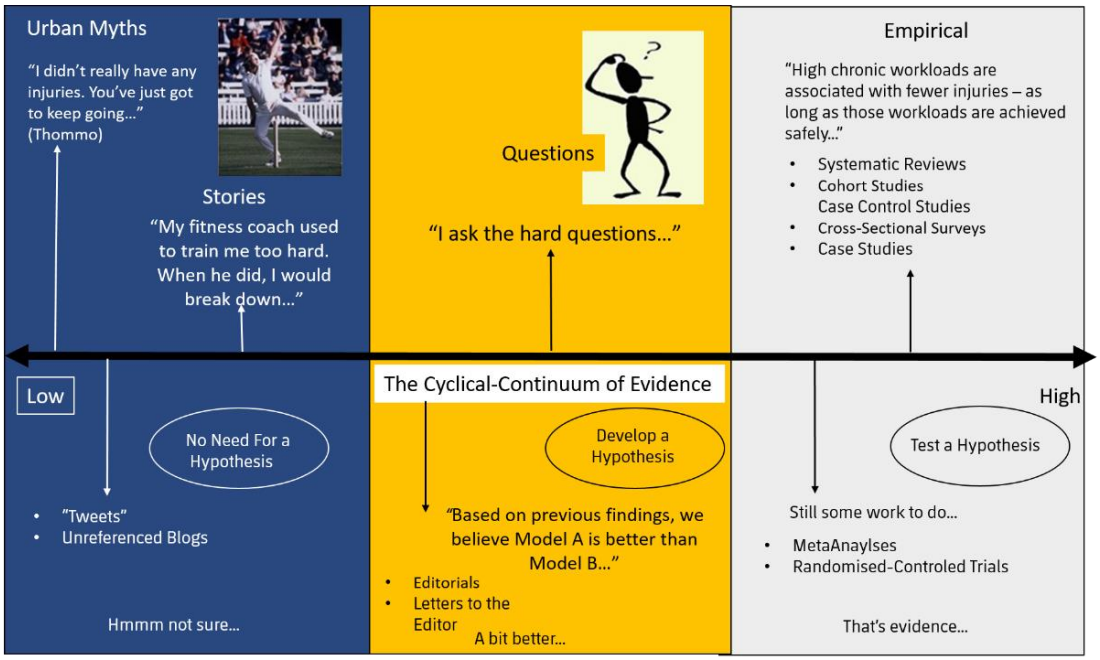
Introduction

This course will cover best practice approaches to training and workload monitoring. Workload monitoring and athlete management are key roles of the sport scientist. They are not the only areas of sport science, but they are key to keeping athletes on the pitch and the court, and ensuring our best athletes are available for as many games as possible. There are two main reasons why athletes' performance should be monitored: first, to make sure that athletes perform at the highest possible level. Second, to minimize the negative effects of training, such as fatigue, burnout and, of course, injury risk. Therefore, this first course will examine (1) the history of training monitoring, (2) why injuries occur, (3) the relationship between training load and injuries and, particularly, (4) some new models of training monitoring. Essentially, the main goal of this course will be to discuss a best practice approach to training monitoring in order to try to keep athletes fit and injury free.

Some decades ago, scientific information always came from peer-reviewed articles. Trainers and sports scientists would read those articles and that was how information was transferred from scientific papers to sport-specific practice.

Figure 1: The cyclical-continuum of evidence applied to training load-injury research



Source: Gabbett and Blanch, 2018, https://bit.ly/2mMnqdS

However, with the advent of the internet, and particularly social media, people obtain information in many different ways. Figure 1 shows how people obtain evidence and generate beliefs about a particular topic. The cyclical continuum of evidence in displayed with training load and injury used as an example. The continuum of evidence refers to high and low levels of evidence. Before social media appeared, scientists would obtain information from peer-reviewed articles. However, practitioners now obtain scientific information from social media (e.g. Twitter, Facebook) or other unreferenced blogs, posts, etc (see left part of Figure 1).

These are particularly low on the continuum of evidence. An example of this is when, in sports, we hear from ex-players (very good players in their days) commenting that: "in my days, we used to train a lot harder and we never broke"; "in my day, we were a lot tougher and we never broke"; "we trained hard, we trained all the time and we never sustained an injury, we just kept on playing, kept on training." The problem with most of these comments is that for many of these sports, official injury surveillance has only really happened in the last fifteen years or so... so there are no official records clarifying if players have sustained injuries or not.

Therefore, when players say, "in my days we trained a lot harder and I have never sustained an injury", this is somewhat of an urban myth. The reality is that the further those players get from the end of their career, the bigger the myth grows. If we move a little further along the continuum of evidence, we have things called "stories". Stories occur when new players come to a team and they make comments such as "my fitness coach used to train me too hard and, as a consequence of this, I would get injured". Stories are not actual evidence. It's important that we listen to them to decide how to train that particular player, but developing a training program for the entire team based on one person's experience is probably not the best way to develop a training program.

If we progress further along the continuum of evidence, we have "questions". All good research comes from good questions and good coaches, fitness trainers, physical therapists and medical practitioners ask good questions in their day-to-day work and support of players. So, they may have a question about why a particular event occurred in training, or they may have a theory (a hypothesis) that a particular way of training is much better from an injury prevention perspective than a different type of training. However, this in itself is not evidence either; it's a theory or a hypothesis and all good research studies and projects come from good questions and good hypotheses. We actually need to conduct some research in order for that question or hypothesis to become evidence.

On the far right of the continuum of evidence, we find "empirical evidence". The current empirical evidence concerning training loads and injury demonstrates

that high training loads are associated with lower injury risk as long as those workloads are achieved safely. This research evidence comes from a wide range of studies. We have cohort studies, case-control studies, cross-sectional surveys; the vast majority of this work has shown that, if an athlete achieves high workloads in a safe manner, the risk of injury will be reduced. However, there is still some work to do. There have been different research designs that have answered these questions, but to date, meta-analysis of this data, and randomized control studies are yet to be conducted. There is still some work to be performed in order for scientists to be confident that high training loads protect against injury. At the moment, the available evidence demonstrates that high training loads are *associated* with lower injury risk, but it is still to be confirmed if training with higher loads has a *protective effect*. Further research is required in order to confirm this.

The final point that is worth emphasizing is that the continuum of evidence is a *cyclical* continuum of evidence. Science does not "sit still". What we know today most certainly will change tomorrow. That's the reality of science. Once someone produces new evidence, someone else will stand on that person's shoulders and develop new pieces of information - this is how science evolves: what we know today can certainly change tomorrow. The other thing to keep in mind is that for every question that we answer with research, probably another five questions come up as a result of that study. Therefore, when empirical research answers a question, researchers return to the middle part of the continuum of evidence, and when we ask more questions, we develop more theories and hypotheses, which allow us to conduct more research. We are constantly evolving and collecting new evidence. We obtain answers and solve particular problems but then more questions arise and more answers come as a result of those questions. This is the *cyclical continuum of evidence*.

I would like you to keep this in mind as we work through this course because you will see a wide range of information that comes from various sources. You will see information that comes from empirical research and from other sources, such as letters to editors and editorials. These do not constitute actual evidence, they are theories and hypotheses. You will also hear stories from the athletes that you work with and it is important that you listen to those stories to help athletes with their training. In addition, when you hear urban myths or read information on Twitter, you should try to think scientifically to decide if those "posts" and "Tweets" are actual evidence or urban myths. I would like to encourage you to try to work at the far (right) end of the cyclical continuum of evidence where you use as much empirical evidence as you can if you want to get better at workload monitoring and managing injury risks in your athletes. After all, how well can a single 140-character "tweet" encapsulate the findings of a complete research study, which may range from 3000 to 5000 words? (Gabbett & Blanch, 2018)

This course analyzes the best practice approach to workload monitoring. Essentially, this course will examine the research investigating the relationship between workload and injury risk and how practitioners can use workload data to manage injury risk and reduce injury in their athletes. The focus of the course is on the positive and the negative effects that come from training. Acute and chronic loads will be discussed, along with the acute-to-chronic workload ratio. This ratio allows practitioners to safely progress training loads to minimize injury risk in our athletes. Finally, practical examples will be provided on how to use this data to manage and reduce injury risk in your players.

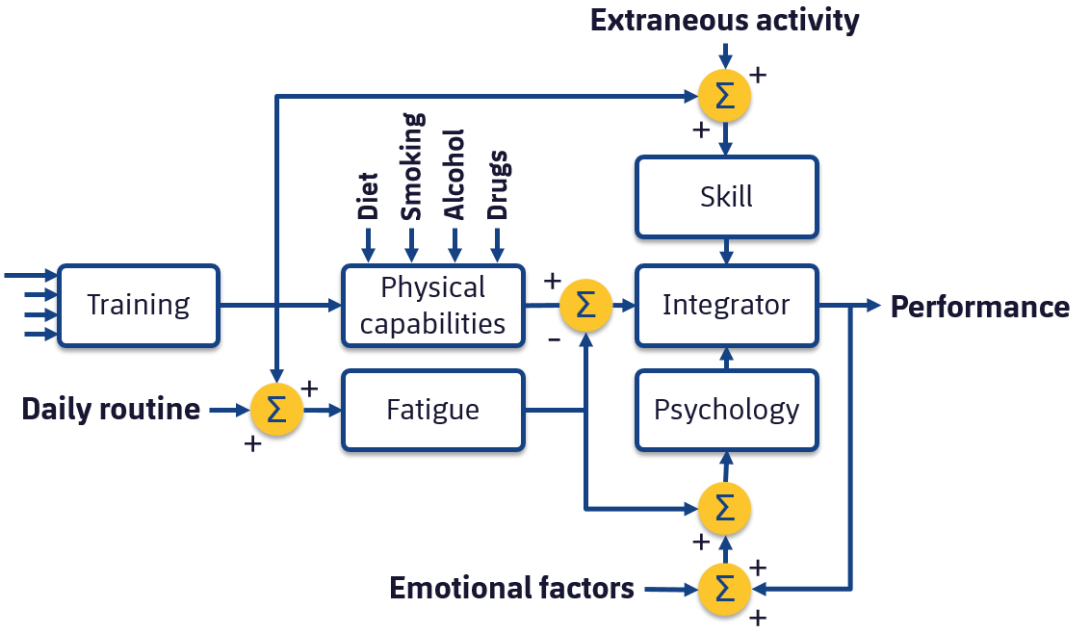
Why do injuries occur?

Before we discuss causes of injuries, it is important to discuss the history of training monitoring and some important landmark studies and events that have occurred in the history of training monitoring. While this text does not cover all of them, there are important ones that should be discussed. Banister, Calvert, Savage and Bach (1975) were the first to investigate training load and how it relates to performance. In order to develop a model that would show the relationship between workload and performance, the first thing to do was to establish some human performance factors capable of being measured and interrelated:

- Physical capabilities are positively affected by the amount and type of training and negatively by the amount of fatigue accumulated by the athlete when training. Of course, things like nutrition, rest and the daily routine will influence those capabilities.
- Emotional factors affect performance in many ways. There are many tools available to measure both positive and negative emotions.
- Increased skills result in a more effective use of the motor platform. Therefore, the athlete will avoid using unnecessary muscle groups and will develop more precise neurological feedback. Because skill development is a process that needs time and practice, it will be strongly influenced by the amount of training the athlete performs. On the other hand, when an athlete improves technical execution (e.g. sprinting), this will save energy, due to elimination of unnecessary movements (Banister et al., 1975).

The following model was developed based on the interaction of the components described above. The model analyzes the fitness and fatigue effects on training.

Figure 2: Banister's fitness-fatigue model

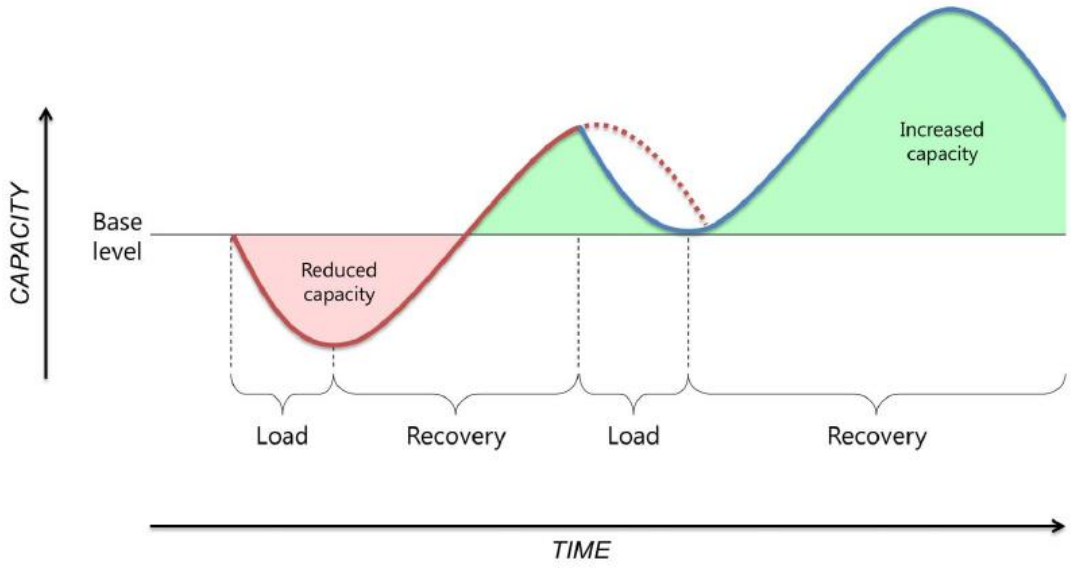


Source: Banister et al., 1975, p. 58

Figure 1 describes the responses to training. There are two possible effects that can stem from training; the effect can be either positive (i.e. "fitness") or negative (i.e. "fatigue"). The equation is very simple: performance is equal to fitness minus fatigue. Most of the work done after this early study was based on this first model.

In fact, according to the 2017 Olympic Committee Consensus Statement (Soligard et al. 2017) about training load and its influence on fitness and fatigue, (i.e. training adaptations), it is remarkable how the performance concept still depends on these two variables. This idea is also applicable to the Biological Adaptation ensured by a proper load-recovery relationship, as shown by Figure 3.

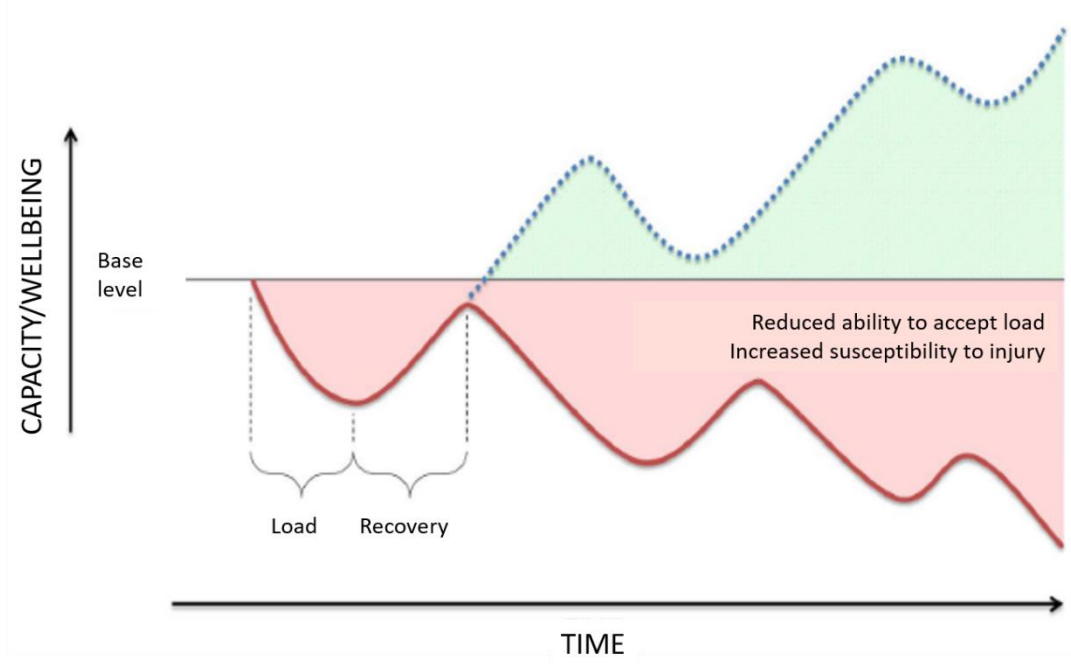
Figure 3: Biological adaptation through load and recovery cycle



Source: adapted from Meeusen by Soligard et al., 2017, p. 1031.

On the other hand, Figure 4 shows the effect of poor load management/inadequate recovery on an athlete's capacity and injury risk.

Figure 4: Biological maladaptation through a load and recovery cycle



Source: adapted from Meeusen by Soligard et al., 2017, p. 1031.

Performance managers (such as coaches and trainers) should be aware that maladaptation not only occurs due to poor training management but also due to non-sport stressors, such as psychological stress, lifestyle or life events (factors influencing human performance). This is the reason why the term that has been used in this matter is 'load' and not 'workload'. The consensus group agreed on a broad definition of 'load' as 'the sport and non-sport burden (single or multiple physiological, psychological or mechanical stressors) as a stimulus that is applied to a human biological system (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual) (Soligard et al. 2017).

Another important landmark, which dates back to the 1970s, was the introduction of wireless monitoring of heart rate. This technology allowed trainers to monitor heart rate using watches and straps attached to athletes' chests.

Some advances were made between the 1970s and 1990s, but another landmark piece of work was published in 1996, when Carl Foster started using the session Rate of Perceived Exertion (RPE)) to monitor training loads. He observed speed skaters and cyclists and analyzed time trial performance. He modified the session-RPE that was originally developed and validated by Gunnar Borg (1970, which can be seen in Figure 5) and examined the relationship between training load (using this session RPE scale) and performance.

Figure 5: Borg's original RPE scale

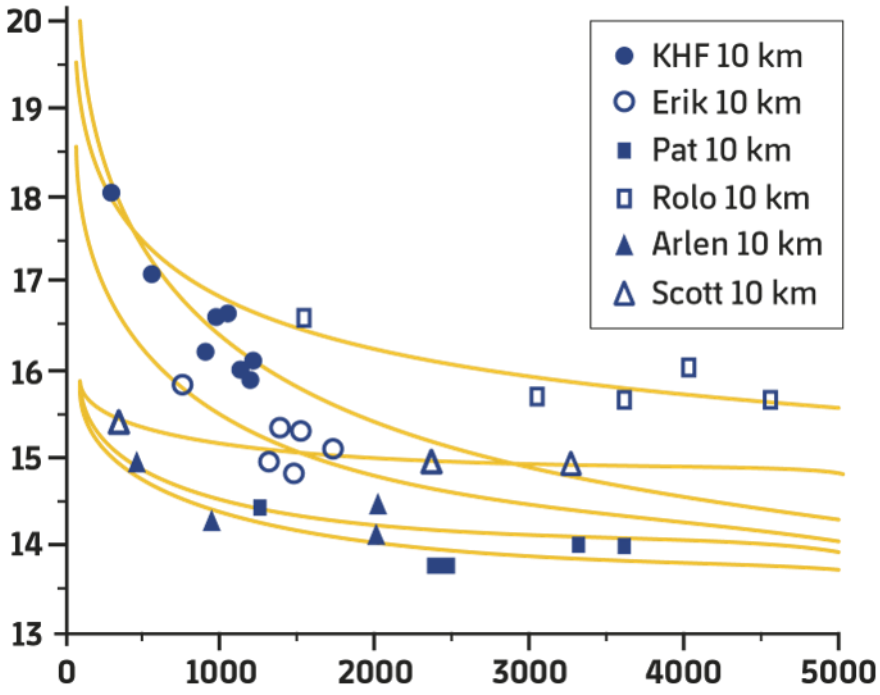
Rating	Perceived Exertion
6	No exertion
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Source: Borg, 1970

In general, Foster found that the athletes with higher training loads had better time trial performance. Many other studies have used the session RPE to quantify internal load in athletes.

Session-RPE is a very good marker of training intensity, even if it is based on the athlete's sensations of the difficulty of physical activity. In fact, Gabbett (2004) found very high correlations between this marker and heart rate and blood lactate concentration (0.89 and 0.86 respectively) in Rugby League players.
Session-RPE provides a measure of intensity. Internal load scores can be calculated by multiplying the RPE value by the duration of the practice (in minutes). This "load" score is expressed in Arbitrary Units.

Figure 6: Performance vs. training load measured in arbitrary units



Source: Foster, Daines, Hector, Snyder, & Welsh, 1996, p. 372.

One of the game changers for sport was when GPS first became available to the public. In the past, GPS had been restricted to military organizations, but in the early 2000s, the United States allowed access to satellites and this caused a boom in the use of satellite technology. We started to see greater use of satellite technology in cars to navigate vehicles, and in 2003, we also saw the introduction of the first wearable GPS. That GPS unit sampled at a very low frequency. In addition, the accuracy, reliability and validity of that first GPS was not particularly great. Athletes would wear it between their shoulder blades, but it was quite large and heavy. Despite this, for the first time we were able to move away from video-based technology to monitor our athletes. That video-based technology was quite time-consuming and labor-intensive. Strength and conditioning coaches were able to get data, which they could download at a later point and look at the speeds that athletes had achieved during the training or competition and the distances that they had covered.

GPS has changed the way to monitor athletes and, since the introduction of GPS, other micro sensors are also embedded in the technology. Now, there are accelerometers, gyroscopes and magnetometers inside a small wearable device. In addition, the sampling frequency of GPS has improved and the validity and the accuracy have improved as well. With the additional microsensors, trainers are now able to quantify sport specific movements, so the information obtained is

not just, how far you run or how fast you do it. These devices can also quantify specific movements, for example, jumps for a basketball player or throws for a baseball player or a javelin thrower. It is also possible to quantify the dives of a goalkeeper and the time that it takes for them to make that dive and then get back to their feet.

Technology is really improving the way in which sport professionals and scientists are able to monitor and manage athletes' workloads. Around the mid-2000s there was some good work done by scientists. A very practical scientist called Andrew Coggan started to use Bannister's early model from 1975, taking the acute and chronic workloads to create a training stress score, and he called this the Training Stress Balance.

Figure 7: Training stress balance

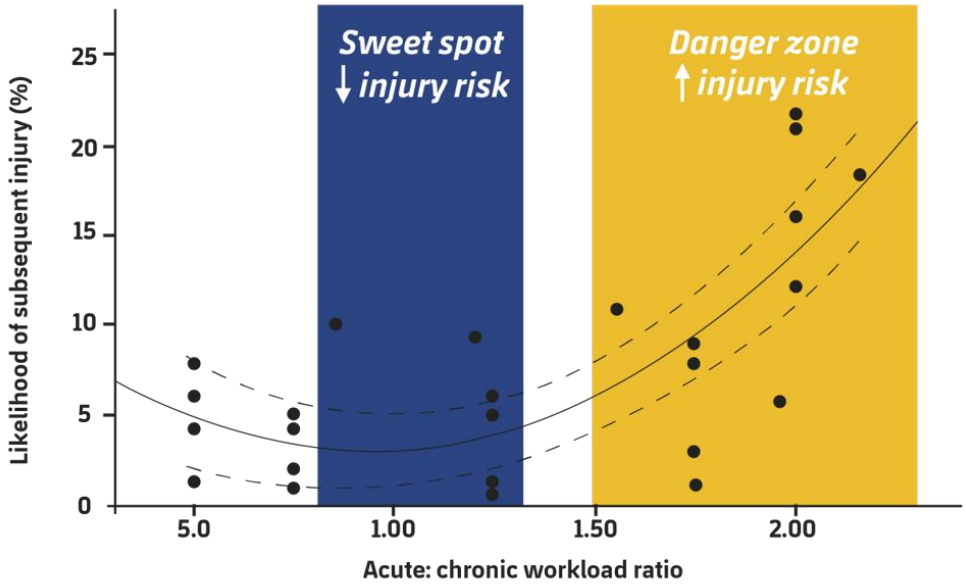
Source: Docal P, (2017) https://bit.ly/2mWNq6B

Basically, if the acute loads were much higher than the chronic loads, this indicated that fatigue was much higher than the fitness that the athlete had developed over a period of time. The athlete would then then have a high training stress balance, which would potentially mean that they would enter a race, or a cycling event, etc., feeling "leg heavy" and not very fit. On the other hand, if an athlete enters a race with reduced acute loads and well-developed chronic loads, then the training stress balance will be low, suggesting that the athlete is well-prepared and ready to compete. This work is being implemented in many different cycling programs, many different cycling coaches use the training stress balance, and we are really standing on the shoulders of some of the great work that Coggan has done.

Then, in recent times, Gabbett (2016) published the acute-to-chronic workload ratio, which he had started to use in 2014. It is a form of training stress balance. This model uses acute and chronic loads as a guide to athlete readiness, which depends on whether he/she is in a relative state of fitness or in a relative state of

fatigue. This acute:chronic workload ratio (ACWR) has been used to safely progress athletes to higher workloads, and to ensure that athletes are having unloading periods within the training program. We have also looked at injury associated to workload and I will talk a little bit more about acute: chronic workload ratios, injury and injury risk later in this course.

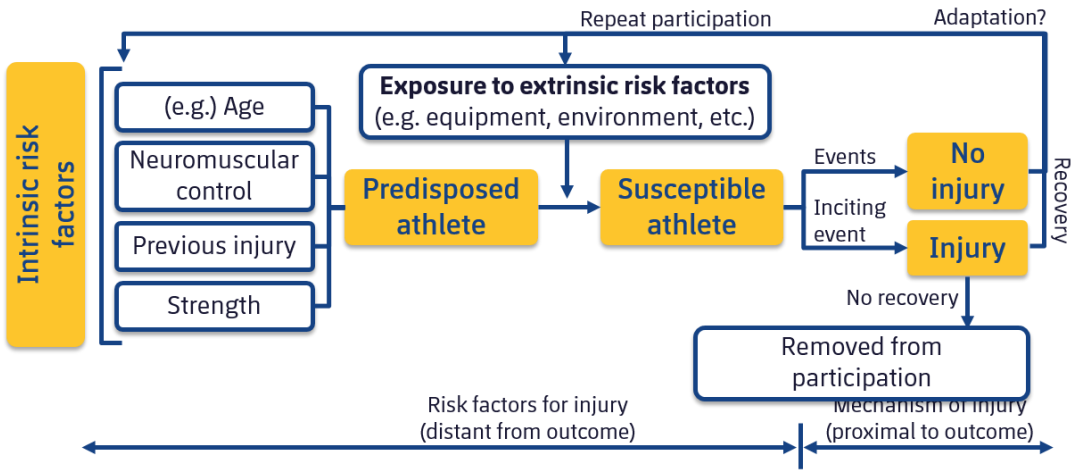
Figure 8: Guide to interpreting and applying acute: chronic workload ratio data



Source: Gabbett, 2016, p. 278.

When we look at injuries, the first thing that comes to our minds is that they occur due to many different reasons; injuries very rarely occur as a consequence of one single event. There is a multifactorial explanation for injuries. When we look at the etiology or causes of injury, a number of models have been developed. Figure 9 shows the first model that was developed by Meeuwisse (1994). According to this author, a few different things must happen for injuries to occur. The first is that there are intrinsic risk factors or internal risk factors. So, this first model looked at a number of these internal risk factors, for example, age, flexibility, body type and previous injuries, one of the major risk factors for subsequent injuries. If an athlete has these intrinsic risk factors, then he will be more predisposed to get injured. If a predisposed athlete is exposed to a particular set of extrinsic risk factors, and there is an inciting event, this may increase his risk of injury. In consequence, the player could be injured.

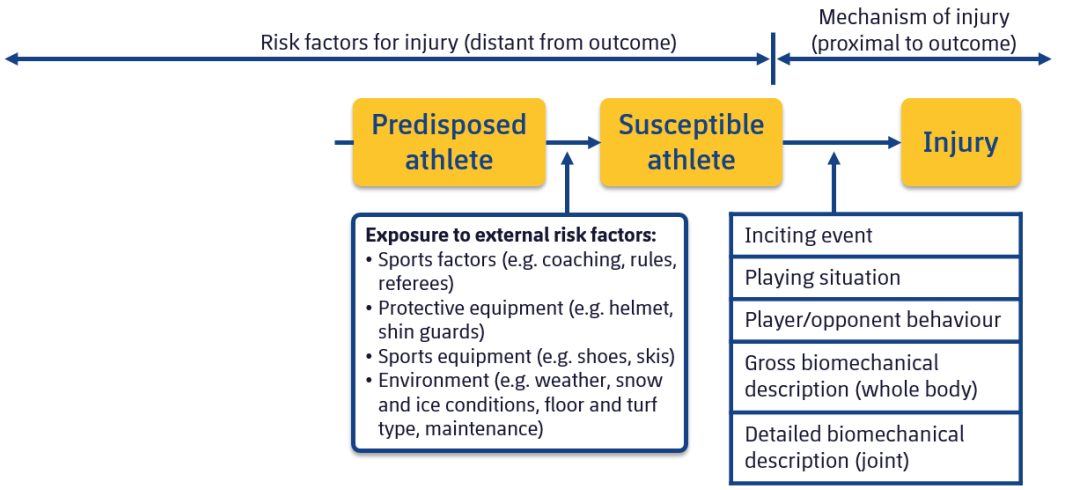
Figure 9: Meeuwisse's injury prevention model



Source: Meeuwisse, 1994, p. 168.

Whenever there is a model such as the one that was developed in 1994, another researcher will look at that model and will say: "I think there's a better way to look at this model" or "I see it a little bit differently". This is why Figure 10, developed by Bahr and Krosshaug (2005) shows a model that is an adaptation of that proposed by Meeuwisse (1994). Essentially, the same process applies. We have a series of intrinsic or internal risk factors but the model expands on those risk factors including things like skill level or physical fitness. Again, there is a predisposed athlete and there are extrinsic risk factors such as sports factors (a particular style of play, for instance) or environmental factors, like a hostile crowd. We also have exposure to an inciting event. Therefore, in this case, this event could be a very aggressive opponent and the combination of intrinsic risk factors, extrinsic risk factors and the inciting event leads to injury.

Figure 10: Bahr's injury etiology model

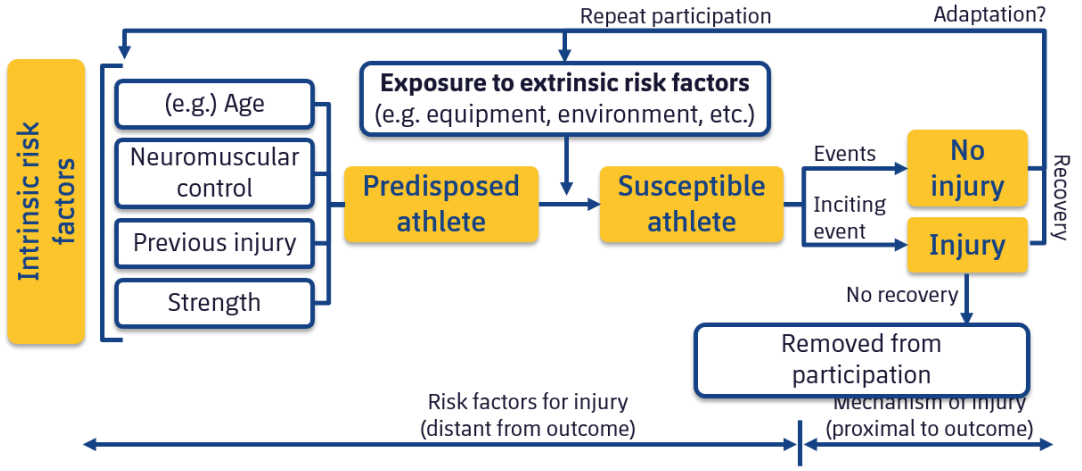


Bahr, R. & Krosshaug, T. (2005). Understanding injury mechanisms: a key component of preventing injuries in sport. Br. J. Sports. Med., 39:324-329.

Source: Bahr, & Krosshaug, 2005, p. 327.

Following Bahr and Krosshaug's adaptation of the model, there is a third model (see Figure 11) (Meeuwisse, Tyreman, Hagel, & Emery, 2007). Again, in this model we have intrinsic risk factors, extrinsic risk factors and, of course, the inciting event. However, the difference with this model is that not all of the intrinsic risk factors and extrinsic risk factors actually lead to injury. In this respect, an athlete can be exposed to an inciting event but this does not necessarily mean that the athlete will definitely sustain an injury just because they had a particular set of risk factors. In the event of no-injury, the athlete will adapt to the training or the workload, recover and then repeat participation. On the other hand, if the athlete does sustain an injury, in some cases the injury will be so severe that the athlete will be required to cease participation or retire. On other occasions, the athlete may sustain an injury, go through a recovery process or rehabilitation, adapt and then return to play and repeat participation. When participation is repeated, the athlete has (a new set of) intrinsic and extrinsic risk factors, may be exposed to an inciting event, either resulting in injury or resulting in no injury.

Figure 11: Meeuwisse's dynamic-recursive injury model

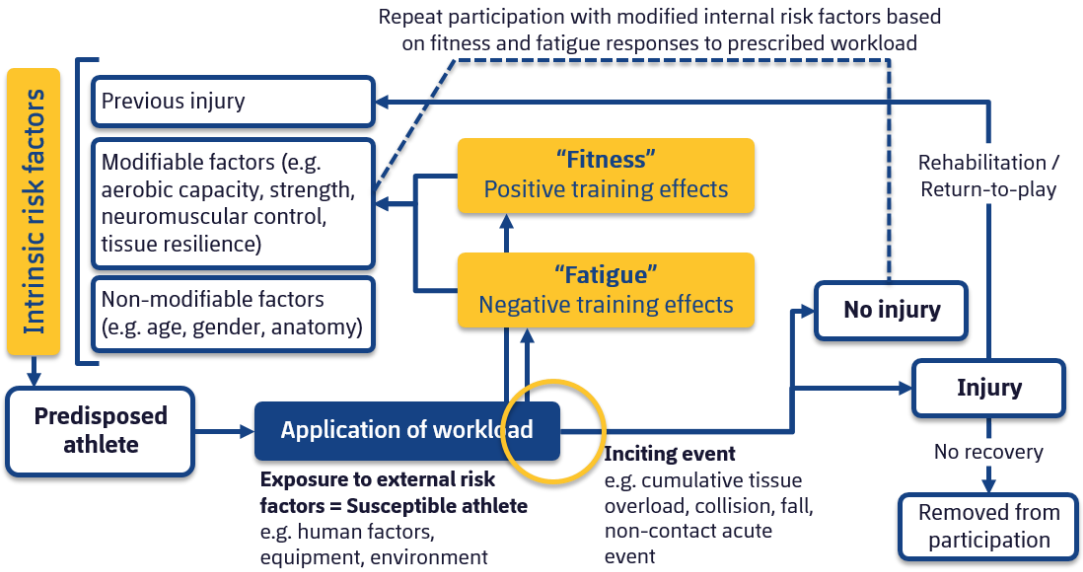


Source: Meeuwisse et al., 2007, p. 217.

Therefore, we are dealing with two key points that differ from the other models. The first is that having intrinsic risk factors, being exposed to extrinsic risk factors and being exposed to an inciting event does not guarantee injury. The second point is that if an athlete does get injured, the process doesn't stop there. Typically, the athlete repeats participation and is exposed again, through training or competition. This is called a dynamic recursive system. So, it's dynamic in nature in that it's changing all of the time and it feeds back on itself like a loop that continues to keep going.

All of these models have contributed significantly to our understanding of why injuries occur. However, one of key components that is missing from all of these models is the application of workload. I can guarantee that an athlete can have all of the intrinsic risk factors in the world, like weak gluteal, tight adductors or weak or tight shoulders, but if that athlete isn't exposed to some sort of workload, be it training or competition, then he/she is not going to sustain an injury. Therefore, this is where we come up with this new model called the Workload-Injury Etiology model, which ties together the early injury etiology models *and* Bannister's fitness-fatigue model. Figure 12 shows a new model: on the left side, we have considered intrinsic or internal risk factors. These intrinsic risk factors have been broken down into modifiable and non-modifiable factors.

Figure 12: The workload-injury etiology model



Source: Windt, & Gabbett, 2016

On the left hand side of this figure, intrinsic or internal risk factors have been considered. It starts with previous injury since we know that previous injury is a risk factor for subsequent injury. We have then broken these intrinsic risk factors down into modifiable and non-modifiable risk factors. Non-modifiable risk factors are things you cannot change, like age, gender and anatomy. But then we have modifiable risk factors. They are things that we can change such as strength, aerobic fitness, neuromuscular control, tissue resilience. These are modifiable risk factors.

As with previous models, this model also includes extrinsic risk factors, but the main difference here is that this one also includes the application of workload: either the external or internal work in preparation for a competition, or taking part in the actual competition. The application of workload can result in either a positive or negative response. For example, excessively high workloads can cause stress, fatigue, burnout or injuries. In addition, if workload is not applied in a sensible way, if excessive workload is used or if there are rapid changes in workload or intensity, then it will likely result in a negative response. These things can occur when training is not prescribed appropriately. However, there is also a positive effect that comes with training, the "fitness effect". Bannister's model shows the two effects of workload. The first one is the negative effect, called fatigue, a general term that encompasses the negative effects that come with training. When athletes are exposed to excessive workloads or rapid changes in workload, then an increased "fatigue effect" will occur. The fatigue effect that comes with that workload outweighs the fitness effect. In addition,

under those conditions, this can lead to a change in the modifiable risk factors and the effect of excessive fatigue can decrease strength, aerobic fitness, neuromuscular control and tissue resilience. Moreover, when we experience those changes in our modifiable risk factors, this may potentially increase the risk of injury.
On the other hand, when appropriate workloads are prescribed, when these workloads are achieved safely, when athletes don't go through rapid increases or decreases in workloads, then they experience the positive effect of training and workload called the fitness effect**.** When an athlete experiences these positive effects of training that also changes the modifiable risk factors, by increasing strength, aerobic fitness, neuromuscular control and tissue resilience. In addition, all of these changes potentially decrease the risk of injury. Therefore, as you can see in this model, we have intrinsic and extrinsic risk factors, but training load in itself is not actually a risk factor for injury. It is rather like a vehicle that can drive your athletes towards injury or, when prescribed properly, it can drive your athletes away from injury.

Therefore, what you can see here from these four models is that the first provides a summary or an explanation of why injuries occur; it is the original injury etiology model. It includes intrinsic or internal risk factors, extrinsic or external risk factors and inciting events that lead to injury. The subsequent model, the second model, builds on that first model by describing the intrinsic risk factors, the extrinsic risk factors and some of those inciting events in more detail. The third model differs from the first two, by highlighting that not all risk factors result in injury and, that it is dynamic and recursive in nature, feeding back on itself, it is always changing and it is continuous. Finally, the workload injury etiology model combines a number of different models: the early injury etiology model which includes intrinsic and extrinsic risk factors; and the early work of Bannister that includes the fitness and fatigue that comes with training. It also states that not all injuries would result from these risk factors and that training load is not actually a risk factor in itself, but rather a vehicle that can drive your athletes towards injury if you do not prescribe it appropriately. However, if you do prescribe training loads appropriately, this can drive your athletes away from injury.

Finally, while some practitioners may believe that restricting workload will minimize the likelihood of injury, decreasing training loads is likely to be detrimental to an athlete's conditioning and performance in team sports, thereby increasing their injury risk. It is important to take in to account that both under- and over-training can increase the risk of injury. In fact, the vast majority of recent training load and injury research has demonstrated that excessive and rapid increases in training load result in sharp increases in injury risk (Gabbett, 2016).

References

Bahr, R., & Krosshaug, T. (2005). Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine* (39), 324-329. doi: 10.1136/bjsm.2005.018341

Banister, E., Calvert, T., Savage, M., & Bach, T. (1975). A systems model of training for athletic performance. *Journal title*, page *57-61.*

Black, G., Gabbett, T., Cole, M., & Naughton, G. (2016). Monitoring Workload in Throwing-Dominant Sports: A Systematic Review. *Sports Med*, *46*(10), 1503-1516. doi: 10.1007/s40279-016-0529-6.

Borg, G. (1970). [Physical training. 3. Perceived exertion in physical work]. *Lakartidningen*, *67*(40), 4548-4557.

Docal P, (2017) https://bit.ly/2mWNq6B

Foster, C., Daines, E., Hector, L., Snyder, A. C., & Welsh, R. (1996) Athletic performance in relation to training load. *Wisconsin Medical Journal*, *95*(6), 370-374.

Gabbett, T. (2004) Influence of training and match intensity on injuries in rugby league. *Journal of Sports Sciences*, *22*(5), 409-417. doi: 10.1080/02640410310001641638

Gabbett, T. (2016). The training-injury prevention paradox: should athletes be training smarter and harder? *British Journal of Sports Medicine* (50), 273-280. doi: 10.1136/bjsports-2015-095788

Gabbett, T., & Blanch, P. (2018). Research, urban myths and the never-ending story. *British Journal of Sports Medicine*, Doi: 10.1136/bjsports-2017-098439.

Meeuwisse, W. H. (1994). Assessing causation in sport injury: a multifactorial model. *Clinical Journal of Sports Medicine* (4), 166-170.

Meeuwisse, W.H., Tyreman, H., Hagel, B., & Emery, C. (2007). A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clinical Journal of Sports Medicine*, 17(3), 215-219. doi: 10.1097/JSM.0b013e3180592a48

Soligard, T., Schwellnus, M., Alonso, J. M., Bahr, R., Clarsen, B. Dijkstra, H. P., & Engebretsen, L. *et al.* (2016) How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury.

British Journal of sports Medicine (50), 1030-1041. doi: 10.1136/bjsports-2016-096581

Windt, J., & Gabbett T. J. (2016). How do training and competition workloads relate to injury? The workload-injury aetiology model. *British Journal of Sports Medicine*, *51*(5), 428-435. doi: 10.1136/bjsports-2016-096653