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REVIEW / SPECIAL ISSUE

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Summary

Findings from efficacy studies have shown decreased in ACL injury rates in (predominantly female) athletes participating in prevention programs. Given the inherent higher ACL injury risk for females, the majority of intervention studies, have focused on female athletes. Subsequently, the content of exercises in ACL prevention programs is directed to target the modifiable ACL injury risk factors for female athletes. The literature is generally scarce regarding the efficacy of prevention programs to reduce ACL injuries in male athletes. In general, reduction of ACL injury rates seem to be limited to (young) female athletes and male athletes playing at low level of sports. Typically, ACL injury prevention programs entail a combination of plyometrics, strength training, agility and balance exercises. A problem is that improvements of movement patterns are not sustained over time. The reason may be related to the type of instructions given during training. Encouraging athletes to consciously control knee movements during exercises may not be optimal for the acquisition of complex motor skills. In the motor learning domain, these type of instructions are defined as an internal attentional focus. An internal focus, on one's own movements results in a more conscious type of control that may hamper motor learning. It has been established in numerous studies that an external focus of attention facilitates motor learning more effectively due to the utilization of automatic motor control. Subsequently, the athlete has more recourses available to anticipate on situations on the field and take appropriate feed forward directed actions. The purpose of this manuscript was to present methods to optimize motor skill acquisition of athletes and elaborate on athletes' behavior.

Keywords
ACL injuries– Prevention– Motor learning– Attentional focus

REVIEW / SPECIAL ISSUE

Using principles of motor learning to enhance ACL injury prevention programs

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Introduction

Team-based exercise training has become a popular method for delivering anterior cruciate ligament (ACL) injury prevention programs in various sports [32]. Systematic reviews of efficacy studies have demonstrated that ACL injury prevention programs reduce injury rates and, as such, provide an evidence base for implementation [4,20,25,43,45]. Even though the benefits of such programs have been demonstrated in efficacy studies, they provide limited knowledge of real-world benefits [18]. The benefits of such programs has largely been undertaken in efficacy studies involving highly controlled settings [18]. However there exists a gap between research and practice in the field of sports injury prevention and safety promotion [24]. The implementation in the real-world setting remains a major challenge [46]. This is often based on the assumption that a transition follows from successful efficacy research to effectiveness research under real-world conditions [21]. Although researchers may have sound biomedical evidence for a prevention training, this is in no way guarantee it will be successfully adopted [16]. For example, only 16.7% in UEFA and Norwegian professional football teams adhered to

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Anwendung von Prinzipien des motorischen Lernens zur Optimierung von VKB-Präventionsprogrammen

Zusammenfassung

Angesichts des höheren Risikos für VKB Verletzungen bei Frauen wurden die Übungen der entsprechenden Präventionsprogramme auf modifizierbare VKB-Verletzungsrisikofaktoren von weiblichen Athleten ausgerichtet. Wirksamkeitsstudien haben gezeigt, dass sie insbesondere bei jungen Sportlerinnen und auf niedrigem Sportniveau spielenden männlichen Athleten erfolgreich sein können. In der Regel beinhalten diese VKB-Präventionsprogramme eine Kombination aus plyometrischen Übungen, Krafttraining, Beweglichkeit und Balanceübungen. Noch ist nicht genau bekannt, welche Faktoren zu ihrer Effektivität beitragen. Auch etwaige erlernte Verbesserungen des Bewegungsmusters können nicht immer langfristig erhalten bleiben. Hierfür könnte die Art der Trainingsanweisungen verantwortlich sein, die darin bestehen, Kniebewegungen während den Übungen bewusst zu kontrollieren. In der motorischen Lerndomäne ist diese Art der Anweisung als interner Aufmerksamkeitsfokus definiert. Dies kann zu einer bewussteren Art der Kontrolle führen, die das motorische Lernen paradoxerweise behindern kann. In zahlreichen neueren Studien konnte nachgewiesen werden, dass ein externer Aufmerksamkeitsfokus das motorische Lernen durch den Einsatz der automatischen motorischen Steuerung effektiver gestalten kann. Nach dieser Theorie stünden dem Athleten mehr Möglichkeiten zur Verfügung, um Situationen auf dem Spielfeld voraussehen und geeignete antizipative Aktionen einleiten zu können. Der Zweck dieser Übersichtsarbeit besteht darin, Methoden zur Verbesserung der motorischen Lernfähigkeiten von Sportlern vorzustellen und das Verhalten der Sportler zu erläutern.

Schlüsselwörter
VKB-Verletzungen – Prävention – motorisches Lernen – Aufmerksamkeitsfokus

an evidence-based hamstring injury prevention program [7]. Only those prevention programs that are adopted by athletes, coaches, other intermediaries and sporting bodies will actually prevent injuries in the real-world [16]. High quality implementation planning can be achieved with a strategic, ecological approach based on a partnership between program developers (researchers) and program implementers (gatekeepers and end users) [16]. It has been recommended that researchers, practitioners and community end users collaborate early in the implementation planning process [16].

In light of the aforementioned, many challenges exist. Looking at effectiveness, ACL injury rates have not decreased over the last decades. To illustrate, an increase in the annual injury rate of ACL injuries per 1000 athlete-exposures for female football players from 0.13 (1990–2002) to 0.25 (2009–2014) has been reported in the National Collegiate Athletic Association (NCAA) [1,41]. In an update of 2004–2013 compared to 1988–2004, increases in the average annual number of ACL injuries were found for male and female players in basketball, ice hockey, field hockey, football and volleyball whilst a decrease has been noted for baseball and women's gymnastics [2].

Considering that ACL injury rates are still high may, in part, be attributed to the fact that not all available prevention strategies have been employed to their full potential (Table 1).

For example, a survey pertaining an injury prevention intervention, revealed that athletes complied well with the protocol, but coaches did not, especially at the middle school level [42]. In female athletes, about 70% of ACL injuries can be prevented, if an injury prevention is done for a total of more than 30 min per week during the in-season (preferably over multiple sessions) [44]. Based on recent work by Haddon et al. intervention strategies against injury can be divided into two dimensions [48]. In regards to sports, in the first dimension, interventions can be targeted at the athlete, rules and regulations, sport equipment and the physical, sociocultural and policy setting or context within which the sports injury occurs. The second dimension deals with the time frame in which an injury occurs, i.e. pre injury event, injury event and post injury event. The purpose of this manuscript was to present methods to optimize motor skill acquisition of athletes and elaborate on athletes' behavior (first domain) and pre injury event (second domain) in the context of ACL injury prevention [48].

The goal is that athletes acquire the ability to sustain optimal motor control while engaging in complex athletic environments, whilst minimizing their risk to sustain an ACL injury.

Target the athlete

In the following section we will present novel motor learning training methods that might improve ACL injury prevention strategies, addressing athletes' behavior in a pre injury event.

Attentional focus

While the efficacy of ACL injury prevention programs has been demonstrated (mainly in handball and football), the ideal combination of training components within these programs remains unclear [20]. Typically, ACL injury prevention programs entail a combination of plyometrics, strength training, agility and balance exercises [4,20,45]. A problem of the current ACL injury prevention programs is that they appear to result in only temporary improvements in movement patterns that are associated with

Table 1. Use of internal versus external focus instructions while learning a double legged jump landing task.

Goal: improve symmetrical landing mechanics	Internal focus instructions	External focus instructions
	Land with feet at shoulder width	Land on tape markers on the floor
	Keep your knee over toe land with a bent knee	Point knees towards cones
	Bend your hips and trunk	Touch the cones with your hands

reduced ACL injury risk. For example, ACL injury rates can be reduced during an intervention, but within one year after cessation of the intervention, rates return to pre-intervention levels [29]. Hence, the protective effects are not sustained after completion of an intervention. Amongst other reasons, the temporary effects may be related to the content of the program and the type of instructions that were given. Commonly, in ACL injury prevention, feedback and instructions are given that directs the athlete's attention to various aspects of their movements. It has been generally assumed that athletes benefit from explicit verbal information about how to best perform a motor skill [30]. In the motor learning domain, this type of attentional focus is defined as internal focus (IF) [52]. Frequent given instructions are "keep your knee over the toe", "land with a flexed knee", "raise your knee to the level of your hip" or "land with your feet shoulder-width apart" [30]. While there may be intuitive reasons that coaches and trainers frequently give IF instructions, this approach may not facilitate the full potential to learn motor skills [51]. IF instructions induce conscious control of one's movements, which may interfere with the normal, automatic motor control processes and lead to a breakdown in the natural coordination of movements [51]. A second concern is that ACL injury programs that use IF instructions may need constant practice. Recent work by DiStefano et al. exemplifies that, as the effects of an injury prevention program resulted in only transient improvements of landing technique [15]. The authors suggested that injury prevention programs may need to be performed constantly, to maintain the protective effects against injury [15]. For sure this is an option, but why don't we try to implement alternative approaches that promote more long term effects in ACL injury prevention programs? Using principles from the domain of motor learning may have that potential. Motor learning is defined as the process of an athlete's ability to acquire motor skills with a relatively permanent change as a function of practice [37]. Retention of motor skills in ACL injury prevention programs with IF instructions are generally disappointing [15]. An external focus (EF), directing attention to the outcome of movements has been shown to be superior over learning with an IF [51]. Relevant for ACL injury prevention, a systematic review revealed that motor skills can be enhanced, relevant to reduce ACL injury risk, using EF compared to an IF instructions [9]. Adopting an EF results in a decreased knee joint loading exemplified by reduced vertical ground reaction forces, increase of center of mass displacement and larger knee flexion angles during landing from a jump [9]. Moreover, performance of athletes as measured with e.g. jump distance, shows better results if EF instructions are provided compared to IF instructions [9].

However, in the majority of ACL injury prevention programs, athletes are instructed to focus on conscious movement execution (IF) [25]. Conscious control of movements (IF) hampers the natural movement coordination [53]. Additionally, encouraging athletes to increase awareness and knee control during standing, cutting, jumping and landing (IF) [26], requires attentional capacity. In turn, this reduces the available capacity to anticipate and respond to situations occurring around the athlete on the field. These attentional and environmental components of neuromuscular function are largely not addressed in current ACL injury prevention programs [23]. In fact, In ACL injury prevention programs, athletes learn motor skills in rather controlled conditions which rely on neuromuscular feedback mechanisms.

Instead of using instructions that induce an IF, we have suggested to adopt motor learning using EF instructions (Fig. 1) in ACL injury prevention [9]. Adopting an EF of attention, requires less attentional demands for one's own movements as these are executed in a more automated fashion [51]. Hence the athlete has more attentional capacity to anticipate and respond adequately and in a timely manner to actions of opponents. Adequate anticipation of a potential high-risk injury situation may give the athlete sufficient time to avoid the situation. In case

Figure 1
Postural stability.
To promote an external focus of attention the athlete should be instructed to ''Focus on keeping the bar horizontal'' Instruction such as ''stabilize your knee'' should be avoided because this induces an internal focus of attention.

the time frame is too short to avoid a high-risk situation (change in direction, perturbation opponent), the athlete still has an opportunity to prepare for the upcoming event. Such feed-forward mechanisms may be important as they allow the central nervous system time to generate muscular force and for example control correct lower extremity alignment during landing to reduce ACL injury risk.

Groups to target

There is evidence from meta-analyses that support the efficacy of ACL injury prevention training to reduce the ACL injuries [4,20]. Sadoghi et al. pooled the ACL injury rates and calculated an overall risk ratio of 0.38, corresponding to a 62% decrease in the risk of ACL injury in the intervention groups [36]. Stratified for gender, the decrease in risk was 85% for male and 52% for female athletes [36]. Of note, the reduced ACL injury risk in males was based on only two studies with very small sample sizes. The literature is generally scarce regarding the efficacy of prevention programs to reduce ACL injuries in male athletes [3]. A recent cluster randomized study revealed that male football players who were allocated to the FIFA 11+ group [39] group had a lower incidence of ACL injuries compared to those who followed their routine warm-up [38]. It should be noted however, that ACL injury reduction was only achieved in players in the lower divisions but not those who played in the higher divisions [38].
In short, findings from ACL injury prevention programs cannot be extrapolated to all sports and at all levels. Future ACL injury prevention interventions should incorporate elements specific for age, gender, type and level of sports tailored to the individual athlete (Fig. 2). This example highlights the need to consider the sports specific context and the athletes at stake in prevention programs. Specifically, incorporating training programs that are challenging, fun may have positive motivational influences for learning, which in turn could improve adherence to the prevention program. Learning style differences between genders should also be considered. In several studies, we were able to demonstrate differences between male and female athletes and how they responded to various type of instructions and feedback [8,50].

Athlete attitudes

The success of ACL injury prevention programs has been limited to the research cohorts and has not translated to widespread effectiveness, as ACL injury rates have not decreased over the last decades [1,22,35]. One reason is that the chances of success is highly dependent on the compliance of athletes and coaches [19,27,30]. Although there is evidence for the efficacy of injury prevention programs, a lack of implementation and uptake and ongoing maintenance of such programs is an ongoing concern [17]. For example, barriers expressed by coaches may negatively affect adherence. Issues like time restraints [33,49], distraction from training [33], skepticism of program effectiveness [34], lack of program variation [39], not sport specific [34,40] or complexity of implementation in their setting [31] are often reported. Lack of adherence from athletes is also a key factor as they state that it "takes too long", "is boring", "has no performance benefits" or "is too difficult" [30].

Figure 2
Practice youth football with elements of sports specific context.
Youth football players dribbling with ball using the SmartGoals (SmartGoals, Eindhoven, Netherlands) system. The SmartGoals consist of 6 frameworks that communicate wirelessly with each other and indicate by a light to which gate the player e.g. has to run or pass a ball. That results in a score. In this example, the players have to respond quickly and run towards the cones that light up. After they have passed through these, the next set of 2 cones will light in a random order.

Current ACL injury prevention programs primarily target the behavioral aspects, as athletes are required to follow specific training programs for it to be effective. But from an athlete's point of view, constantly doing the same intervention routine during each training session may, not surprisingly, reduce their motivation.
An additional approach would be to develop programs that are less formally structured and will be adopted by more athletes in order to improve effectiveness. We will illustrate this by the following assumptions. If we can reach for example 30% of the athletes in a real-world setting this hampers effectiveness. In case we change programs that are more easily implemented in regular training we could reach may be 60% of the athletes. Even though in the second example a less formal program is introduced, if it is used by more athletes and for a longer period, overall effectiveness may go up in comparison to traditional implementation methods.

Verhagen et al. point out that in order to translate biomedical knowledge to real-life injury prevention, behavioral aspects of athletes are important to consider [47]. Positive results are seldom fully adopted by a sports population, unless we understand the behavioral aspects [47]. Thus, we need to address what's in for the athlete and the coach if we expect them to adopt a program that from a medical standpoint may be sound but is not perceived as such by the stakeholders.
In the domain motor learning domain, the role of motivational influences on acquisition of motor skills has also been acknowledged [13]. In current ACL injury programs, the details of the training session are predetermined and are often directed by a coach or physical therapist. For example, they decide in which order tasks are practiced, the practice duration, and when or if instructions or demonstrations will be given. Thus, while coaches and physical therapists generally control most aspects of practice, athletes assume a relatively passive role. Yet, there is converging evidence that the effectiveness of skill learning can be considerably enhanced if the athlete is given some control [28]. Giving the athlete some autonomy over a practice session (e.g. order of exercises, variations, when to receive feedback) enhances motor learning in comparison with prescribed training schedules [5,12,14,54]. Self-controlled learning has been shown to initiate a more active involvement, enhances motivation and increases the effort invested in practice [6].
The type of feedback should also be considered, as positive feedback enhances interest and enjoyment and encourages athletes to raise their goals and expectancies for future performance [54]. Negative feedback may hamper motor learning and be less effective [13]. It provides negative competence information and therefore, decreases intrinsic motivation and beliefs about personal capability [6,11]. During ACL injury prevention programs, it would therefore be wise to give feedback after good instead of after poor trials (mention the correct instead of faulty movement patterns). Interestingly, most athletes when given self-control over practice, will request feedback after good trials [10]. In other words, athletes do not always require additional (negative) confirmation by a coach or physical therapist if an exercise was performed poorly.

Summary

Motor learning with an EF is effective in acquiring safe movement patterns. Adoption of instructions or feedback that induce an EF therefore has important implications for ACL injury prevention. It has been shown that retention of motor skills is

sustained when practice involves EF instructions. Differences in learning preferences between males and female athletes need to be taken into consideration.
Moreover, a generic program for athletes may have a group effect but may not effectively target those at most risk. ACL injury prevention programs should be tailored to the specifics of a sport, match contextual factors and be developed for athletes at most risk. The authors suggest that future ACL injury prevention should take into account the gender and the level of expertise of athletes and fit within the context specific to that sport.

Conflict of interest

There is no conflict of interest.

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