Arthroskopie 2023 · 36:164–170
https://doi.org/10.1007/s00142-023-00606-1
Accepted: 6 March 2023
Published online: 26 April 2023

Redaktion
A. M. Müller, Basel
J. Paul, Basel

Motor learning principles during rehabilitation after anterior cruciate ligament injury

Time to create an enriched environment to improve clinical outcome

Alli Gokeler[1,2] · E. M. Nijmeijer[3] · P. Heuvelmans[1] · I. Tak[2,4] · C. Ramponi[5] · A. Benjaminse[3,6]

[1] Exercise Science & Neuroscience Unit, Department of Exercise & Health, Paderborn University, Paderborn, Germany
[2] Department of Public and Occupational Health, Amsterdam Movement Sciences, Amsterdam Collaboration on Health and Safety in Sports, Amsterdam UMC, Amsterdam, The Netherlands
[3] Center of Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
[4] Fyiotherapie Utrecht Oost, Utrecht, The Netherlands
[5] Kiné Rehab & Orthopedic Center, Treviso, Italy
[6] School of Sport Studies, Hanze University Groningen, Groningen, The Netherlands

In this article

Abstract

Athletes who wish to resume high-level activities after an injury to the anterior cruciate ligament (ACL) are often advised to undergo surgical reconstruction. Nevertheless, ACL reconstruction (ACLR) does not equate to normal function of the knee or a reduced risk of subsequent injuries. A rising concern is the high rate of secondary ACL injuries, particularly in young athletes, with up to 40% of those returning to sport in the first year after surgery experiencing a second ACL rupture. Aside from the increased risk of secondary injury, patients after ACLR have an increased risk of developing early-onset osteoarthritis. Unfortunately, current ACLR rehabilitation programs may not be optimally effective in terms of addressing deficits related to the initial injury and the subsequent surgical intervention. Motor learning to (re)acquire motor skills and neuroplastic capacities are not sufficiently incorporated during traditional rehabilitation, attesting to the high reinjury rates. 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 secondary ACL injury. The novel motor learning principles presented in this manuscript may optimize future rehabilitation programs to reduce the risk of secondary ACL injury and early development of osteoarthritis by targeting changes in neural networks.

Keywords
Prevention · Performance · Neural networks · Osteoarthritis · Neuroplasticity

One of the most frequent injuries sustained while playing sports is an anterior cruciate ligament (ACL) tear. Athletes who want to continue playing pivoting sports typically elect to undergo ACL reconstruction (ACLR), which is followed by lengthy periods of rehabilitation. However, the competitive, young athlete (< 20 years) who resumes pivoting-type sports following ACLR has a high risk of secondary ipsi- or contralateral ACL injury. Injury rates of up to 40% have been reported in this young cohort in the literature [1]. The risk for a second ACL injury after ACLR has been associated with abnormal movement patterns, which may also help to explain

Table 1 Example exercises and attentional focus strategies for early-phase rehabilitation

Early				
Using a criteria-based, evidence-based constructed approach to rehabilitation after ACL surgery is essential to systematically and successfully progress a patient through the rehabilitation process. It is imperative to control postoperative pain, inflammation, and swelling during the first weeks of rehabilitation. Calming the knee down initially and starting slowly will allow the rehabilitation to accelerate faster in the long run. Postoperative rehabilitation begins with a range of movement exercises, emphasizing full passive knee extension and weightbearing activities immediately postoperatively				
Exercise examples				
Knee extension on a bolster	Straight-leg raise	Glute bridge	Balance (single leg on balance board)	Gait
Internal focus				
"Press your knee toward the table"	"Lift your leg 6 inches off the ground"	"First, tighten your abdominals, keep them activated, then lift your hips off the floor"	"Focus on keeping your pelvis as still as possible"	"Extend your knee while walking"
External focus				
"Press the bolster toward the ground"	"Lift your shoe 6 inches off the ground"	"Push into the ground and bring this marker off the floor" (marker on waist)	"Minimize the movement of the balance board"	"Focus on the markers drawn on the floor" (markers based on symmetrical gait cycle)

why not all athletes return to their preinjury level [2]. Of great concern in also the onset of early osteoarthritis (OA). There is an almost seven- and eightfold increase in the odds for development of knee OA post ACL injury and after ACLR, respectively [3].

Although development of OA is multifactorial, aberrant biomechanics have been identified as a risk factor. For example, a systematic review of gait analysis revealed that patients with ACLR knees may exhibit persistent altered joint loading patterns and tibial rotation compared with the uninjured contralateral knees or healthy patients [4].

Rehabilitation includes restoring range of motion, reducing pain and swelling, neuromuscular training, strengthening, and agility [4]. The assumption is that by performing these universal workouts, the athlete develops the necessary neuromuscular control and strength to deal with unexpected circumstances, such as a rapid change in the planned movements that could lead to significant joint loads. As a result, the effectiveness of secondary injury prevention largely hinges on neuromuscular feedback systems. Practicing preplanned motor tasks in a controlled environment with an emphasis on lower extremity alignment is a common component of ACL rehabilitation programs. It might be argued that this approach does not adequately prepare athletes for the complex and unpredictable demands they face while returning to the field [5].

Moreover, emerging evidence demonstrates that an ACL tear can cause cognitive disruption and have the potential to lead to maladaptive neuroplasticity [6], the motor and premotor parts of the cortex being more active during basic movement tasks compared to people who are not injured [6]. A shift in attention to the injured part, such as the knee, may be brought on by loss of function, discomfort, fear of reinjury, and other psychological variables. As a result, while performing movement exercises, the injured athlete concentrates excessively on that area [2]. This increased attention to body motions and the related brain adjustments may hinder motor function. The authors recently proposed that more emphasis should be given to the integration of somatosensory and neurocognitive factors [5, 7]. This is particularly important from the earliest stages of rehabilitation.

Based on the aforementioned considerations, there is room and need for optimization of current ACL injury prevention and rehabilitation programs. To present an overview, this article has been outlined in four sections:

1. Debunk the myth that one ideal movement exists.
2. Movement assessment.
3. Motor learning:
   a. External focus including variable practice.
   b. Constraints-led approach.
   c. Differential learning.
4. How to plan and organize rehabilitation.

Accept that there is no single perfect movement

The way we move is determined by a combination of mental and physical factors but also by the external demands placed on a movement. There is a clear difference between whether the execution of a movement is the goal or whether the movement serves to achieve a goal. An athlete can achieve this goal with different variations in movement patterns. The pursuit of one optimal movement pattern therefore does not seem desirable. In fact, one-sided training grinding a single optimal movement pattern leaves the athlete with a void regarding how to respond to situations that would require a different movement.

Traditionally, sentiments (*there is a perfect technique*) and versatile training (*not striving for a perfect technique*) are diametrically opposed to each other. The common view regarding the goals of rehabilitation after ACLR is that the athlete (re)learns ideal motor skills [8]. Any deviation and error from this "ideal" model is corrected. However, movement variability always occurs when the same action is repeated, and even the elite athlete cannot reproduce identical movement patterns [9]. Movement variability has been viewed as an unwanted source of error that should be eliminated or reduced. However, the functional role of movement variability is essential to expert performance in many sports. In sport performance, although basic movement patterns need to be acquired, there exists no ideal movement pattern, since relatively unique functional movement solutions emerge from the in-

Fig. 1 ▲ An example of how to enhance engagement of the athlete from the early phase of rehabilitation. The athlete selects her favorite football team (**a**), a video of a match will appear (**b**), and we ask her to simulate every passing action her favorite team makes. This results in more active involvement, improved motivation, and increased practice effort. (With permission, © the Authors, all rights reserved)

teraction of task and environmental constraints [10]. From the complex systems perspective, movement variability is not perceived as detrimental or as the reflection of inconsistency in a motor skill, but rather as a key signature of adaptability [10]. Adding variability and exploration to practice serves to reduce the risk factors for ACL injury. Thus, we need to guide athletes in producing variable movement patterns to adapt to the changes in the complex environment.

Movement variability increases the adaptability of the athlete to handle different situations (e.g., perturbation by another player while jumping, playing on wet grass) as they emerge on the field.

Movement assessment

Human movement is complex, and one learns by trial and error. Motor learning largely explains how we learn those motor skills. Motor learning is generally defined as a set of processes aimed at (re)learning and refining new motor skills by practicing them [11].

Hence, before specific motor learning principles are applied to ACLR rehabilitation, it is imperative that a baseline measurement of a movement task is conducted.

The qualitative assessment of movement is something health professionals perform every day. After all, looking closely at how a movement is performed can provide a lot of information about where improvements are possible for performance, but also about which movements can lead to possible injuries. However, this clinical approach has limitations in systematically and objectively quantifying and comparing movements. This is why it is important to have good knowledge and skills to be able to carry out a movement analysis systematically.

Kinematic variables are the form of biomechanical data that we measure and see most in practice, because data on joint movement is the easiest to measure—both with and without movement analysis equipment. However, it is important to realize that it is the kinetic factors (forces, moments) that determine where and when tissue damage occurs.

Motor learning principles

Detailed motor learning principles have been reported recently [7]. The following updates are a selection of key concepts that may enhance rehabilitation by targeting movement asymmetries and which prepare the athlete for re-integration in sports after an ACLR in as safe a manner as possible:

1. External focus of attention.
2. Self-control.
3. Constraint-led approach.
4. Differential learning.

External focus of attention

A subtle change in the wording of exercise instruction prior to movement execution can promote an external focus of attention so that attention is directed toward the athlete's intended effect of the movement (goal-directed attention). In contrast, an internal focus of attention occurs when the athlete pays attention to their own body movements [2].

An external focus of attention uses less conscious control, simulating the circumstances that athletes would experience when they return to sports. Contrary to popular belief [12], external focus instructions can and should be given starting from the early phase of rehabilitation [2, 5–7]. In ◘ **Table 1**, various examples are presented for the early phase of rehabilitation.

For the more advanced phases of rehabilitation, continuing to using an external focus of attention reduced landing stiffness and improved landing biomechanics in female athletes more quickly than using an internal focus of attention. In a jump-landing study, participants who trained with an external focus of attention (i.e., pushing themselves off the ground as hard as possible after landing on the force plate) displayed a greater knee flexion range of motion than those who trained with an internal focus of attention (i.e., extending their knees as quickly as possible after the force plate landing). These outcomes were not only retained a week later, but they were also applied to an unplanned sidestep cutting [13]. Gokeler et al. [14] showed that knee flexion at initial contact landing from a single-leg hop increased when athletes after ACLR adopted an external focus.

Collectively, these findings suggest a decrease in ACL injury risk if external focus instructions are provided during rehabilitation.

Fig. 2 ▲ An example of how differential learning principles can be applied to squats. Practicing a variety of movement solutions in a random manner facilitates development of movement patterns that can be adapted to different situations. (With permission, © the Authors, all rights reserved)

Self-control

Make the athlete part of the rehabilitation program

The importance of motivating factors in the development of motor abilities has also been recognized in the field of motor learning [15]. The specifics of the training session are set in ACL rehabilitation programs and are instructed by the rehabilitation specialist. For instance, they determine the type of exercises, duration of practice sessions, the order in which activities are practiced, and provide instructions or feedback at their own discretion (Fig. 1). As a result, athletes play a somewhat passive role during practice, with the rehabilitation specialist in charge.

However, there are increasing data to suggest that giving the athlete some control can significantly increase the effectiveness of skill learning [15]. Contrary to predetermined training regimens, giving the athlete some autonomy over a practice session (e.g., the order of exercises, variations, and when to receive feedback) improves motor learning [7]. More active involvement, improved motivation, and increased practice effort have all been linked to self-controlled learning [15].

Specifically, incorporating rehabilitation programs that are challenging and fun may have positive motivational influences for learning, which in turn could improve adherence to the rehabilitation program.

Constraints-led approach

Task–environment–athlete relationship

In sport, there are always constraints that influence how a player achieves an outcome; each individual player will inevitably come up with their own slightly different way to overcome these constraints. These constraints are categorized as either individual, task, or environmental.

Adding constraints is most commonly practiced by changing the task. It is important to point out that adding a constraint does not necessarily imply more complexity, as it is equally possible that adding a constraint in fact results in the task becoming less difficult, as fewer options are available to choose from. For example, if a player is practicing passing kicks, an added constraint could be to pass the ball over a small obstacle (instead of playing the ball over the ground). Another example of introducing a task constraint would be sprinting in a straight line for 20 m with a 180-degree change of direction and then adding a small hurdle right before the 20 m line, so that the athlete would have to jump over this prior to making the directional change. The added constraints could be used to measure either coordination error or performance decreases of the athlete.

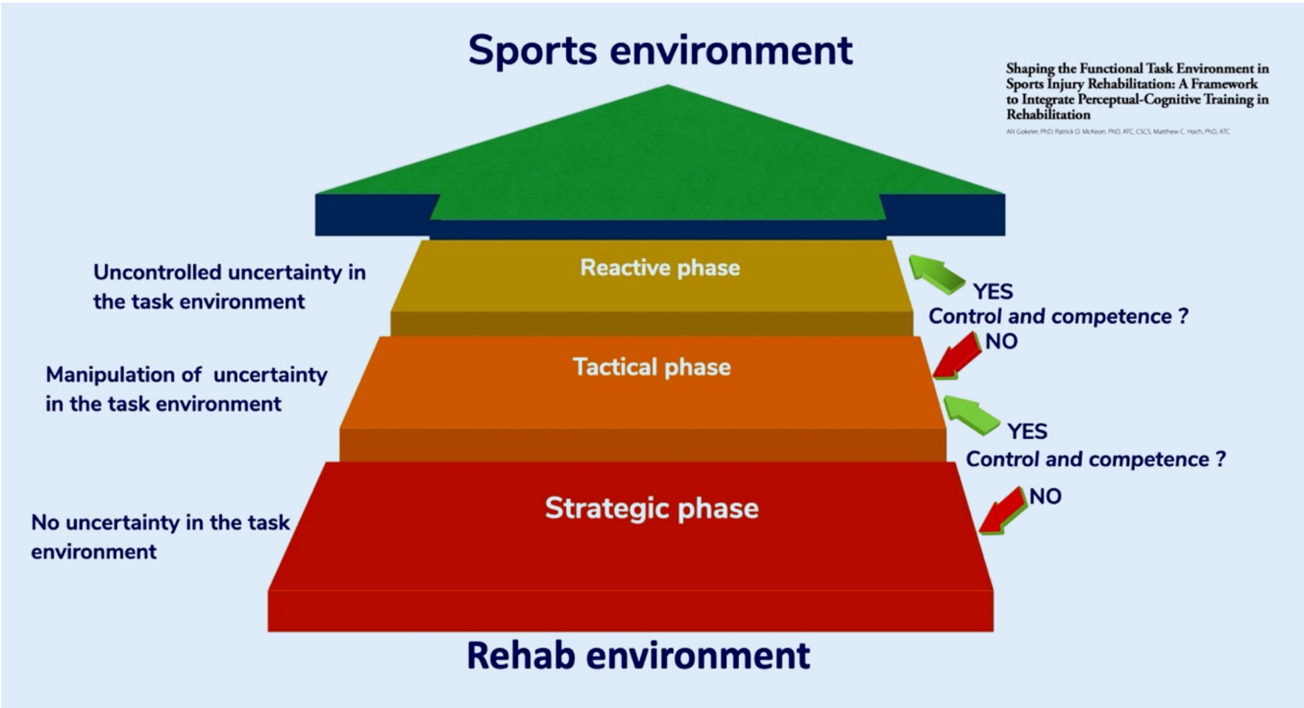

Fig. 3 ▲ Shaping the functional task environment to challenge both physical and perceptual–cognitive demands may be an important missing link in rehabilitation strategies and the ability of injured athletes to return to preinjury performance levels. (With permission, © the Authors, all rights reserved)

Applying the constraints-led approach in the context of the Return-to-Sport (RTS) continuum is innovative and may play an important role in the design of future RTS programs.

Differential learning

The theory of dynamical systems is the foundation of differential learning [16]. According to this theoretical idea, athletes can start a self-organized learning process by performing a variety of movement patterns [16]. Hence, the movement patterns themselves are purposefully varied during practice when using differential learning for movement skills. Athletes develop a customized motor solution that works best for them given the physical limitations of their bodies and the environmental context. This is the result of the process of experimentation with various movement patterns, target goals, and alternative methods of performing a task (rather than only practicing the supposedly "correct" movement form).

The athlete practices various variations of a broad jump, for instance (◘ **Fig. 2**). No more than twice are the same variations used. Engaging in environmental variations is one way to guarantee differential learning. This can guarantee the transfer of motor patterns learned in the clinical setting to a variety of situations and contexts. The idea is that practice should expose athletes to as many different combinations within a class of skills (such as jumping, throwing, and running) as is practical. The athlete must learn how to adapt a specific movement strategy to achieve a desired result under various circumstances.

Recent work by Tassignon et al. [17] indicated that differential learning may have potential to result in greater average improvements of motor skill learning compared to non-variability-based motor learning methods.

How to organize the rehabilitation

Gokeler et al. [18] have recently presented a model on how the concept of a constraints-led approach can be systematically and incrementally introduced to the athlete to assure a safe progression based on clinical milestones of movement competence and performance as well as psychological response of the athlete. The moment-to-moment interaction between the athlete pursuing a particular goal in sport situations is defined as the functional task environment (Fig. 3) [18].

Here, the degree of unpredictable complexity can be controlled (safely) and gradually/phased (timely) adjusted in all kinds of dimensions (speed, timing, difficulty). Through this integration we will be able to better capture how an athlete deals with the combination of physical and neurocognitive load as experienced in training or competition.

Rehabilitation has predominantly used simplified training and testing protocols that fail to replicate the tight coupling between perception and action that would typically be present in the on-field environment (i.e., designs lack representativeness). Failure to do so will not prepare the athlete for the complex demands upon returning to in-field training and matches. We therefore propose to consider an ACL injury as a biomechanical–neurophysiological–neurocognitive injury. Adopting this more comprehensive approach is likely to improve outcomes.

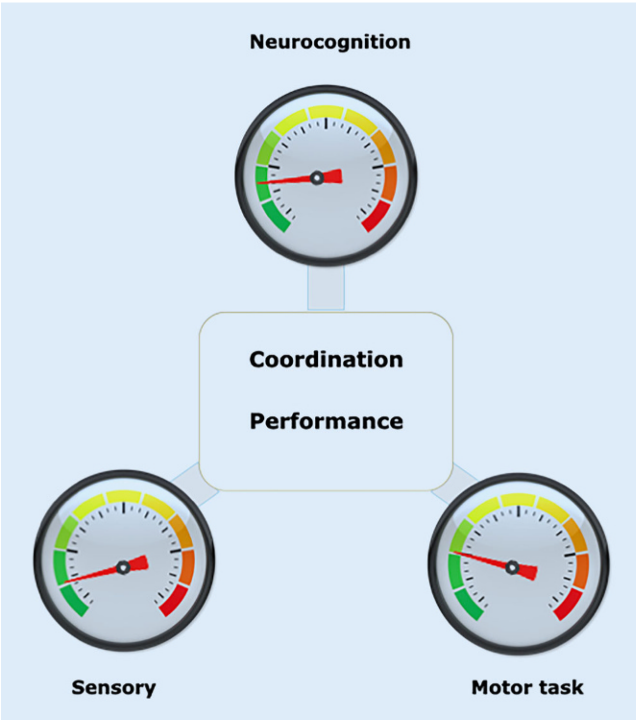

Fig. 4 ◀ This model shows the interaction of the motor task, sensory and neurocognition and how this can be manipulated for testing and used to develop tailored rehabilitation

For purposes of comprehensive postoperative ACLR rehabilitation, a model that integrates function in subsystems of motor tasks, sensory information (based on central nervous system [CNS] changes), and neurocognition serves as the foundation. The model is a modified version previously published by Baumeister, who presented a sensorimotor control model that integrates sensory information, subsequent processing in the brain, and the resultant motor action (◘ **Fig. 4**). In the model, the sensory subsystem supplies the CNS with visual, vestibular, and proprioceptive stimuli. This information is necessary for movement control. Integrated testing of sensory and neurocognitive function and the relationship between them is examined. As discussed before, the components of motor function, the sensory system, and neurocognition should not be viewed in isolation, as these subsystems are intertwined.

The objective of the model is to assist clinicians with a framework on how manipulations within the subsystems (motor, sensory, neurocognitive) influence movement coordination and/or performance. Of note, movement coordination is the emerging result of an athlete perceiving sensory information and acting within a given context [19]. The clinical implication is that small adjustments of the motor, sensory, and/or neurocognitive subsystems may cause significant changes in the movement coordination and/or performance. For example, adding neurocognitive load to change of direction or jump-landing tasks elicits movement patterns that may increase lower extremity injury risk [20–23].

Conclusion

According to the available data, asymmetrical joint loading is closely connected to an elevated risk of secondary ACL injury. After an ACL injury, motor learning should be used to support neuroplasticity. Because each person's brain is unique, the ideal approach might include individualized motor learning principles. In this article, some innovative motor learning ideas have been introduced. In order to target biomechanical and neuromuscular risk factors identified in patients after ACLR, we have presented how novel motor learning principles can be applied to rehabilitation in athletes after ACLR. Future studies should concentrate on identifying, if indeed they exist, combinations of the unique motor learning principles that produce the best clinical results.

Corresponding address

Dr. Alli Gokeler
Exercise Science & Neuroscience Unit, Department of Exercise & Health, Paderborn University
Warburger Str. 100, 33098 Paderborn, Germany
alli.gokeler@uni-paderborn.de

Declarations

Conflict of interest. A. Gokeler, E.M. Nijmeijer, P. Heuvelmans, I. Tak, C. Ramponi, and A. Benjaminse declare that they have no competing interests.

For this article no studies with human participants or animals were performed by any of the authors. All studies mentioned were in accordance with the ethical standards indicated in each case.

References

1. Webster KE, Hewett TE, Feller JA (2021) Anterior cruciate ligament injuries in Australian rules football: incidence, prevention and return to play outcomes. Open Access J Sports Med 12:33–41
2. Singh H, Gokeler A, Benjaminse A (2021) Effective attentional focus strategies after anterior cruciate ligament reconstruction: a commentary. Int J Sports Phys Ther 16(6):1575–1585
3. Webster KE, Hewett TE (2022) Anterior cruciate ligament injury and knee osteoarthritis: an umbrella systematic review and meta-analysis. Clin J Sport Med 32(2):145–152. https://doi.org/10.1097/JSM.0000000000000894
4. Gokeler A, Benjaminse A, van Eck CF et al (2013) Return of normal gait as an outcome measurement in ACL-reconstructed patients. A systematic review. Int J Sports Phys Ther 8(4):441–451
5. Grindem H, Engebretsen L, Axe M et al (2020) Activity and functional readiness, not age, are the critical factors for second anterior cruciate ligament injury — the Delaware-Oslo ACL cohort study. Br J Sports Med 54(18):1099–1102
6. Gokeler A, Grassi A, Hoogeslag R et al (2022) Return to sports after ACL injury 5 years from now: 10 things we must do. J Exp Orthop 9(1):73. https://doi.org/10.1186/s40634-022-00514-7
7. Piskin D, Benjaminse A, Dimitrakis P et al (2021) Neurocognitive and neurophysiological functions related to ACL injury: a framework for neurocognitive approaches in rehabilitation and return-to-sports tests. Sports Health. https://doi.org/10.1177/19417381211029265
8. Gokeler A, Neuhaus D, Benjaminse A et al (2019) Principles of motor learning to support neuroplasticity after ACL injury: implications for optimizing performance and reducing risk of second ACL injury. Sports Med 49(6):853–865. https://doi.org/10.1007/s40279-019-01058-0
9. Risberg MA, Holm I (2009) The long-term effect of 2 postoperative rehabilitation programs after anterior cruciate ligament reconstruction - a

randomized controlled clinical trial with 2 years of follow-up. Am J Sports Med 37(10):1958–1966
10. Bartlett R, Wheat J, Robins M (2007) Is movement variability important for sports biomechanists? Sports Biomech 6(2):224–243. https://doi.org/10.1080/14763140701322994
11. Seifert L, Button C, Davids K (2013) Key properties of expert movement systems in sport. Sports Med 43(3):167–178
12. Schmidt R, Wrisberg C (2005) Motor learning and performance. Human Kinetics, Champaign, IL
13. Faltus J, Criss CR, Grooms DR (2020) Shifting focus. Curr Sports Med Rep 19(2):76–83. https://doi.org/10.1249/JSR.0000000000000688
14. Benjaminse A, Welling W, Otten B et al (2018) Transfer of improved movement technique after receiving verbal external focus and video instruction. Knee Surg Sports Traumatol Arthrosc 26(3):955–962. https://doi.org/10.1007/s00167-017-4671-y
15. Gokeler A, Benjaminse A, Welling W et al (2015) The effects of attentional focus on jump performance and knee joint kinematics in patients after ACL reconstruction. Phys Ther Sport 16(2):114–120. https://doi.org/10.1016/j.ptsp.2014.06.002
16. Wulf G, Lewthwaite R (2016) Optimizing performance through intrinsic motivation and attention for learning: the OPTIMAL theory of motor learning. Psychon Bull Rev 23(5):1382–1414
17. Schollhorn WI, Mayer-Kress G, Newell KM et al (2008) Time scales of adaptive behavior and motor learning in the presence of stochastic perturbations. Hum Mov Sci 28(3):319–333
18. Tassignon B, Verschueren J, Baeyens J-P et al (2021) An exploratory meta-analytic review on the empirical evidence of differential learning as an enhanced motor learning method. Front Psychol. https://doi.org/10.3389/fpsyg.2021.533033/full
19. Gokeler A, McKeon PO, Hoch MC (2020) Shaping the functional task environment in sports injury rehabilitation: a framework to integrate perceptual-cognitive training in rehabilitation. Athl Train Sports Health Care 12(6):283–292. https://doi.org/10.3928/19425864-20201016-01
20. Bolt R, Heuvelmans P, Benjaminse A et al (2021) An ecological dynamics approach to ACL injury risk research: a current opinion. Sports Biomech. https://doi.org/10.1080/14763141.2021.1960419
21. Almonroeder TG, Kernozek T, Cobb S et al (2018) Cognitive demands influence lower extremity mechanics during a drop vertical jump task in female athletes. J Orthop Sports Phys Ther 48(5):381–387
22. Giesche F, Stief F, Groneberg DA et al (2021) Effect of unplanned athletic movement on knee mechanics: a systematic review with multilevel meta-analysis. Br J Sports Med. https://doi.org/10.1136/bjsports-2021-103933
23. Schnittjer A, Simon JE, Yom J et al (2021) The effects of a cognitive dual task on jump-landing movement quality. Int J Sports Med 42(01):90–95. https://doi.org/10.1055/a-1195-2700

Zusammenfassung

Prinzipien motorischen Lernens während der Rehabilitation nach vorderer Kreuzbandverletzung. Zeit, reichhaltigere Rahmenbedingungen zur Verbesserung der klinischen Ergebnisse zu entwickeln

Sportlern, die nach einer Verletzung des vorderen Kreuzbands (VKB) das Training wieder auf einem hohen Level aufnehmen wollen, wird oft geraten, eine chirurgische Rekonstruktion durchführen zu lassen. Dennoch ist eine VKB-Rekonstruktion nicht gleichbedeutend mit einer normalen Kniefunktion, auch besteht kein vermindertes Risiko für Folgeverletzungen. Zunehmende Besorgnis verursacht die hohe Rate an sekundären VKB-Verletzungen, insbesondere bei jungen Sportlern, wobei bis zu 40 % derer, die im ersten Jahr nach der Operation den Sport wieder aufnehmen, eine zweite VKB-Ruptur erleiden. Neben dem erhöhten Risiko einer Sekundärverletzung weisen die Patienten nach VKB-Rekonstruktion ein erhöhtes Risiko für eine früh einsetzende Arthrose auf. Leider sind die Rehabilitationsprogramme bei VKB-Rekonstruktion derzeit möglicherweise nicht optimal wirksam in Bezug auf Defizite durch die Initialverletzung und die anschließende chirurgische Behandlung. Motorisches Lernen für die (Wieder-)Erlangung motorischer Fähigkeiten und neuroplastischer Kapazitäten ist nicht ausreichend in die herkömmliche Rehabilitation integriert, wie die hohen Wiederverletzungsraten zeigen. Ziel der vorliegenden Arbeit ist es, neue klinisch integrierte Prinzipien des motorischen Lernens zur Förderung der Neuroplastizität vorzustellen, welche die funktionelle Leistungsfähigkeit der Patienten und das Risiko einer sekundären VKB-Verletzung vermindern können. Indem sie auf Veränderungen in neuronalen Netzen abzielen, können die neuen Prinzipien des motorischen Lernens, die in dieser Arbeit vorgestellt werden, zur Optimierung zukünftiger Rehabilitationsprogramme beitragen, die zur Verringerung des Risikos sekundärer VKB-Verletzungen und vorzeitiger Entstehung einer Arthrose dienen.

Schlüsselwörter
Prävention · Leistungsfähigkeit · Neuronale Netze · Arthrose · Neuroplastizität