THE COMPLEXITY OF BEES, BICYCLES, AND INJURIES

AN OVERVIEW OF THE PREVENTION PARADIGM SHIFT AND ADVICE FOR CLINICAL PRACTICE

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INTRODUCTION

Those working in the sport and exercise medicine community are continuously trying to improve and refine ways to protect the health of athletes and minimise the risk of injury. We are experiencing a shift in general healthcare from curative disease management to practicing preventative evidence based medicine[1]. And although this focuses on chronic health diseases such as diabetes, arthritis, and cancer, the shift towards prevention is also evident in sports medicine[2,3]. Unfortunately, injury rates across different sports have not changed[4,5], and we are in need of a radical paradigm shift in our approach to injury prevention.

It has been over 30 years since the injury prevention research model was first defined by van Mechelen et al[6], creating a framework for injury prevention. The model suggests three steps:

1. identify the magnitude of the problem (incidence or severity),
2. ascertain the aetiological risk factors or injury mechanism responsible, and based on these findings
3. introduce a preventative measure to address the injury occurrence. Finally, the effect of the intervention is evaluated by repeating the first step.

The causation model proposed by Meeuwisse et al further developed our understanding of injury risk by accounting for the interaction of multiple risk factors, both intrinsic and extrinsic[7]. Bahr and Krosshaug expanded on the characteristics of the injury mechanism during the inciting event as a component of the causal pathway[8]. The causation model was later updated to capture the non-linearity of sports injury in the dynamic recursive model[9]. This allows for the potential of the inciting event to change the athlete's intrinsic risk factors and their predisposition to injury. This model moved beyond the simple identification of extrinsic and intrinsic factors that might be associated with injury. Finch et al advanced this model further by addressing implementation and effectiveness of such interventions, through the Translating Research into Injury Prevention Practice (TRIPP) framework[10]. In this framework, two important steps were added before repeating step one - determining the ideal
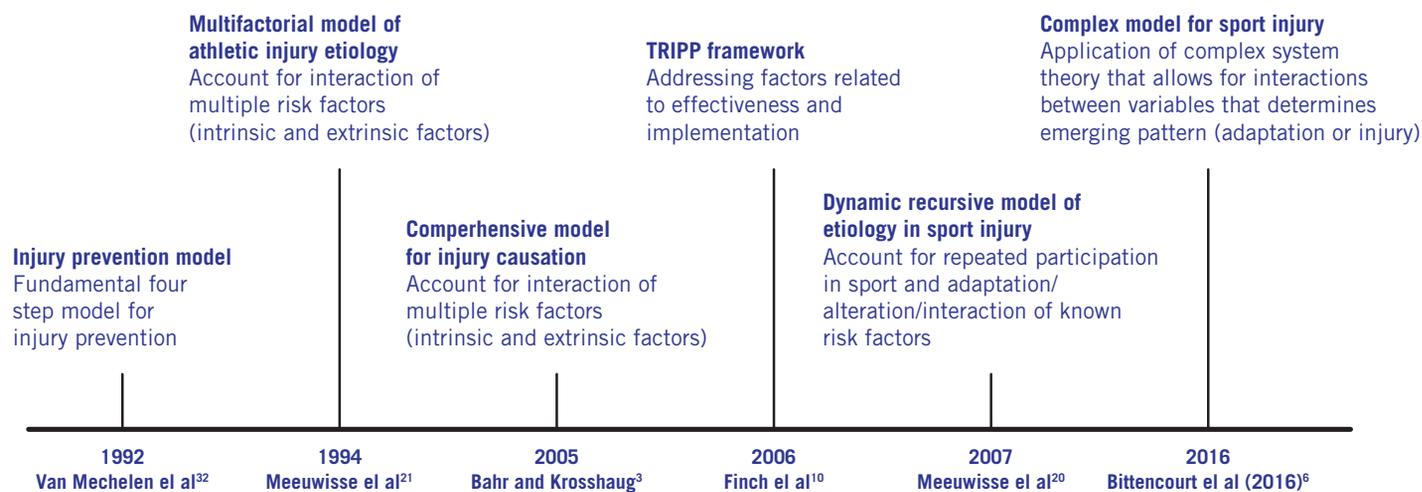
Figure 1: Temporal development of injury prevention models, with key characteristics for each model highlighted (with permission).

conditions to perform the preventative measure, and evaluating the effectiveness of the prevention programme in an implementation context. A summary of these injury prevention models and their key characteristics can be found in Figure 1.

A vital part of all these models is the identification of risk factors that may predispose the athlete to injury. However, risk factor analysis is still presented as the breakdown of the big problem (injury) into smaller units (risk factors), which resolved through analyses and rational deduction. This represents an oversimplified, reductionist view of the problem. What is required is greater awareness of the complexity involved in sports injuries, with newer models outlining how these factors mediate, moderate, and interact with each other[11].

In 2009, the International Olympic committee (IOC) released a consensus statement regarding the use of periodic health evaluations, commonly referred to as "screening." It suggested screening to be set up as research projects, and called for future research to perform large-scale population-based studies to "evaluate the components of history and examination that can be used to identify athletes at risk, intervene, and change outcome[12]." In agreement with this recommendation, the Aspetar Injury and Illness Prevention Programme (ASPREV) was initiated at Aspetar, with similar projects performed all over the world. The results from these studies regrettably highlight the

ineffectiveness of our current approach to risk factor identification and analysis.

The purpose of this article is to present examples of simple injury prevention programmes that work, highlight some reasons for the inefficiencies within these programmes, and propose the paradigm shift needed in our understanding of injury risk.

WHY OUR CURRENT MODELS DON'T WORK - THE (LACK OF) CLINICAL UTILITY IN STATISTICALLY SIGNIFICANT RESULTS

When statistically significant results are reported, we need to establish how well these findings translate into clinical practice. To illustrate, let us consider the incidence for hamstring injuries in Qatar, reported as 11%[13]. This is known as the "base rate" for hamstring injury in this population. Eccentric hamstring strength is often found to be a significant risk factor for hamstring injury; in this population reported with an odds ratio of 1.37 (CI 1.01-1.85, p=0.04)[14]. If we apply this odds ratio of 1.37 to the base rate for hamstring injury, the risk of injury for the athlete changes from 11% to 14.6% (Figure 2). Is this change meaningful enough to change your clinical practice? Furthermore, consider the burden and severity of the injury, such as the time to return to play (for hamstring injury, reported as 21 days on average). We might take very different clinical decisions when the 37% increase in relative risk (as the odds ratio indicates) is translated into a 3.5% increase in absolute risk, for an injury

that needs 21 days to recover. In addition, it would be very difficult to determine a clear cut-off point for significant eccentric weakness that effectively separates the high risk (will be injured) athletes from the low risk (will not be injured) athletes[15]. The lack of clinical utility demonstrated in these tests highlight the difficulty we face when interpreting these significant findings.

This type of analysis and interpretation of risk factors still relies heavily on the statistical p-value, which conceal other relevant analyses, such as effect size or clinically meaningful differences. Although p-values are useful to determine probability in hypothesis testing, it is not valuable in assigning clinical meaning to a finding[16]. Despite this obvious limitation, we quickly assign the "importance" of a particular finding based almost entirely on this one component of an analytic assessment. At its root level, a p-value is the probability of obtaining a result that is as extreme as the one that was actually observed, using the assumption that the null hypothesis is of actual value[17]. Consequently, statistical significance is not the same as clinical significance[18].

This highlights the important issue of applying appropriate statistical modelling to answer research questions comprehensively, which might include Bayesian probability, aggregated decision tree, or stochastic time-series methods[19]. Even though two groups might be statistically different (and when using p-values, this might merely reflect the

power of chance or a function of the sample size), clinically they would appear almost exactly the same. Therefore, risk factor findings are not always in agreement.

OPPOSING RISK FACTOR FINDINGS

Many risk factor studies have delivered contrasting results. Hamstrings injuries provide evidence for this, where strength is often identified as a risk factor for hamstring injury. In fact, the most comprehensive meta-analysis to date could only identify three factors associated with increased risk of injury, with increased quadriceps strength being the only modifiable risk factor (the two non-modifiable risk factors being age and previous injury)[20]. Yet two recent publications on strength as a risk factor for hamstring injury - from the largest prospective risk factor study performed to date - produced somewhat contradicting results[14,21].

The first study reported two statistically significant results. A decrease in isokinetic concentric quadriceps strength and eccentric hamstring strength were significantly associated with an increased risk (approximately 40%) of injury. The second study reported that an increase in isokinetic concentric quadriceps strength @300°/s was associated with hamstring injury when categorised into strong (two standard deviations above the mean) and weak (two standard deviations below the mean) groups; while athletes with stronger quadriceps being twice as likely to suffer a hamstring injury[21]. So in these studies, performed in two similar study populations with exactly the same methodology and design, both increased and decreased quadriceps strength were associated with an increased risk of injury? Confounding factors such as age and previous injury were accounted for in both studies, yet these opposing results suggest that we have not accounted for how the different variables might influence, or even alter, the direct effect of another specific variable.

These examples demonstrate a faulty reductionist view. Reductionism focuses on the identification of one or more risk factors in isolation, such as quadriceps strength, that is directly associated as the causes for the outcome, whether the outcome is injury or the development of a specific pathology.

	TABLE 1	
Prevention programme	*Description*	*Effectiveness*
Nordic hamstring exercise[23]	*Nordic hamstring exercise in weekly prevention programme*	*51% reduction in hamstring injuries*
FIFA 11+ prevention programme[22]	*A inclusive soccer specific programme including exercises for running, strength, plyometrics, balance, acceleration/ deceleration, and change in direction*	*25% reduction in overall injuries*

Table 1: Examples of injury prevention programmes and their effectiveness.
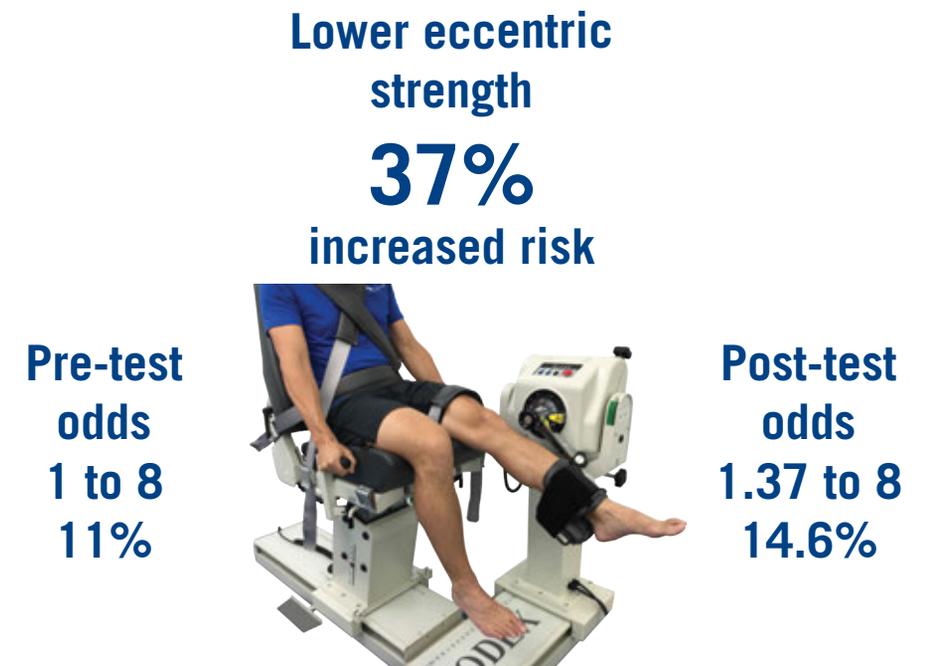

Figure 2: An illustration of how to apply a specific odds ratio to the base rate of an injury to interpret the clinical value of the finding (with permission).

Therefore, predicting the outcome is made possible by accounting for the sum of the system's units by identifying these direct relationships. This reductionist approach assumes a linear relationship exists between these factors and the outcome, not accounting for the complexity rooted within these findings[11]. As shown in our example, we must appreciate that a multitude of factors (modifiable and non-modifiable) may affect the influence of one specific variable.

Although risk factor studies continue to deliver contradicting results[20], we observe a puzzling paradox within the literature. Regardless of risk factor identification, intervention studies using prevention exercises implemented at the group level have consistently been successful.

SIMPLE SOLUTIONS TO A COMPLEX PROBLEM?

Currently, low-cost, non-invasive hamstring injury prevention programmes exist, such as the Nordic hamstring exercise and the FIFA 11+ programme in soccer[22,23]. The effectiveness of these programmes are often limited by poor compliance or lack of implementation, influenced by team culture, attitudes and beliefs, as well as stakeholder involvement[24,25]. However, apart from these difficulties that we need to
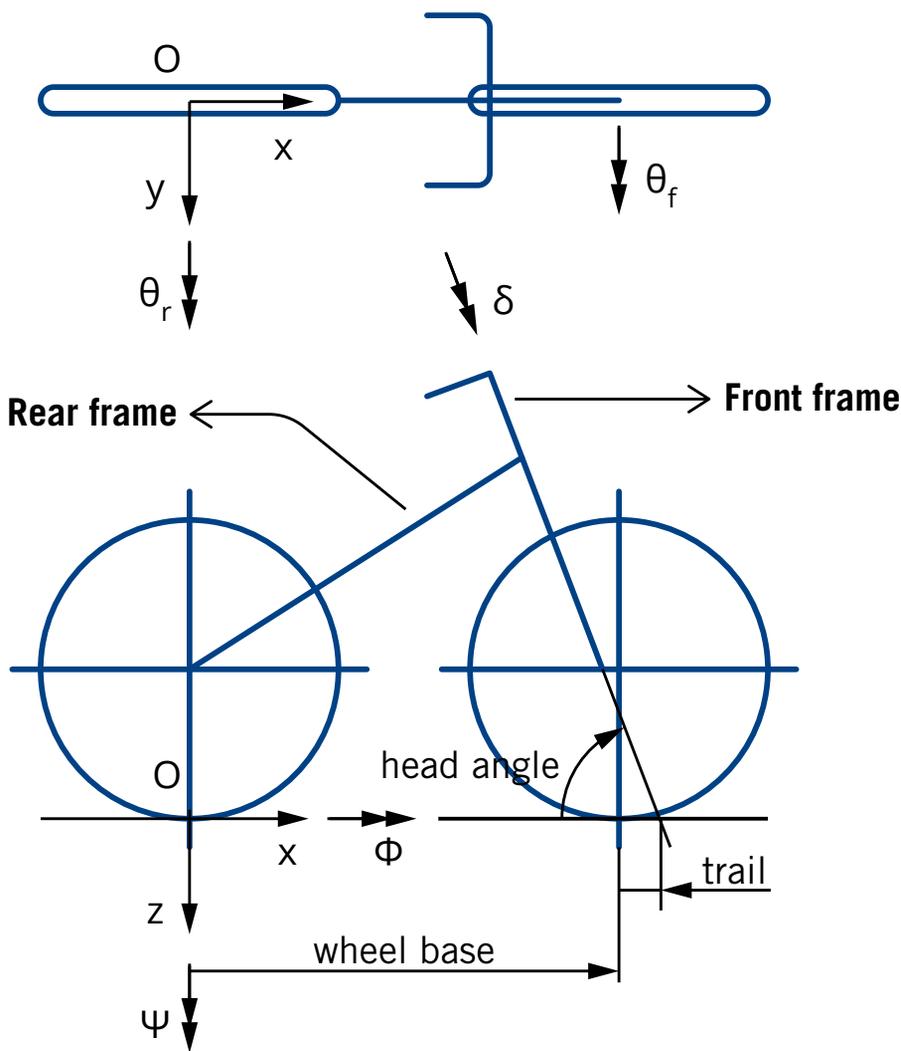
Figure 3: The complex dynamics of how bicycles remain upright.

address, the positive preventative effect of these programmes are undeniable (Table 1).

Such programmes are important tools for clinicians; they will continue to form part of prevention efforts as our ability to monitor the athlete improves. Yet we are unable to consistently identify risk factors that support the results of these successful interventions. Understanding how injuries occur, and identifying patterns that might refine and optimise these interventions, requires something else - an appreciation of complexity.

THE COMPLEXITY OF BEES, BICYCLES, AND HOW IT APPLIES TO INJURY PREVENTION

First, let's consider some examples of complexity. Healthy beehives with many different elements (thousands of bees) produce highly functional, ordered patterns. They may consist of up to 70,000 bees; if you remove a few hundred, or even the queen bee, the system would merely adapt - other workers would take over the tasks of the missing bees, or the hive would breed a new queen[26]. The interaction between different variables are also evident in the "simple" task of riding a bicycle. Explaining how bicycles stay upright requires about 25 mathematical variables (Figure 3). But even after altering a key element needed for balance and motion (such as the gyroscopic force of the wheel) that would technically make them "unrideable", it remains stable and on track[27]. This is due to an understanding of the interaction of the various parts, as well as the complex action of the human riders to intuitively keep the bicycles stable and upright. So what do bees and bicycles have to do with injury? They are all examples of complex systems.

Complex systems are dynamic, open systems with inherent non-linearity and unpredictability that exhibit self-

organisation. A large number of interacting individual agents form an emergent behaviour (not derivable for the sum of the activity of these agents alone)[28]. Our traditional screening prevention models include the assumption that we are dealing with a static, non-dynamic closed system, which includes predictors that are too refined and restrictive to translate to the "real world" setting[19]. Similar to beehives and bicycles, athletes also have a multitude of different agents (previous injury, age, technique, playing style, motivation, strength, neuromuscular control, emotional health) acting and interacting to form the emergence of injury. These systems are robust and can easily adapt to change, but when the balance between order and disorder is disrupted, it fails.

A complex systems approach has been suggested to better reflect the dynamic nature of sports injuries[11]. This new approach would require investigations of interactions between different (risk) factors, how these interactions might influence, or even alter each other to form different emergent patterns of injury. Unpredictability and contradiction are ingrained in complex systems, and some things will remain unknowable[32]. However, by moving away from a list of risk factors towards developing risk profiles, we might be able to better manage the emergence of sports injuries, and protect our athletes. This approach considers the interconnected and multidirectional interaction between all factors.

STRATEGIES FOR CLINICAL PRACTICE

Predictive modelling and complex approaches may not be available in our clinics yet. However, we propose three take-away strategies from the themes discussed here to assist the clinician in better translation of risk factor findings into meaningful action.

1) Apply risk factor findings reported in large prospective cohorts to base rates

When the odds ratio findings are applied to base rates of the injury, we can better understand how these findings translate to our clinical setting. This approach, often referred to as Bayesian thinking, allows us to adapt our conclusions as new evidence emerges. Starting with our pre-test odds

CONCLUSION

> ## *It is time to leverage our collective strength and share our resources to advance the management and prevention of hamstring injury, and indeed all sports injuries.*

(prior probability), we apply an odds ratio, and end up with post-test odds (posterior probability) (Figure 2). Now this post-test result becomes our new prior, and we can apply another piece of information to further shape our clinical reasoning. These factors also change in the context of different athletes. Comparing an older athlete competing in the final season of a long career to a young draft pick just starting, who may represent a multi-million-dollar investment to the organisation, the level of acceptable risk and decision to play might be very different. Applying a specific odds ratio to the base rate, and considering contextual factors, may assist the clinician in optimal decision making when interpreting risk factors.

2) Screening can detect ongoing musculoskeletal issues - action required

Screening should focus on early identification of current health problems (sometimes called secondary prevention) and assess 'old' injuries to prevent their recurrence (tertiary prevention). It is imperative that these results then lead to some form of follow-up action for the athlete. Screening without action is simply data collection and holds no value for the individual[29]. Furthermore, screening can be a valuable opportunity to establish trust between the clinician and the athlete, perform baseline testing for performance, review medication and supplement

use, and is occasionally necessary to fulfil medico-legal requirements[12]. This information is valuable in a shared decision making process, where different members of the management team can review the information as permitted, and act together to improve the health and performance of the athlete[29].

3) Large group-based prevention strategies

As illustrated in our discussion of complexity, it is likely that several different factors combine to produce a specific sequence of events to cause an injury. An athlete may experience fatigue towards the end of a match, followed by a sudden acceleration movement, combined with low muscle flexibility and decreased strength, creates a sufficient sequence of events to cause an injury. However, as is the case with most causes of interest in healthcare, these injuries are made up of different factors to be sufficient, although they are not sufficient in isolation. And most often, by removing or changing one of these factors, we can prevent the sequence of events necessary for the injury to occur. This is evident from the success found in the intervention programmes aimed at addressing one specific component of the multifactorial injury model. We recommend prevention programmes targeting known risk factors be implemented at a team level (or an entire group of athletes training at a club or federation).

THE WAY FORWARD

To challenge current paradigms, we need to understand how a complex system functions, interacts and adapts. Specialist knowledge of the system we are investigating is crucial. We need, in addition to statistics, mathematical modelling and machine learning; new ways of analysis which are already used in other areas of science and medicine[30]. This approach may reduce the number of studies with limited subjects and isolated variables, and stimulate the emergence of qualitative research projects including large subject populations and a multitude of interacting variables. More importantly it will require collaboration between sporting organisations, their affiliated teams, researchers and practitioners, to allow for the appropriate scientific and clinical veracity needed to make meaningful conclusions. It is time to leverage our collective strength and share our resources to advance the management and prevention of hamstring injury, and indeed all sports injuries.

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