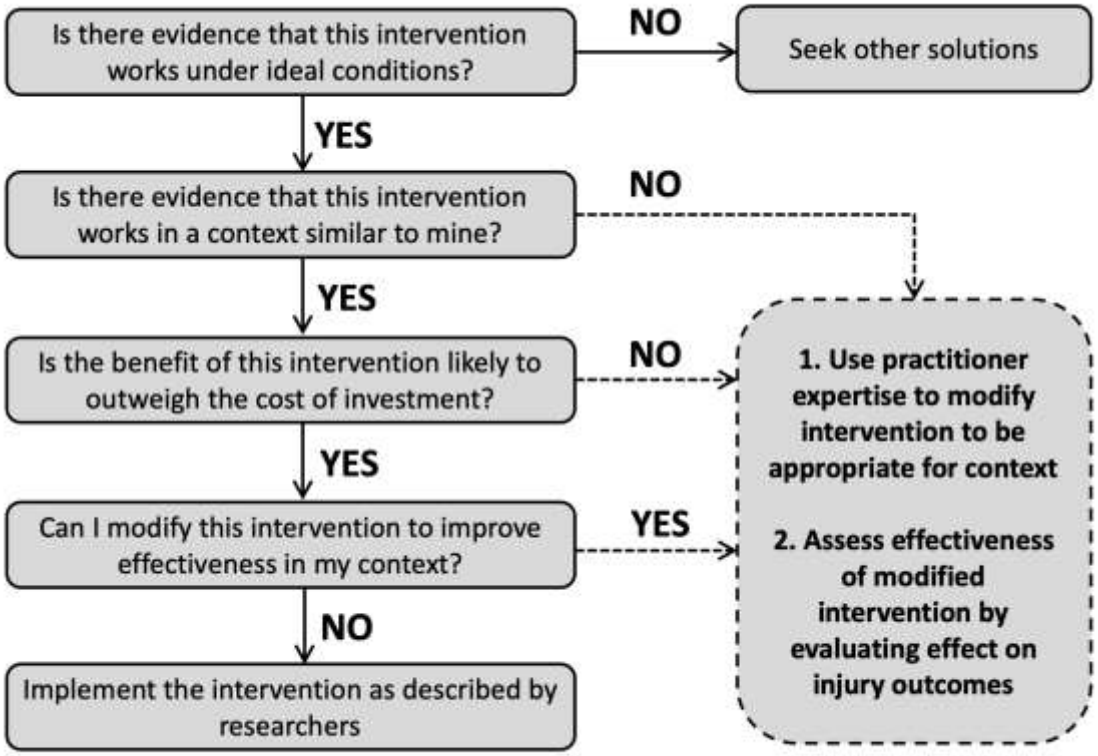

Fig 1 Representative decision making flow chart for practitioners considering whether to implement and injury prevention intervention

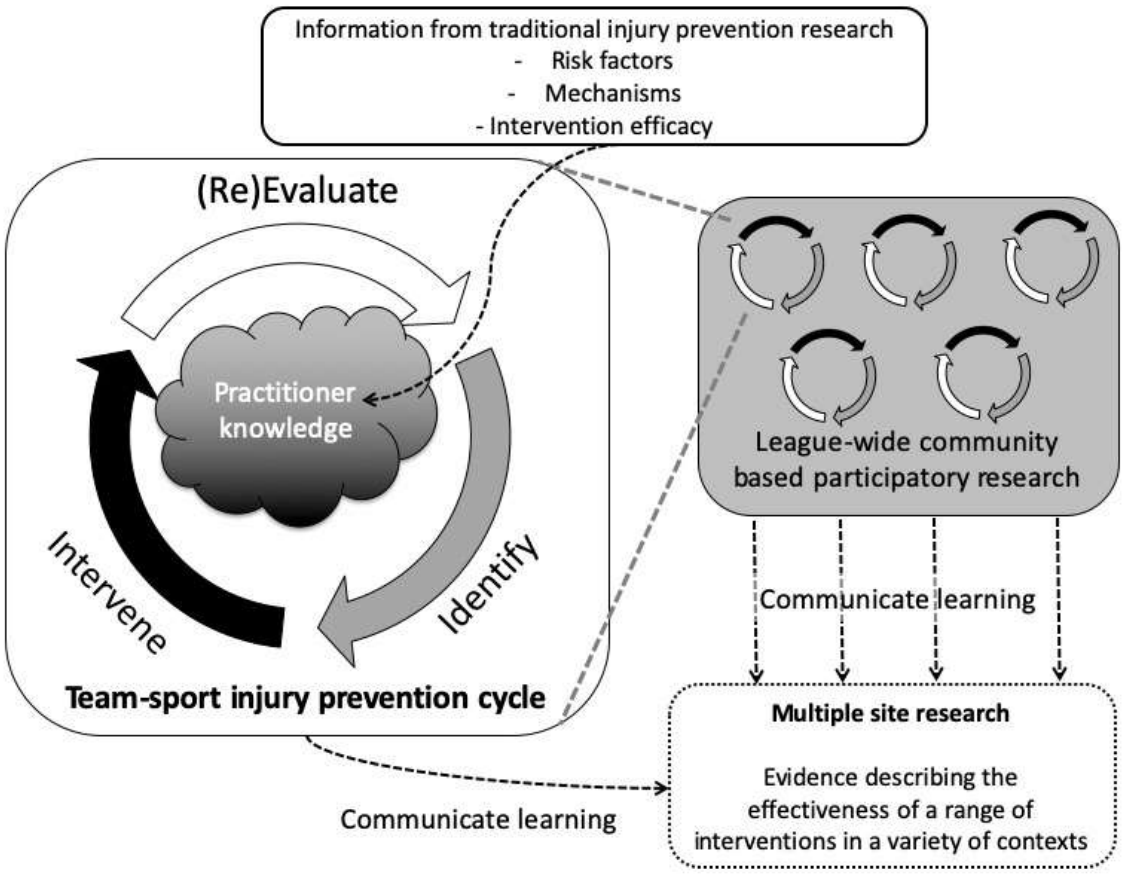

Fig 2 Utilising the team-sport injury prevention cycle as a feedback loop to inform the continuous development of injury prevention interventions in context

Table 1 Types of information that will be useful for injury prevention research end users (coaches, administrators and medical staff) in determining implementation strategies.

Information type	**Type of research required**	**Reasoning**
Injury etiology	Risk factors and mechanisms	How does this injury occur in my context?
Can the intervention work?	Randomised controlled trial	If an intervention doesn't work under highly controlled settings, it is unlikely to work in the real world.
Does the intervention work in other real world settings?	Ecological controlled trial	If it works in another setting it might work for me.
In what contexts is the intervention effective? – Level of competition – Training history – Injury history – Experience – Resources available – Physical ability (e.g. strength or aerobic ability) – Training schedule – Match frequency and exposure	Ecological controlled trial Single team case studies Community-based participatory research	Information about how different a context is to the practitioner's context assists judgements regarding the likelihood of success.
How does the intervention interact with other preventative measures?	Single team case studies Community-based participatory research Practical clinical trials Process evaluation research	Supports judgement around the implementation of new preventative measures around established practices.
Range of effects	Ecological controlled trial Single team case studies Community-based participatory research	Supports analysis of cost vs. potential benefit of implementation
Minimum effective dose	Dose response trial Process evaluation research	How much effort is required to obtain the desired effect?
Parameters available for intervention modification	Process evaluation research Single team case studies Community-based participatory research	Can I modify this intervention to fit within my context?
Is this intervention subject to diminishing returns?	Longitudinal studies	Will this remain effective, or does it need to evolve?
Feasibility	Process evaluation research Single team case studies Ecological controlled trial Qualitative research	Can this be implemented in my context?
Cost and economic analysis	Cost-effectiveness analysis	Can we afford to implement this?
Why has this intervention been successful/unsuccessful in other contexts?	Process evaluation research Single team case studies Qualitative research Community-based participatory research	How or why did this intervention work? Can we replicate those conditions?