APPLYING THE PRINCIPLES OF MOTOR LEARNING TO OPTIMIZE REHABILITATION AND ENHANCE PERFORMANCE AFTER ACL INJURY

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INTRODUCTION

Most athletes who wish to continue sports participation after an anterior cruciate ligament (ACL) injury are advised to undergo ACL reconstruction (ACLR)[1]. Traditionally, rehabilitation programs have mainly focused on restoring symmetry in range of motion, balance, strength and neuromuscular control. For young athletes (<25 years of age) returning to competitive sports involving high intensity jumping and cutting activities, secondary ACL injury rates of 23% have been reported, and these frequently occur early during the return to sport (RTS) period[2].

Restoration of symmetry alone is not sufficient to reduce an athletes risk of reinjury. Focus should also be placed on addressing underlying deficits that likely contributed to the primary ACL injury[3]. In addition, a series of inciting events are likely to occur prior to the actual injury[4], and different playing situations provide further complexity. For example, ball possession, position of team mates and actions of opponents all impose different challenges and problems for the athletes to solve[5,6]. Thus, perceptual capacities play an important role in team and ball sports[7] by enahncing perception in rapidly changing environments. Interpreting situational information correctly and efficiently allows them to select the most appropriate response. The impact of these chaotic environments should not be ignored when second ACL injury prevention is the goal. However, components of neurocognitive training are often not addressed in current ACL rehabilitation programs[8].

An ACL injury induces neurological changes to the central nervous system (CNS), due to the loss of information from mechanoreceptors, pain and developed motor compensations[9]. This neuroplastic disruption progresses until altered motor strategies potentially become the norm. Subsequent restoration of baseline function then becomes a fight against maladaptive neuroplasticity developed in the wake of altered CNS input and motor output compensations[10]. Rehabilitation should therefore also consider central neurological (brain) drivers of control and ultimately these strategies should be incorporated into secondary injury prevention programs[11]. Considering the high re-injury rates, current approaches may not be effective in fully targeting residual deficits related to the initial injury and the subsequent surgical intervention[12]. Furthermore, rehabilitation after ACLR should focus on addressing the underlying neuromuscular control deficits that led to the initial injury and that may be amplified subsequent to ACL injury and reconstruction. The purpose of this article is to present novel clinically integrated motor learning principles to support neuroplasticity that can improve patient functional performance and reduce the risk of second ACL injury.

WHAT IS MOTOR LEARNING?

Motor learning is defined as the process of an individual's ability to acquire motor skills with a relatively permanent change as a function of practice or experience[13]. Currently the most used method to test motor learning is to assess the behavioral resultant outcome[13]. To assure that motor learning takes place, a skill must be rehearsed repeatedly. However, there are many variables to consider when planning and structuring practice. Even for commonly used factors such as instructions and feedback, clinicians should be cognizant of the effects that the amount, type, and schedule of instructions respectively can have on long term skill retention.

Optimal practice should ensure long-term learning and this is measured by retention and transfer of skills. In addition, task-specific practice should be used that is meaningful to the patient

Further, it is important to ensure the task being practiced is meaningful, challenging and motivating for the patient. Examples of important influencing factors to support the motor learning processes during ACL rehabilitation will be described in this article.

ATTENTIONAL FOCUS

In almost any training situation where motor skills are to be learned, patients receive instructions about the correct movement pattern[14]. Is is important to be aware that instructional language has an influential role on motor learning outcomes[15]. Typically, a physical therapist instructs the patient to flex the knee more when landing[16] (see Figure 1). Instructions that direct the patient's attention to their own movements induce an internal focus of attention[17].

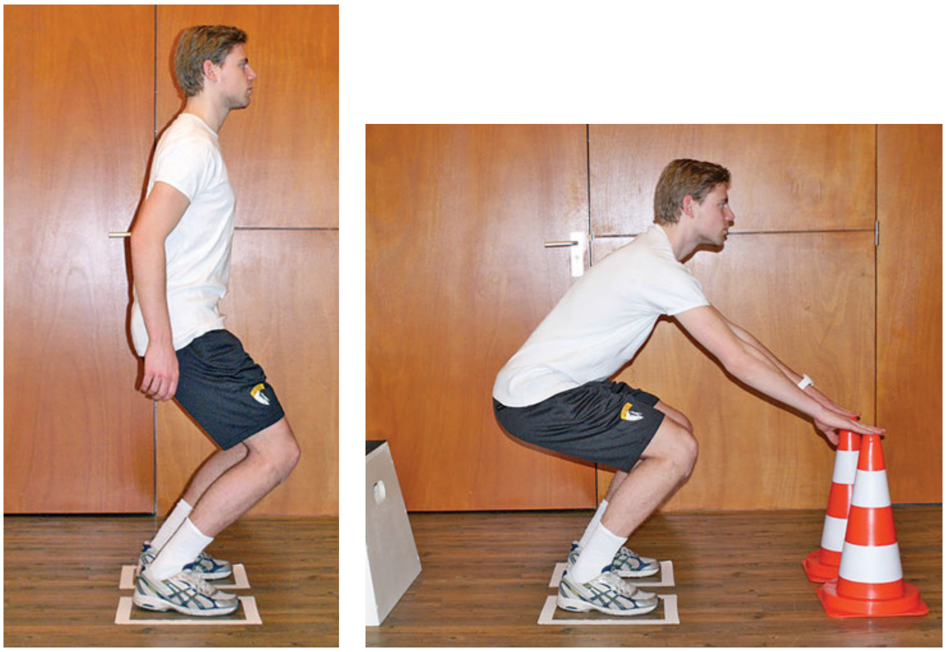

Figure 1: Internal focus (a) versus external focus (b) instructions during a drop vertical jump. In (a), the patient was instructed to land while bending the hips and knees; in (b), the patient was instructed to touch the cones when landing. Note the increased flexion of trunk, hips and knees (as shown in Figure 1b compared to 1a) indciating a 'safer' landing strategy despite the fact that no specific task instructions were provided

It has been shown that 95% of physical therapists provide instructions with an internal focus[18]. However, a growing body of evidence shows that this type of attentional focus may not be as effective as previously thought[19].

Interestingly, a simple change in the wording of instructions can have a significant impact on performance and learning. For example, directing the patient's attention to the effects of the movements on the environment promotes an external focus of attention. In this case, to increase knee flexion when landing from a jump (promoting a soft landing), a physical therapist instructs the patient to touch cones when landing (Figure 1)[16]. A focus on the movement effect promotes the utilization of unconscious or automatic processes, whereas an internal focus directs attention to one's own movements results in a more conscious type of control that constrains the motor system and disrupts automatic control processes[20]. Wulf et al. have termed this the 'constrained-action hypothesis' as the explanation for the attentional focus phenomenon[21]. Support for this view comes from studies showing reduced attentional demands when performers adopt an external as opposed to an internal focus, as well as a higher frequency of low-amplitude movement adjustments, which is seen as an indication of a more automatic, reflex-type mode of control[22]. The cumulative body of evidence indicates the beneficial effects of using external focus instructions over internal focus instructions[22,23].

IMPLICIT LEARNING

The aim of implicit learning is to minimize the amount of explicit knowledge about movement execution during the learning process. An example of this would be trying to describe in as few words as possible how you ride a bicycle. Commonly, we have a hard time explaining this using a verbal description. The reason is that we 'just do it' (riding a bicycle) and we really don't need a large pool of conscious detailed knowledge to outline how to execute the movement. If we accept this premise, we can also ask ourselves what we do in a clinical situation with a patient. Commonly, we as clinicians provide a lot of detailed information to the patient. Interestingly, physiotherapists working with children can't use the explicit instructions and often use implicit learning methods. An example of how implicit learning can be induced is by providing analogies rather than explicit instructions during the acquisition of motor skills[24].

Analogy, or metaphorical description of the action, connects with a visual image, e.g. 'pretend you are landing on eggs', to promote a soft landing.

Implicit learning reduces the reliance on the working memory and promotes more of an automatic process[24]. It is for this reason that it can be more effective in the execution of complex tasks. Competitive sports can be psychologically demanding, and decision-making accuracy deteriorates in athletes when they are under pressure and must deal with increased task complexity[25]. The negative influences of pressure can be observed in several ways. Of interest in connection to learning is 're-investment', when an athlete begins to direct attention to the skills and movements which should already be automatic, and do not need conscious control. This re-investment may cause the athlete to make sudden mistakes in technical actions, which are relatively simple and have been performed, without error, a thousand times before[26].

Explicit learning can promote re-investment because the athlete reverts to memory by a detailed, step-by-step explicit instruction about movement execution. Under stress, an athlete may unwillingly start to follow this guidance and divide smooth and fluent execution into separate blocks that would be detrimental for expert performance (choking). Additionally, such excessive attention to the technical details can draw working memory resources from other aspects of athletic performance[24].

One of the most interesting and widely unexplored aspects of implicit learning in rehabilitation is its connection with anticipation and decision making. This may be important in the later stages of rehabilitation when the patient is approaching the RTS phase. An athlete should be progressively exposed to physical, environmental, and psychological stressors that are comparable to those they will experience in the sport they participate in. Considering secondary ACL injury prevention and an increased need to re-establish sports performance skills, training in this phase of the rehabilitation should emphasize motor control factors such as anticipation, responses to perturbation, and visual-motor control within complex task and environmental interactions. Heightened anticipatory and sensorimotor skills obtained through implicit learning may give the athlete an improved capability to anticipate the need for corrective motor actions and avoid potentially high injury-risk scenarios. Evidence of this is present whereby implicit training using limited visual information about the direction of the ball in tennis, improved athletes' prediction accuracy after the intervention[27]. Conversely, an explicit learning group, who received specific kinematic information about the tennis serve of the opponent, didn't demonstrate any improvement in anticipatory skills[27].

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Progressing the learning challenge through contextual interference

Practice has a key role in the acquisition of motor skills during ACL rehabilitation. When a movement is executed, a learner strengthens his/her motor schemas, storing information about (a) the initial conditions, (b) the response specifications of the motor program, (c) the sensory consequences of the produced response, and (d) the effects of the movement on the environment[13]. Hence, the way the practice is scheduled influences the acquisition of motor skills. Random, or variable practice involves performing variations of the task or completely different tasks throughout a rehabilitation session. For skill transfer to occur, a review of the literature has suggested that variable practice may be more effective[28]. Contextual interference in motor learning is defined as the interference in performance and learning that arises from practicing one task in the context of other tasks[28]. Contextual interference is the effect on learning produced by the order of skills changing across trials. A non-systematic order of skills execution, as well as a non-consecutive execution of the same skill (A-C-B-C-A-B-A-B-C), is observed during random practice. The amount of contextual interference may vary and is generally low in blocked practice and high in random practice. Practicing under conditions of high contextual interference (i.e., with a random practice order) degrades performance during acquisition trials compared with low contextual interference conditions (i.e., with a blocked order, where practice is completed on one task before practice on another task is undertaken)[28].

While higher contextual interference (random practice) may lead to poor(er) immediate performance, it frequently leads to better learning (as measured by retention and transfer tests) compared with blocked practice[29].

Clinicians must decide how to best schedule practice to facilitate learning. As mentioned, the skill level of a patient is a factor that may need to be considered in terms of the amount of contextual interference provided[29]. In general, lower level athletes benefit more from low contextual interference, whereas elite athletes often thrive in learning environments where high levels of contextual interference are present.

Table 1

Examples of autonomy supportive language	*Examples of controlling language*
1. You have the opportunity to....	*1. Your job is to....*
2. Once you begin....	*2. You may not begin until....*
3. Feel free to....	*3. Make sure you....*
4. You may organise in a way you prefer	*4. Do not!*

Table 1: Comparison of wording that support autonomy versus wording that is more controlling.

MOTIVATION

Practice conditions that support fundamental psychological needs such as competence, autonomy, and social relatedness[30] appear to create circumstances that enhance motivation and optimize performance and learning[31] and further details and practical strategies for each are outlined below.

Autonomy

In most rehabilitation situations, clinicians determine the content and specific details of the training session. For example, they decide the order in which tasks are practiced, the duration, and when or if instructions, demonstrations or feedback will be provided. Thus, while clinicians generally control most aspects of practice, patients assume a relatively passive role. Self-controlled learning (where the patient has the choice when to request feedback or may choose an exercise) is a powerful tool in motor learning and has shown advantages in comparison with prescribed training schedules[32-34], some examples include:

1. Encourage the patient to choose three exercises for any given rehabilitation session (while considering variation in level or equipment).
2. Ask the patient to choose the type of material of a given exercise.
3. Suggest the patient determines when to receive feedback during selected exercises.

In practice you may provide the patient with three options when practicing a squat:

1. practicing on a BOSU ball,
2. practicing in front of mirror with barbell,
3. practicing as a goblet squat.

When you give the patient the option to chose one of these exercises, in all likelihood, patients will chose what they like best[35]. This choice is based on:

1. feelings of competence ('yes, I can do this!') or
2. feeling of relatedness ('I feel most comfortable / challenged when doing this variation of the exercise').

Of note, the physiotherapist is still responsible for creating the (safe) environment for learning, offering exercises with similar difficulty level, where a range of materials can be chosen.

Positive feedback and autonomy supportive language

It is also important to realise that athletes have a preference to receive positive feed-back. Experiencing competence through feedback on good trials positively affects motor learning through motivational influences such as intrinsic motivation, interest, and enjoyment[32,36]. For example, providing feedback after good trials (e.g. "That was an excellent jump, you landed very softly') plays a strong role in confirmation of competence, provides confidence and enhances intrinsic motivation[37]. Self-controlled feedback schedules also have the potential to help patients become more involved in their learning process by inducing an active role during rehabilitation sessions which subsequently enhances motivation and increases effort and compliance[38-40].

Finally, the way in which task instructions are phrased can have a profound influence on learning. Instructions that suggest to learners a certain degree of choice in how they perform a task can promote a more effective learning environment than over utilisation of prescriptive instructions that imply no room for choice. This is very easy to implement through the use of subtle changes in wording. For comparison see the wording in Table 1.

SUMMARY

Enhancing movement quality and training transfer are key outcomes of rehabilitation to reduce the risk of reinjury and enhance performance. While the development of physical capacities is of fundamental importance, a large part of the movement solution is grounded in neuromechanics (i.e., the interaction of the brain and muscles to produce coordinated movements in different conditions). Strategies to optimize motor learning can begin early in the rehabilitation process and should continue as the athlete aims to return to sport and optimal performance. Some examples have been outlined in this article including the use of positive, externally focused feedback and increasing levels of contextual interference. However, the optimal solution also needs to be individually tailored to the athlete, and they should also be encouraged to play an active role in their rehabilitation journey. Future research should focus on which combinations of the techniques presented here are most effective for long term skill retention, create the least dependence on external feedback, and provide the greatest transfer to the sporting environment.

References

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