

## Risk Factors for Muscle Injury: Can Adaptability and Neuroplasticity Improve the Risks?

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**Conflict-of-interest statement:** The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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Received: January 22, 2019

Revised: March 3, 2019

Accepted: March 7 2019

Published online: December 28, 2019

### ABSTRACT

Risk factors associated with sport injury is well researched but without a decrease in injury occurrence in football. The multifactorial nature of injury risk is accepted. A greater understanding is needed of the effect of interactions between risk factors that converts routine action into a triggering event ending in a non-contact muscular injury. Adapting the possible modification of risk factor paradigm to fast and slow modifiable and using an integrative approach that combines the neuroplasticity and perceptual- cognitive, musculoskeletal, psychological profiles with situational may have greater practical significance. Neuroplasticity must be considered as a tool to modify risk factors.

**Key words:** Injury prevention; Neuroplasticity; Risk factors

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Grive RP, Bahdur K. Risk Factors for Muscle Injury: Can Adaptability and Neuroplasticity Improve the Risks? *International Journal of Orthopaedics* 2019; 6(6): 1193-1198 Available from: URL: <http://www.ghrnet.org/index.php/ijo/article/view/2560>

### REVIEW

Sports injuries have become a well-published research topic with more than 12000 papers available on PubMed from the last five years. Many studies have focused on risk factors linked with injury but despite the large volume of research there has not been a reduction in sports injury occurrence.

Existing models acknowledge the multifactorial nature of non-contact injuries but lack insight into interactions between risk factors to produce an injury in an *in vivo* environment. In real life models many risk factors may be present to some degree but there must be greater understanding over what interactions and conditions convert common actions (e.g. a shot) into a triggering event that results in the muscular injury. Understanding this, and coming up with solutions to control these interactions instead of just the individual risk factors can lead to a significant reduction in the incidence of injury<sup>[1]</sup>.

The multifactorial nature of the injury makes it necessary to use detailed and precise diagnostic terminology and to avoid merely traumatic definitions such as “dynamic overload” or “muscle imbalance”, which are insufficient and do not provide relevant information to identify the potentially modifiable causes of injury<sup>[2]</sup>.

To date, medical literature divides risk factors into two categories: intrinsic and extrinsic factors classified as modifiable or non-modifiable. There is a need for a risk factor model that explains the interactive, dynamic and emergent behaviour of risk factors in the real life scenario. Intrinsic and extrinsic risk factors were classified and conceptualized, with a broad description related to the extrinsic in the literature and minimization of the intrinsic that will later be described as “slowly-modifiable”. The intrinsic factors are predisposing factors, while extrinsic factors increase the susceptibility of a player to injury. Interactions within or between these groups will then result in an injury. Currently the paradigm should be focused on

the functionality, plasticity and interactivity of these risk factors, to detect their adaptability and the relationships that each one has in the specific context modifying the risk of injury.

Classifying risk factors into those that can be fastly-modifiable and slowly-modifiable factors is much closer to the current reality, where not all factors considered as intrinsic are unchangeable. Some factors change slowly respect to the macroscopic function they produce and thus, have a long lasting effect and can be experienced as constant. They were classically classified as structural “freezing” their behaviour.

Newer scientific knowledge creates a broader new scenario that will enable an understanding of all risk factors can modifiable or adaptable but all plastic. The target of this article is to go over the risk factors and give the new approach related to this conceptualization and on how to manage a possible shift in scoring variables in every situation.

Some scientists have developed predictive models based on statistical methods to define and identify these athletes at risk. These would be of value in casethat can be completely predicted but the football world is variable, random, unpredictable, with many possible unforeseen and unplanned scenarios playing out and the consequences varying based on individual traits and reactions. The paradigm must be changed with a focus on how individual and contextual modifications can potentially change injuries profile or/and susceptibility. For example, each coach has his methodology and training techniques that affect the injury profile, thereforewe could state that many trainers “do not produce hamstring injuries” and are more prone to generate calf injuries.

Scores or markers for specific risk factors have been described in order to assess and quantify the risk, but these methods should be changeable or adaptable, as risk factors do not always behave in the same way as a result of complex and emergent biological systems behaviour. The interaction of molecules and organelles form cells whose properties cannot be explained by properties of the isolated components; cells form tissues, which have different properties than isolated cells, and such tissues are combined in organs, which in turn form systems, organisms, and so on, through a self-organised process. Muscle *in vivo* function involves all these correlated levels which are nonlinearly and dynamically integrated. At each level new properties and functions that cannot be explained by any single component emerge; thus, variations of isolated variables are unable to capture the coordinated activity that involves all the functional levels.

Each level functions at different time scales (i.e. while the bottom levels (molecules and muscle cells) vary at very short time intervals (ms), upper levels change slowly (motor system reflexes last tenths of seconds and voluntary motor activities tens of seconds). When a change affects any system level, a qualitative re-organization within and between the micro and meso components try to keep the functionality. For example, developing fatigue through exercise, physiological regulation involves local mechanisms (at cellular level) that compete on short time scales. When the local balance is progressively lost, more distant mechanisms (e.g. supra-spinal, cortical) that compete on larger time scales need to intervene till the effort was untenable within that state. Then recovery time or an injury is needed for the longer time scales mechanisms to be ready again. So, with prevention purposes, we should think about that coordinated multiple time scales functionality in biological systems.

Many professional players have suffered injuries that have left an imprint on their musculoskeletal system, or have been exposed to some disease or disorder which they manage playing their sport.

The injury has to be understood as a process of natural selection, to which the athlete is constantly adapting and that will bring the qualities and capabilities to be able to excel or stop playing definitively<sup>[3]</sup>. Imbalances that have caused an injury have to be considered as positive adaptations before implementing preventive measures of correction, which in most cases and especially in professional athletes can be highly counterproductive, because in most cases due to the interactive relationship between them it generates an overload increasing the susceptibility to injury.

It must be considered that a stimulus or factor that has been harmful in a given situation can become protector in another completely different. Training load is a good example of this antagonistic effect. Both over- and under-training has been shown to increase the injury risk<sup>[4]</sup>. The same workload may produce a protective effect or under different conditions, increases risk of an injury or cause an injury directly<sup>[4]</sup>. For instance, low as well as high speed resistance-training levels can increase hamstrings injury risk. Due to the antagonistic effect of workloads, we shouldn't study training and competitive loads volume but the individual and temporal adequacy of that loads and an understanding of the time of season and schedule.

Neuroplasticity is a process that represents the ability of the nervous system to change its reactivity as a result of successive activations<sup>[5]</sup>. Such reactivity allows the nervous tissue to undergo adaptive changes in perception and cognition. For this reason it should be considered as a tool of countless value to support a controlled, replicable plan of neuro-rehabilitation/ readaptation<sup>[6]</sup>.

We refer to plasticity as changes in neural networks in response to training, injury, rehabilitation, pharmacotherapy, electrical stimulation and gene and stem cell therapies<sup>[7]</sup> being distinguishable two groups: plasticity of neural networks and plasticity at synapses.

## NEW APPROACH PROPOSAL

### **Anatomical variability (intrinsic/ unmodifiable/ adaptable)**

This is a key factor to assess the risk of injury. For instance, soleus muscle injuries show different patterns related to their aponeurosis. On average an injury located in the posterior fascia is considered a mild lesion but in a situation of anatomical variability with absence of central aponeurosis becomes severe. The posterior aponeurosis assumes the central one in terms of connective support. The same risk factor could have different score depending on the anatomical variability. Anatomical variation can also play a role in differences in gender injury profiles. Lower body injuries can link with angle of bone attachment (like at the hip joint), joint laxity, bone density etc.

### **Training and match load (extrinsic/modifiable/adaptable)**

When adjusting the volume and intensity of football training and matches without a proper periodized plan, there is associated with an increased risk of injury<sup>[8,9]</sup>. Rather than evaluate training and competitive load in an absolute way, we should analyse in an individualized way, looking for individual patterns. Within that it's fair to say that current top football teams schedule density, with deficit recovery time between games, contributes to increasing the risk of injury<sup>[10,11,12]</sup>. There is evidence that rate of injuries increases when playing 2 matches per week. The congested fixtures result in teams having minimal training sessions with a focus during the season usually on tactical strategy and minimising workloads to enable adequate recovery between games. Within a team sport like football it is important to balance the workload of all the players, ensuring that uninjured players not getting enough match time, still undergo

adequate loading, while ensuring that players playing most of the match minutes have enough recovery time. This would vary between different players, players age and total volume of work.

#### **Global health (intrinsic/ modifiable/adaptable)**

The lowering of immune defence in sports is associated to moments or periods of high cortisol that decrease the lymphocyte rate and specifically natural killer lymphocytes<sup>[13]</sup>. Values below 4% of this population can be associated with overtraining and chronic fatigue with predisposition to recurrent infections such as Epstein Barr, herpes zoster etc. having negative impact both health and performance. The marked and sustained increase in IL-6 together with other cytokines such as TNF alpha or ultrasensitive C-reactive protein can be identified as an inflammatory profile active and predispose to pathology and injury<sup>[14]</sup>.

The increased intestinal permeability associated with stress and intestinal ischemia, dysbiosis, opportunistic infections or SIBO (Small Intestinal Bacterial Overgrowth), and other situations can define a gastrointestinal system called "gut athlete" that requires special care to avoid its progression to more severe inflammatory or immunological conditions with chronic fatigue symptomatology.

Searching for individual optima and detecting situations of important changes in these ranges that allow early detection of fatigue, sleep disturbances, and predisposition to injury is a key point on identify plastic risk factors. It is important to keep in mind that values of normality provided by the laboratory for the general population may have a different meaning in the athlete population and may not conform to the objectives sought.

The travel involved in modern day football can increase the risk of illnesses as players may be exposed to different climatic conditions every few days, different quality of food, hygiene standards and in some countries require combatants against things like malaria.

#### **Age (intrinsic/ unmodifiable/adaptable)**

Age as a risk factor has always been circumscribed to the chronological, but there is a huge scope to be considered into account when dealing with risk factors. Biological age, maturity age or even mental age has to be considered<sup>[3]</sup>.

Age is an important risk factor for the injury. Players under 22 had a significantly lower incidence than players between the ages of 22 and 30. Although, it should be mentioned that the process of growth and maturation of the individual is not totally parallel to his chronological age. There are subjects who have an accelerated maturation process and show developments anticipated at their age and which is called early maturity. There are subjects who show slower development with respect to their age called late or immature mature and others who have a development according to their age. Premature maturity, from the sporting point of view, has advantages such as the ease to be integrated into sports programs and the achievement of early sports results. Late maturity has advantages by allowing a progression according to age, the absence of pressure to achieve results and possibly the absence of sports saturation. It is evident that when young age categories (children, cadets and juniors or juveniles) are considered, those born in the first part of the year are in an evolutionary state superior to those born in the last part of the year. Hence, it is frequent that sports teams tend to have more individuals born in the first months of the year than in the latter. That is why, there are research lines that advocate and take into account more the biological maturation of the individual than the chronological age. Less developed players, constantly required to

compete and train against more early developers compromises the development of the player and increases the likelihood that loading patterns will not be fair for all players and increases the likelihood of injury<sup>[6]</sup>.

Aging also links with cognitive ability, what a player lacks in physical attributes he makes up in cognitive ability, quicker decisions and reading of the game. Makes their play more efficient and economic and adjusts role within the team<sup>[3,15]</sup>.

A lot of the research related to youth and biological development has been focused on male players, but their needs to be a greater understanding on the effect of puberty on female players. This could also ensure that integration between male and female players does not continue from childhood to a point where it is detrimental to the female player<sup>[3]</sup>.

#### **Gender (intrinsic/ modifiable/adaptable)**

Low ferritins levels without anaemia is common for female players and determine the possibility of adaptation table and energy savings. On the other hand, very diminished ferritin has been associated with difficulty falling asleep, symptomatology of restless legs and a bad rest that in the long run is reflected by decreases in values of IGF-1 (somatomedin C) manufactured in the deep sleep phases. These conditions linked with Iron deficiency could increase the risk of injury.

#### **Ethnicity (intrinsic/ unmodifiable/adaptable)**

Ethnicity seems to be an intrinsic and unmodifiable point related to risk factors, but have to make sure that the phenotype coincides with genotype, otherwise could be very confusing in terms of classifying individuals. While ethnicity and genetic profile cannot be altered treatments and prevention strategies can be enhanced when considering the genotype. Modifiable factors related to ethnicity can be cultural specifications and geographical conditions, which can affect the players diet intake and food tastes, as well as surfaces and equipment they begin playing on.

#### **Biological basis and genetics (intrinsic/ unmodifiable/non-adaptable)**

For long physical and physiological tests have been cornerstones of talent identification and development. While weaknesses are often just considered in isolation, the information obtained from such assessments can be useful to help identify additional risk factors, such as seeing a player is much weaker or slower when turning of one leg than the other, or finding not just strength but proprioceptive differences in the limbs. Aspects such as core strength and stability can also help decrease injury risk in other regions of the body. Analysing movement efficiency and localised and general fatigue and when it occurs can also be important as they provide the ceiling of performance for the player. In addition to specialised sport specific tests, there are some general tests such as functional movement screening and isokinetic tests.

#### **Body composition (intrinsic/ modifiable/adaptable)**

The body composition is a modified risk factor. There are very few studies that analyses the correlation between the rate of injuries and body composition. The exploration like dual energy x-ray absorptiometry allows to determinate the variation of body weight and composition. This exploration could tell if the variation is due to lean or fat mass and where is that mass being accumulated<sup>[16]</sup>.

Some hypothesis say that the athletes with high percentage of body fats have diminished body control that could complicate the

coordination of body actions or it produce faster the body fatigue that leads to injury. This study tried to determinate the association between the body fats and injury rates and found no differences but observed the association between abdominal obesity and increased risk of lower body musculoskeletal injuries<sup>[17]</sup>. Knowing that fatigue is one of the risk factors of MSK injuries and overweight or abdominal obesity can precipitate it we propose the periodic monitor of body composition to decrease the fat mass.

#### **Type of fibers(intrinsic/ unmodifiable/non-adaptable)**

There are two major muscle fiber types: type I and type II fibres. The humans muscle is composed of a mixture of type I and type II. The fiber type depends not on any intrinsic feature of fiber itself but on the motor neuron supplying that particular fiber. The speed of muscle fiber contraction is directly proportional to relative myosin ATPase activity while fatigability relates to relative oxidative capacity. Type I fibers have low ATPase activity are slow twitch, have high oxidative and low glycolytic capacity, and are relatively resistant to fatigue. Type IIA fibers have high myosin ATPase activity are fast twitch, have high oxidative and glycolytic capacity, and are relatively resistant to fatigue. Type IIB fibers have high myosin ATPase activity are fast twitch, have low oxidative and high glycolytic capacity, and fatigue rapidly<sup>[18]</sup>.

Type IIX fibers have high ATPase activity are fast twitch, have low oxidative and high glycolytic capacity, and has intermediate resistant to fatigue between that of type IIA and type IIB. Slow fibers contract more slowly and generate less mechanical power but also spend less ATP, particularly in relation to tension development. Fast fibers can produce higher mechanical power and contract more quickly, but have a higher ATP expenditure. The two aspects, mechanical and energetic, together make slow fibers more suitable for low-intensity and long-lasting activity, whereas fast fibers are best for short and strong contractile performance. In both cases, a full consistency is required between the properties of the molecular motors and the metabolic processes aimed to ATP regeneration<sup>[19]</sup>. Mitochondrial content varies significantly in relation to fiber type. In human fibers, the mitochondrial volume varies from 6% in type I fiber to 4.5% in type IIA and 2.3 % in type IIX fibers<sup>[20]</sup>. The human body is mainly composed of type I and type IIA fibers. During the aging the histochemical fiber type profile does not appear to change in human skeletal muscle but the relative proportion of fast fibers is reduced probable due to neurogenic changes leading to selective denervation of these fibers. The motor neurons may change the total amount of activity, but they cannot change their frequency pattern. In these cases, like extrinsic stimulator, the training protocols play very important role that could increase motor neurons activity<sup>[19]</sup>. And we have to take it account for specific training programs and in case of injury during the rehabilitation.

For example, during the injury the former scar tissue is histologically and functionally inferior then normal muscle fibres. The repair mechanism during the muscle injury distinguishes three stages: destruction, repair and remodelling or fibrosis stages<sup>[21]</sup>. During the healing is very important to extend the regeneration phase and abbreviate the fibrosis stage, to avoid the formation of dense scar tissue within injured muscle. To prevent this complication the active treatment should be started gradually. After few days of immobilization the isometric training should be introduced then followed by isotonic training and later by isokinetic training always when the corresponding training could be performed without any pain.

#### **Type of spent energy(intrinsic/ modifiable/adaptable)**

Football is an intermittent sport whereby players utilise all three energy systems. The ATP-PC system is important for the quick, sharp and often match changing events such as jumping, shooting, tackling etc. When these actions last a little longer or are in quick succession players, will begin breaking down carbohydrate sources and producing lactic acid. Recovery from these high intensity actions and fuel for low to moderate intensity actions relies on the aerobic system. While carbohydrates and fats can be used to provide the fuel, the fat oxidation pathway takes longer, thus the main source of energy for athletes is carbohydrates. The correct intake of carbohydrates before, during and after exercises can improve endurance and performance<sup>[22]</sup>. The management of the energy sources during the training, rehabilitation and re-training program must be present because the correct nutrition could help to reach better target of rehabilitation and training without losing lean mass and increasing fat mass. The nutrition strategies must be adapted individually to athletes, to type and intensity of the exercise, fluid losses and environmental conditions. When players are unable to maintain the energy levels required for the activity, fatigue may set in which compromises both the technical execution of actions and the perceptual and cognitive ability, compromising decision making and reducing things like reaction time, speed, power etc. All of this can combine to increase the risk of injury<sup>[15]</sup>.

#### **Previous injury(extrinsic/ unmodifiable/adaptable)**

The history of previous injury has been demonstrated the most regular risk factor for future injuries in different sports<sup>[23,24]</sup>. The presents of previous injury is non-modifiable risk factor. The changes in strength, proprioception and kinematics could lead to better motor control and function but any prevention program cannot change it but anyway the previous injury must be identified because then modification of training methods could be incorporated. Depending on sport the previous injury regardless of body location has moderate evidence like a risk factor<sup>[25,26]</sup>.

It is also important not just to look at the history of injury in terms of anatomical site but return to training and play, level and progression of rehabilitation and return. Returning too early can increase the risk of both reinjury and related injury.

#### **Cognitive-perceptual (intrinsic/ modifiable/adaptable)**

Football players of high level of cognition skills have the change to reduce the recovery time after an injury<sup>[27]</sup>. Players are faced numerous stimuli at the same time. Most of the time the player must identify which are the relevant stimuli and respond accordingly. Film and video are being used as a tool to sport specific training<sup>[27]</sup>. Evidence shows in football that the highest prevalence of contact injuries emerges in one-on-one interactions and that information-movement couplings regulate the emergence of affordances for preventing contact injuries during team game performance<sup>[28]</sup>. Incorporating affordances into training may be implemented as part of player rehabilitation, in order to safely bring an individual back to full playing capacity with enhanced knowledge of the environment. From that point of view, there would be players more able to avoid contact injuries than others. Sport specific cognitive training can be combined with physical movements or can be useful when players are injured or at risk of overtraining to bring about cognitive change without the physical risks.

Personal cognitive skills such as risk taking, impulsivity, reflex, special awareness, pattern identification can all be key. Players with high levels of special awareness and pattern identification will anticipate play better, and decrease the likelihood of decreased



technical performance. However, such players are at increased risk of contact injuries, as other players might be slower to react to the threats they pose, increases the number of tackles and challenges made on them etc<sup>[15]</sup>.

Poor visual and verbal memory has been linked with higher injury risk. Stress (both physiological or mental) have neurocognitive responses and can lead to compromising cognitive and physical performance, which increases risk of injury<sup>[29]</sup>.

#### **Psychosocial(intrinsic/modifiable/adaptable)**

Mental skills such as stress, anxiety, anticipation, reaction time can all indirectly influence risk of injury. A player who is distracted will likely compromise his technical execution resulting in biomechanical related injuries. Stress, and anxiety also compromises decision making and perceptual skill, which means players might not be able to identify possible threats and avoid those situations and also make decisions that might lead to injuries. Personality type and experience can also be considered the risk factors. Certain personalities are more likely to adapt a play through the pain attitude, hide injuries, return to play earlier, push themselves too far during rehabilitation programmes, and overtrain<sup>[15]</sup>.

Match and off-field situations including team dynamics, player-coach interactions, contract length, team standing can all also have an indirect relation to injury as these can all impact the focus and match actions<sup>[15]</sup>.

#### **Nutrition (extrinsic/modifiable/adaptable)**

Sports nutrition today is no longer a matter only of macronutrients energy and calories but aspects such as brain neuroplasticity, epigenetics, or the intestinal microbiome can make a difference. In a team there are players with a big diversity who perform all of them at a high level but carry out different nutritional strategies, which makes us think that there is a great “metabolic flexibility” due to factors such as adaptation to sports, gene expression, quality of rest and sleep or even motivational or neurophysiological aspects.

#### **Training methodology(extrinsic/modifiable/adaptable)**

Stretching has long been included as an important part of the training program both for improved flexibility, but also as a tool of injury prevention. Traditionally static stretching was incorporated into both warm-ups and cool-downs and seen as adequate for injury prevention. Varying options exist on the method of stretching; some research indicates that static stretching might be counterproductive for speed movements, which follow the stretching session. Periods of static stretching in the warm-up tends to also bring down the heart rate, with newer warm-up methods endorsing more dynamic forms of stretching and focusing on specific muscle activation. Muscle activation is not just a muscular process, and incorporates a strong neural element, highlighting the importance of the central nervous system in execution of action. Neuromuscular training and inclusion of proprioceptive training in the warm-ups also reduces the risk of injury<sup>[30]</sup>. Lack of flexibility rather than joint laxity seems to be linked more with injuries.

#### **Specific sports actions(extrinsic/modifiable/adaptable)**

Players are at increased risk of both contact and non-contact injuries during specific football actions. Contact injuries are likely to occur during dual challenges for the ball, or tackles and with both the tackler and the tackled player at same risk. Other high-risk actions include interactions with the goalkeeper such as when the

goalkeeper jumping to catch/punch the ball, kicking and striking the ball, landing after a jump, accelerations and decelerations. All other actions tend to be low risk. Playing position and team and individual style of play could relate to the number of high risk actions per player. A study of German female footballers found defenders to be at the highest risk of injury, followed by strikers, goalkeepers and lastly midfielders. The period of the match also has some relationship with injuries. The first and last 15 minutes of each half tend to have the highest number of injuries with the first 15 minutes at risk for mild injury (possible as a result of not being well warmed-up or mentally in the game) and the last 15 minutes for moderate injuries (probably with fatigue playing some role). When players experience fatigue, eccentric strength decreases. The eccentric overload increases the risk of tearing in the muscle-tendinous unit. The time of season can also link with injury risk. Quadriceps injuries tend to be higher in pre-season with hamstring injuries higher in season.

Compensatory mechanisms can often apply to make up for incorrect technique. These mechanisms can increase risk of injury. A functional movement screening can identify weaknesses in key movement patterns. Football includes complex movements incorporating different mechanical systems that must be co-ordinated to enable fluid and correct movements. The central nervous system plays a key role in co-ordinating the series of actions, perceiving information required to correct or adapt the action and to decide follow-up actions.

## CONCLUSIONS

In the time of new cognitive approaches neuroplasticity has to be taken into account as a tool to modify or adapt intrinsic and extrinsic risk factors and consider the score variable according to the scope, which player is involved in. Pushing to change the actual paradigm of prevention to adaptation, more dynamic and function will be able to reduce the incidence of injuries and increase the performance of professional players.

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