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ACL injury prevention, more effective with a different way of motor learning?

Anne Benjaminse · Egbert Otten

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Abstract

Purpose What happens to the transference of learning proper jump-landing technique in isolation when an individual is expected to perform at a competitive level yet tries to maintain proper jump-landing technique? This is the key question for researchers, physical therapists, athletic trainers and coaches involved in ACL injury prevention in athletes. The need for ACL injury prevention is clear, however, in spite of these ongoing initiatives and reported early successes, ACL injury rates and the associated gender disparity have not diminished. One problem could be the difficulties with the measurements of injury rates and the difficulties with the implementation of thorough large scale injury prevention programs. A second issue could be the transition from conscious awareness during training sessions on technique in the laboratory to unexpected and automatic movements during a training or game involves complicated motor control adaptations. The purpose of this paper is to highlight the issue of motor learning in relation to ACL injury prevention and to post suggestions for future research.

Conclusion ACL injury prevention programs addressing explicit rules regarding desired landing positions by emphasizing proper alignment of the hip, knee, and ankle are reported in the literature. This may very well be a sensible way, but the use of explicit strategies may be less suitable for the acquisition of the control of complex motor skills (Maxwell et al. J Sports Sci 18:111–120, 2000). Sufficient literature on motor learning and it variations point in that direction.

Keywords Motor control · Explicit learning · Implicit learning · Knee injury

A. Benjaminse (✉) · E. Otten
University Medical Center Groningen, Center for Human Movement Sciences, University of Groningen, Antonius Deusinglaan 1, 9713 AV Groningen, The Netherlands
e-mail: a.benjaminse@med.umcg.nl

A. Benjaminse
SportsFieldLab Groningen, School of Sports Studies, Hanze University Groningen, University of Applied Sciences, Groningen, The Netherlands

Introduction

ACL injury prevention training strategies mainly focussing on warm-up, technique, balance, strengthening, and agility exercises have continued to evolve and represent an ever-increasing and equally important research focus [12, 14, 21–23, 29, 30, 40, 42, 43, 48, 53, 65]. Recent epidemiological data, however, suggest that in spite of these ongoing initiatives and reported early successes, ACL injury rates and the associated gender disparity have not diminished [2]. The disparity between positive laboratory results and actual effects on injury outcomes suggests a missing link between current research outcomes and clinical applications for neuromuscular training interventions. One problem could be the difficulties with the measurements of injury rates and the difficulties with the implementation of thorough large-scale injury prevention programs. It is difficult to evaluate whether the preventive measure had any effect at all when we know very little about whether sports-active people have implemented or adopted information about preventive training or not. Another issue could be the fact that the transition from conscious awareness during training sessions to unexpected and automatic movements during a training or game involves complicated motor control adaptations. Post-intervention lower extremity positions and loading of the joint in the laboratory do not necessary reflect those on the field. The purpose of this paper is therefore to highlight the issue of motor learning in relation to ACL injury prevention and to post suggestions for future research.

Implicit versus explicit motor learning

Instructions can be effective in conveying goal-related information and educators commonly use them to teach and refine motor performance at all levels of skill [25]. There are ACL injury prevention programs using instructions and addressing explicit rules regarding desired landing positions by emphasizing proper alignment of the hip, knee, and ankle [22, 23, 26, 28, 30, 40, 41, 43, 46, 48, 51–53]. For example, the main goal of the neuromuscular training program of Holm et al. was 'to improve awareness and knee control during standing, cutting, jumping, and landing'. The players were encouraged to focus on the quality of their movements with emphasis on the knee-over-toe position [26].

This may very well be a sensible way, but the use of explicit strategies may be less suitable for the acquisition of the control of complex motor skills [34]. It has been shown that instructions that direct performers' attention to his or her own movements can actually have a detrimental effect on performance and learning and disrupt the execution of automatic skills, particularly in comparison with an externally directed attentional focus [33, 37, 67–69]. We want to emphasize that we need to make sure that a better landing technique after a jump happens automatically. Therefore, pre-programming with automatization with transfer for laboratory to field is most important.

The exact reasons for the beneficial effects of an external focus of attention are still relatively unclear. However, trying to consciously control one's movements might interfere with the normal, automatic motor control processes, leading to a breakdown in the natural coordination of the movement [32, 37].

The performance and learning of motor skills has been shown to be enhanced if the performer adopts an external focus of attention (focus on the movement effect) compared to an internal focus (focus on the movements themselves) [68]. In other words, implicit motor learning refers to the acquisition of a motor skill without the concurrent acquisition of explicit knowledge about the performance of a skill that is normally processed in an automatic way, explicit motor learning does refer to acquiring motor skills with an internal focus and specific knowledge about the performance of a skill [34]. Motor skills that are acquired explicitly tend to be less resilient under psychological [7, 18, 19, 32, 39] and physiological fatigue [31, 54], tend to interfere with the normal automatic processing of the motor schema [20, 32], tend to be less durable [5] and less robust [66] when a fast response is required and explicit learning may be affected to a greater extent by an individual's intelligence than implicit learning [17, 45, 57].

Considering the benefits of implicit learning, we feel that in the prevention of ACL injuries, we need to discover the possibilities of this method as it may produce more stable solutions under stress, anxiety-provoking conditions and fatigued states. The research group McNair, Onate and Prapavessis set up an interesting series of research projects, in which they examined the effect of different types of feedback on jump landing technique and subsequent landing forces [36, 49, 50, 55, 56]. The patterns shown in their results confirmed the theory mentioned earlier. They have compared technical instructions, visual feedback, auditory cues, and metaphoric imagery to controls. They first found that subjects can assimilate precise instructions related to the modification of lower limb kinematics and effectively and immediately lowered their ground reaction forces (GRF) [36, 50, 55]. However, in 2003 Prapavessis et al. found that the retention of these technical instructions is poor when the follow up is longer than 1 week [56]. Continuing this research, Onate et al. concluded in 2005 that reviewing one's own performance or one's own performance plus an expert model is more useful than expert only modeling (i.e., viewing an expert model trained in proper landing technique) for increasing knee angular displacement flexion angles and reducing peak vertical GRF during landing. They therefore suggested that visual feedback of one's own performance or one's own performance plus an expert model should be used in the implementation of instructional programs aimed at reducing the risk of jump-landing ACL injuries [49].

Currently, we do not know yet at what age an injury prevention program should be implemented to reduce potential neuromuscular and biomechanical risk factors [64]. From a motor learning standpoint, it is desirable that children at the youngest age groups (age 6–12) develop correct playing techniques from the beginning on. This also gives ample time for movements to become automatized. However, children are at a relative low risk for injury, e.g., soccer is actually a safe sport for children [16]. It seems therefore that spending effort, time, and money on implementing preventive methods might therefore not be desirable and should potentially start from 12 to 14 years [44]. But without calling it injury prevention (but e.g., exercises for performance enhancement [44]) in the younger age groups, enhanced body awareness will very likely already start and result in a more complete and accurate feeling of the body when learning certain movement skills.

Transfer from the laboratory to the field

The use of an explicit process is less efficient, attention-demanding, and slow [34]. Having to pay attention to the lower extremity is impossible as attention to the game, players and ball and fast acting is required. A high-cognitive task will be less robust during the game.

In the ACL injury enigma, psychological and physiological pressure or fatigue is an important factor. Myklebust et al. reported that athletes are at a higher risk of suffering an ACL injury during a game than during practice [43]. Fatigue has also been proposed to be a contributor to non-contact ACL injuries [24, 47, 61]. For obvious reasons, a game constitutes more psychological and physiological stress compared to a practice session. Especially in later stages of competition, fatigue may have a cumulative, unfavorable effect on neuromuscular control and may potentially result in hazardous movement strategies [35]. The decreased capacity for controlling body movements after fatigue will potentially be more prominent when appropriate landing techniques have been taught in an explicit manner. Also, the possibility that implicit learning may immunize the athlete more against the often debilitating influence of psychological stress on motor output should not go unheeded.

In summary, extensively repeating the ideal movement that is explained and demonstrated might be too 'cognitive'. As implicit learning has proven to be effective in establishing a certain movement goal or effect [37, 62, 67–69], we assume and propose that implicit motor learning might also be potentially beneficial for injury prevention. Lowering chances of injury during a high performance task is an integrated part of that task itself. This implies that not only the interaction with the environment can be optimized but also the conditions within the body in terms of balance of joint loads for instance. This optimization could be achieved by assisting the athletes to find individual optimal performance patterns for given complex motor skills and to find an individual way, including its effective variations, to control the forces that belong to those complex tasks. In this paper, we would like to put forward that implicit learning could well be an effective way to let the brain and body of the athlete reach a condition in which performance is high, yet the chances of injury low.

Mirror neuron system

Implicit, observational learning, where imitation of what is shown plays an important role, might be a good alternative in trying to reduce the ACL injury incidence. Imitation is the copying of body movements that are observed [8]. A fundamental question with imitation is: "How does the observer's motor system 'know' which muscle activations will lead to the observed movement if the observer does not see the underlying muscle activation in the actor?" [8]. It has been suggested that the mirror neurons resolve this correspondence problem by automatically mapping observed movements onto a motor program, thus leading to the widely held view that the mirror neuron system is crucial for imitation and observational learning [9, 13, 27, 38, 58–60]. Mirror neurons are visuomotor neurons that fire both when an action is performed and when a similar or identical action is passively observed [59]. A template of the movement becomes active through the mirror neurons by which the movement itself becomes clear in terms of motor actions, without high cognitive reflections [60]. Mirror neurons mediate understanding of action because neurons that represent an action are activated in the observer's premotor cortex. This automatically induced, motor representation of the observed action corresponds to that which is spontaneously generated during active action and whose outcome is known to the acting individual. An important functional aspect of mirror neurons is therefore their ability to link visual and motor properties.

It is interesting to note that the amount of mirror neuron activation correlates positively when the athletes are already proficient in performing that skill [10]. Also, stronger mirror neuron activation is found when observing the same gender [11]. An additional prospective study showed that dancers who were initially naive to certain steps showed an increase in mirror activation over time when they received motor training in which they became skillful in performing the same steps [15].

Implications for ACL injury prevention and future research

The previously mentioned studies [36, 49, 50, 55, 56] offer a direction for the development of a method of ACL injury prevention, based on implicit learning. They indicate that the solution to injury prevention is hidden in the brains of the subjects themselves. That solution needs to be awakened by a proper intervention of implicit learning. Since every brain and every body is different, the optimal solutions are also different. Future research should provide more detailed information on the way these solutions are linked to certain types of body architecture and motor control capacities. Long term effects of visual feedback need to be explored. The results support the need for individualized visual augmented feedback using a self model to enhance jump-landing instruction and substantiates that this works best in the motor learning process [36]. The ability for individuals to view themselves performing correctly or making mistakes and responding to the corrections is of greater value to individuals than is viewing an expert model performing the task correctly. One theoretical approach is that learning is a problem-solving process; the more involved the individual is in analyzing his or her own performance, the greater the learning value [1, 63]. With implicit learning the position of the knee will be part of the position of the whole body. The subject will explore and then select the solution that fits best in their body.

Preventive studies we have referred to in this article mostly contain exercises that improve performance and reduce injuries by improving strengthening and conditioning. From these investigations, we have learned that ACL injuries can be prevented by a combination of balance/coordination, strength, plyometric and agility exercises [3, 4]. Immediate feedback of someone's own performance is an area which is still relatively unexplored and can aid in achieving long term results.

For laboratory studies, one's performance could be recorded with a high-speed camera from a posterior view (in order to give the right perspective to the athlete). When using infrared camera's and a force plate, 3D load at the knee can be calculated through inverse dynamics and the best performance so far can be presented to the subject without any explicit instructions on the lower extremity position. For on-field training, a simple camera could be used and with user-friendly software, the athlete's own performances could be reviewed and improved.

Conclusion

The transition from conscious awareness during technique training sessions to unexpected and automatic movements during a training or game involves complicated motor control elements that might not fit in explicit learning strategies [6]. We therefore encourage to explore the use of implicit learning in ACL injury prevention. Future ACL intervention programs may need to provide individualized visual instructional review of jump-landing technique to allow individuals to view how they personally perform the movement task and actively problem solve (by evaluating the mistakes and corrections of their trials) to develop techniques, and find individual ways to achieve those techniques, to obtain proper jump-landing. There is a need for further development of the learning model of visual demonstration and real time feedback. At any rate, the effects of attentional focus on motor performance not only provide interesting insights into the effectiveness of automatic control capabilities of the motor system, but they also have important implications for performance improvements in applied settings.

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