Arşiv Kaynak Tarama Dergisi
Archives Medical Review Journal

DERLEME/REVIEW

Functional Outcomes of Motor Learning Interventions in Anterior Cruciate Ligament Injuries

Ön Çapraz Bağ Yaralanmalarında Motor Öğrenme Müdahalelerinin Fonksiyonel Sonuçları

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ABSTRACT
Anterior cruciate ligament injury is one of the pathologies that affect the daily and professional life of the majority of athletes. When the treatment options are examined, there are two options surgical treatment and conservative treatment. Rehabilitation is essential in both cases, with or without surgery. Especially for returning to sports, long-term rehabilitation after surgery has become essential. While many different exercise methods have been tried in the prevention of anterior cruciate ligament injury and rehabilitation after reconstructive surgery, many have focused on strength training. The abnormal movement pattern that occurs with the somatosensory loss seen after anterior cruciate ligament injury results in a functional loss in the injured extremity and the contralateral extremity in the long term. Considering the incidence of injury, studies to establish the normal movement pattern and restore motor control are very important. For this reason, motor learning-based interventions that support neuroplasticity are of great interest today. This review aims to examine the functional results of current motor learning-based interventions in anterior cruciate ligament rehabilitation in line with the literature.
Keywords: Anterior cruciate ligament; exercise; motor skills; rehabilitation

ÖZET
Ön çapraz bağ yaralanması sporcuların oldukça büyük bir kısmının karşılaştığı günlük hayatını ve profesyonel hayatı büyük ölçüde etkileyen patolojilerin başında gelir. Tedavi seçenekleri incelendiğinde cerrahi tedavi ve konservatif olmak üzere iki seçenek mevcuttur. Cerrahi olsun veya olmasın her iki durumda rehabilitasyon süreci şarttır. Özellikle spora dönüş için cerrahi sonrası uzun dönem rehabilitasyon elzem kılınmıştır. Ön çapraz bağ yaralanmasını önlemede ve rekonstrüktif cerrahi sonrası rehabilitasyonda birçok farklı egzersiz yöntemi denenmesiyle beraber birçoğu kuvvet eğitimine odaklanmıştır. Ön çapraz bağ yaralanmasından sonra görülen somatosensoriyal kayıp ile beraber meydana gelen anormal hareket paterni yaralanma olan ekstremite ve uzun dönemde kontralateral ekstremite de fonksiyonel kayıp ile sonuçlanır. Yaralanma insidansı dikkate alındığında normal hareket paternini yerleştirip motor kontrolü yeniden sağlamaya yönelik çalışmalar oldukça önem arz etmektedir. Bunun için nöroplastisiteyi destekleyen motor öğrenme temelli müdahaleler günümüzde büyük ilgi görmektedir. Bu derlemede, ön çapraz bağ rehabilitasyonunda motor öğrenme temelli güncel müdahalelerin fonksiyonel sonuçlarının literatür doğrultusunda incelemek amaçlanmıştır.
Anahtar kelimeler: Egzersiz; motor beceriler; ön çapraz bağ; rehabilitasyon

Introduction

The anterior cruciate ligament (ACL) is the most frequently injured in the knee joint in contact or non-contact sports, especially in sudden twisting, jumping, and cutting movements or due to a blow to the knee[1]. Although it occurs at different rates in different populations, approximately 200,000 ACL injuries are recorded annually in the United States, and it has been reported that 75% of them undergo reconstruction within the first year after injury[2]. As a result of injury, athletes' participation in sports decreases. An ACL injury may also be accompanied by meniscal tears, which cause long-term subchondral lesions and is associated with osteoarthritis and motor coordination disorders[3]. Treatment includes surgical or non-surgical methods. Whether surgical intervention is performed or not, a rehabilitation process is needed in

2023;32(1):33-41
doi:10.17827/aktd.1169499

both cases. Especially for returning to sports, reconstruction and long-term rehabilitation can be considered essential[1, 4]. Many rehabilitation treatment methods have been created from the past to the present to prevent ACL injuries. Unfortunately, not all established treatment modalities focus on correcting abnormal movement patterns and restoring motor control[5]. However, considering the increase in the incidence of injury[6], altered knee kinematics after injury, incomplete or incorrectly received afferent stimuli may cause ipsilateral or contralateral injuries later on[7]. In the long term, it has been associated with osteoarthritis [8].

ACL is a connective tissue within the knee joint but extra synovial[9]. While it limits the tibial translation, which is its main task, it controls the rotational forces affecting the knee[10, 11]. According to the stretching patterns of the knee in different positions, each bundle of the ACL contributes significantly to knee joint stabilization[12]. ACL affects the somatosensory system thanks to the specialized receptors it contains. The sensorimotor system greatly contributes to functional stabilization. Somatosensory, visual, and vestibular information is transmitted to the central nervous system where it is interpreted and provides the formation of functional stability[13]. There are many specialized receptors in the ACL. Pacinian corpuscles, classified as dynamic receptors, are velocity sensitive. It quickly adapts to low-level stimuli on the joint. Golgi tendon organs and Ruffini endings, on the other hand, adapt more slowly because of the high threshold level and provide information about the position of the knee joint[13]. These proprioceptive receptors are reduced in people with ACL injuries; Ruffini endings and Golgi tendon organs adapt slowly with a high-stress threshold and provide information about the position of the knee joint. In acute inflammation or pain after an ACL injury, proprioceptive input is affected due to an unstable capsule. In this case, the somatosensory input in the central nervous system changes, resulting in decreased proprioception[14]. If left untreated, over time the joint slowly adapts to its new condition (neuroplasticity) and impaired sensory input, resulting in misalignment. This causes functional losses. Based on the above-mentioned kinesiological and neuromuscular disorders, treatment methods require a set of exercises that increase neuromuscular function that supports neuroplasticity as well as increasing muscle strength and endurance to be effective in the long term[15, 16]. To complete the exercise program more holistically, the exercises should focus on postural alignment and should be suitable to be performed not only indoors but also in an individual-specific daily life or field-applicable environments[17].

Due to the central nervous system changes caused by the ACL injury, rehabilitation programs that include various components of motor learning to provide an appropriate rehabilitation program aiming to support the formation of adaptive neuroplasticity attract great attention today. This study aims to examine the functional results of current motor learning-based interventions in ACL rehabilitation in line with the literature.

Motor Learning

Motor learning is an individual's ability to acquire motor skills with a relatively permanent change in performance. Evaluation of behavioral outcomes best detects motor learning (Figure 1)[18]. Motor learning depends on plasticity in the motor areas of the brain. Explicit/implicit learning, facilitations, activity-specific repetition and repetition with different movements for the same purpose, correct afferent input, body diagram, feedback, active participation, all or part of the task, mental imagination, environmental adaptation, family training, and instructions are effective steps in the process of motor learning[19]. The focus of attention has a significant contribution to the efficiency of movement, as well as the effect of factors such as muscle strength, speed, and endurance on movement efficiency and productivity[20]. When individuals completed the movement with externally directed instructions during movement, it had positive effects on performance and learning. A skill needs to be repeated in different ways for the development and adaptation of learning. In addition, the choice of activity should be patient-specific and purposeful. The popularity of the various factors that influence motor learning has changed over the years. Motor behavior often takes place in society and can be adapted. Although the presence of other people in the environment is sometimes supportive (group exercises), it can sometimes be prohibitive (the state of consciousness may step in and be afraid of making the wrong move). When the state of consciousness is activated, motor performance can be improved by focusing on the effect or result of the movement; performance is negatively affected when focusing on the coordination of movement[20]. A successful experience can increase performance by creating positive expectations. For example, an athlete who is interested in skiing relies on his ability to acquire sport-specific skills and can manage to maintain his balance while skiing, without taking into account that the people around him are watching, without involving any cognition of his balance skills. Lewthwaite and Wulf presented the motor learning theory, a theory that takes into account the 'social-cognitive-emotional' nature of behavior: The OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) Theory. The basis of this theory is based on motor behavior. The OPTIMAL theory theoretically consists of three pillars: enhanced expectancies, autonomy support, and an external focus of attention. İn enhanced expectancies; Confidence is an indicator of motor performance in young people. As the confidence levels increase, the motivation of the person and the next performance increase, and learning develops. Instead of telling the individual who has had an ACL injury to repeat this movement during exercise, saying that if you complete this movement, you will move to a new weight next time, increases motivation by reducing internal focus[21]. Strategies to increase expectancy, according to OPTIMAL motor learning theory, include positive feedback, social comparative feedback, ability concepts, perceived task difficulty, and self-modeling. Positive feedback after good trials reinforces learning compared to after bad experiences. Autonomy support, on the other hand, is a process in which the individual actively participates in his behavior as a basic psychological need. It was concluded that it would reinforce motor learning by giving individuals the right to choose and edit a part of the program[22].

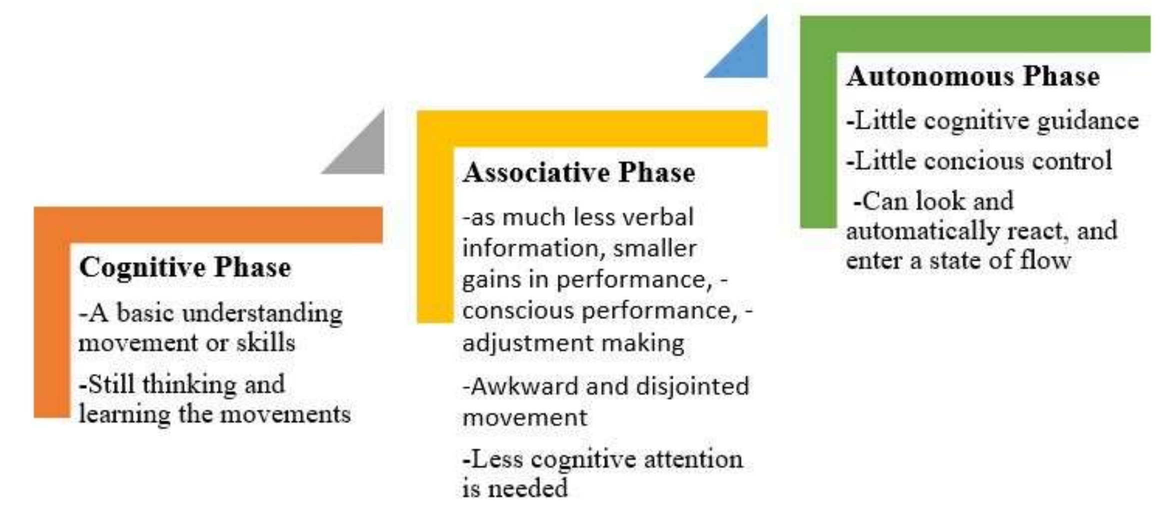

Figure 1. Motor learning phases

Machan T. and Kroppus K. proposed a different rehabilitation program called the trident model to gain neuroplasticity in ACL rehabilitation [23]. The model first aims to ensure that the athlete returns to sports most safely by providing motor learning. For this, it is based on the execution of the exercise together with the choice of appropriate sensory stimulus, which he defines as the three gears of the exercise, decision-making, and distraction. Considering these basic components, rehabilitation consists of 4 stages. In the first stage, the patient's joint range of motion should be provided, if any, effusion should be removed and active quadriceps contraction should be ensured, and all of these should be combined with the home program. Different from the standard acute period of ACL, different cognitive activities can be loaded into the treatment at this stage or virtual reality glasses can be worn during activities. For example, during the intervention, the patient may be asked to think as if he is pushing the table or to think as if he is hitting the ball. It progresses towards complexity in cognitive tasks given over time. In the second stage, the main goal is to create the right motor pattern, minimal load resistance training, and dynamic loading. Decision-based tasks are presented to provide randomization with appropriate engine patterns and minimal loading. The third stage is plyometric and agility training. Unlike the standard procedure, sensory manipulations are also used a lot. For example, the perception of jumping on an unstable surface by wearing stroboscopic glasses during jumping activity, or turning the head left and right while jumping. Stage 4 is the return to the sports stage. To return to sports, the patient must have developed a sufficient amount of explosiveness, strength, and power. Unlike the 3rd stage, this stage involves similarly simulating sports-specific activities. At all stages, attempts are made to achieve neuroplasticity[23].

Acquiring motor skills in ACL injury prevention programs is based on the neuromuscular control mechanism[24]. To explain motor learning in ACL injury from a general perspective, Gokeler et al. stated motor learning principles with 4 basic principles: external focus, implicit learning, differential learning, and self-controlled learning (Figure 2)[25].

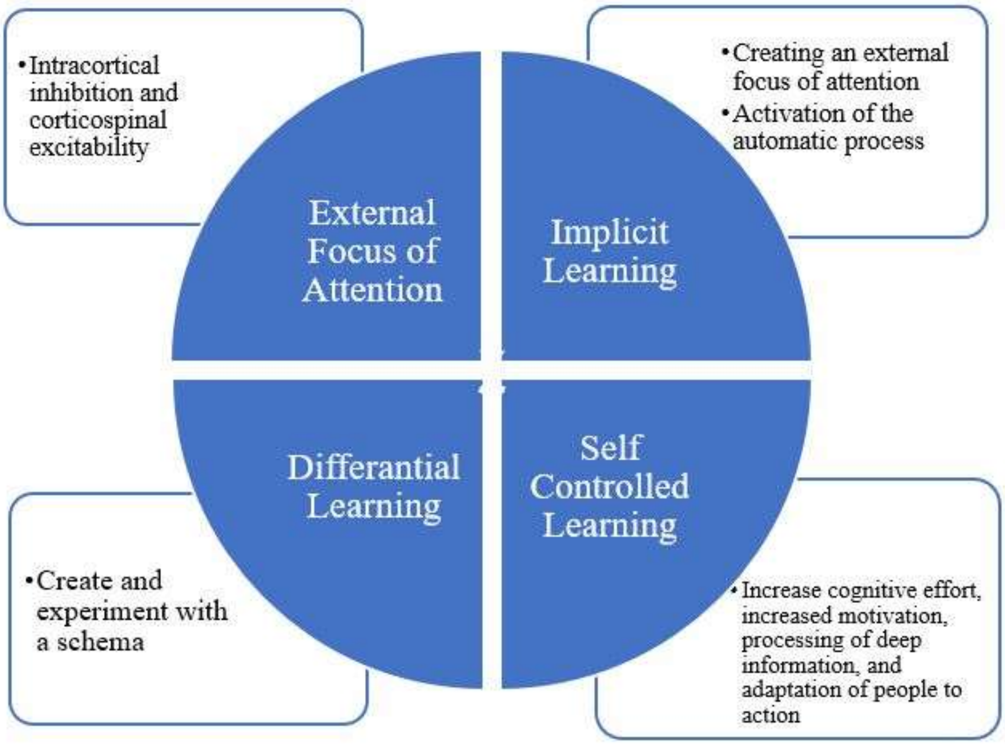

Figure 2. Motor learning principles in ACL injuries

External Focus of Attention

In cases where motor skills are to be learned, the patient is given instructions suitable for motor skills. These instructions include appropriately positioning the patient's extremity or trunk by movement. For example, in the stepping phase of walking, telling the patient to keep the foot, leg, and hip straight to transfer the weight to the ground is an internal instruction that directs the patient's attention to his movement. Internal instructions cause conscious control of movement, while conscious control inhibits movement coordination[26]. Recent studies have concluded that internal instructions are not effective enough. It has been observed that more effective movements are produced by directing the patient's attention to something outside instead of directing his/her attention to his/her own body. For example, imagine that you trace your sole on the ground during the stepping phase. To give another example, the person trained on the balance board can be asked to hold a stick in the balance hand and hold it exactly horizontally without disturbing it. In this way, attention is directed not to one's own body but to an external object. Thus, the individual focuses on the effect of the movement rather than the coordination during the movement. In this way, it was observed that the learning process accelerated with external focus [25]. The main factor here is the provision of intracortical inhibition. It occurs simultaneously with intracortical inhibition and corticospinal excitability, reducing primary motor cortex activation. Because ACL injury can alter intracortical facilitation, depressed intracortical inhibition has been associated with quadriceps inhibition. Quadriceps activity can be restored as intracortical inhibition is achieved by external focus training[27].

Implicit learning

Implicit learning aims to increase motor skills by automating motor learning. Therefore, it is considered a more effective learning method for more complex tasks [28]. In implicit learning, instructions for movement should contain specific analogies rather than giving explicit information about physical location. For example, during the squat movement, instead of saying open your feet shoulder-width apart, point your knees forward, think as if you are holding a big ball between your legs, and try not to drop this ball while bending down, so the need for working memory is reduced and the movement is automated. Implicit learning also serves motor learning by creating an external focus of attention. Thanks to implicit learning, the possibility of making mistakes in complex tasks, multitasking, or under stress is minimized by further activation of the automatic process[28].

Differential Learning

According to the dynamical systems theory, the errors and variations that occur in the process of motion have left their place to fluctuations, which is a more neutral expression. In the process of learning the motion, an increase in fluctuations is observed for the system to find a more suitable mode when passing from one phase to the other[30]. These fluctuations, which occur according to differential learning (DL), form one of the basic steps of motor learning. To learn a skill with differential learning, it is necessary to be exposed to different movement variations in different environments. Unlike traditional motor learning methods, differential learning creates a dynamic basis for motor learning. With the differential learning method, the athlete will perform various sports-specific movement patterns and choose the most appropriate movement pattern for that performance. For example, a football player will try different variations while shooting and finally choose the most suitable pattern for him. Although not able to explain the neurophysiological mechanism of DL alone, Heinz D. et al. examined the brain activities of badminton players with EEG after different learning and repetitive training to examine the neurophysiological mechanism of differential learning. They observed increased activity in the contralateral parietooccipital region and posterior after DL[30].

Self-controlled learning

The self-controlled learning method allows the patient to self-select certain parts of the movement [31]. For example, in a rehabilitation program, the patient decides which sequential activities to do and in what order. Determining the task difficulty, choosing the application time, and predicting the results when the patient is managed by himself; provide more motivation and more effective learning than external guidance [30]. Several mechanisms have been identified for the basis of self-control learning. These; The necessity to increase cognitive effort, increased motivation, processing of deep information, and adaptation of people to action [32-34]. Meanwhile, clinicians can provide positive feedback to motivate patients.

Video-feedback motor learning

According to video feedback, motor learning is also an effective way of learning motor skills. Guadagnoli et al. tested the effectiveness of video feedback in learning the golf swing. The subjects included in the study were divided into 3 groups video, self-instructed and verbal instruction. As a result of the study, they had the best performance in the group studied with video instruction[35]. Clark et al. also compared children's actual performance in swimming learning without video feedback compared to video feedback, and as a result, students in the group watching edited videos showed the best swimming performance, similar to other studies[36].

Contextual intervention

It has a key role in the concept of motor learning. It is when an individual learns an action as part of another intervention [37]. In this way, the function gained for movement in the individual will be realized automatically, not consciously. The application is provided in three different sequences blocked, serial, and random. The number of blocked application repetitions is the key. A single task is done over and over again. In serial application, a predetermined task is done in a determined order. Random execution, on the other hand, requires doing a random task in random order. The variance of the movement is increased as the progress application.

The Role of Motor Learning in ACL Rehabilitation

An ACL injury is not a new condition. Many exercise programs have been tried in his rehabilitation from the past to the present. Graft selection, whether the patient is an athlete or not, moves exercise rehabilitation away from standardization. Although many different rehabilitation programs such as isometric, isotonic, and resistance training, including muscle strength training, have been applied from the past to the present, it has been revealed by current studies that many different parameters are affected by the loss of muscle strength of the individual with anterior cruciate ligament reconstruction (ACLR). The injury affects the articular branch of the posterior tibial nerve and the afferent nerve fibers extending into the joint. The surgical treatment of the anterior cruciate ligament is aimed to restore its biomechanical function, but the affected sensory part or functional loss is not treated [38]. Neuroplasticity rapidly develops at the site of the lost neurosensory component[39]. It is necessary to understand the pathology well to avoid possible risk of injury or to ensure the best recovery after surgery. Kapreli et al. In their study in which they evaluated neuroplasticity in patients with ACL injury with functional MRI, defined ACL injury not as a simple musculoskeletal injury but also as a neurophysiological disorder. For this reason, only strength training will not be sufficient to fulfill the function lost during the rehabilitation process. More attention should be paid to the attentional and environmental components of neuromuscular rehabilitation in ACL rehabilitation. Neural and sensory functions must be activated in rehabilitation. The results of this review are that interventions based on the motor learning principle can be used safely in patients with ACL reconstruction or the prevention of anterior cruciate ligament injuries[40].

Brederin et al. When examining the effects of variable external focus of attention on physical fitness performance, they provided external and internal focus on the participants, and results were better for those with external focus regardless of gender[41]. Similarly, Mcnair et al. asked athletes to listen to the sound of their descent during the jump movement to ensure external focus during descent, and they achieved a lower ground reaction force compared to the control group, minimizing the risk of ACL injury[42]. Internal focusing can cause co-contraction during movement, preventing smooth movement[43]. Porter et al. To examine the effect of external focus of attention on jumping, 120 people were divided into two groups, one group with external and the other group with internal attention focus. He examined the standing long jump performance of all participants. In the internal focus group, "I want you to focus on extending your knees as much as possible while trying to jump as far as possible"; The group who wanted external focus was given instructions such as "I want you to jump as far as possible from the starting line while trying to jump as far as possible". As a result, it was observed that the group with external focus exhibited longer jump performance than the group with internal focus[44].

Implicit learning also helps automate movement by creating an external focus of attention. In a study, 35 individuals with little or no table tennis experience were taught indirect[18] and direct[19] table tennis strokes. Simultaneous high and simultaneous low complex decision-making about where to direct the shot was also made for each individual. As a result, they found that implicit learning outperformed explicit learning. On the other hand, in the open learning group, they achieved better results in the low complexity group than in the high complexity group[45]. Similarly, Farrow et al. In his study, video-based perceptual training was planned to improve the estimation skills of tennis players: the first group was determined as explicit learning, the second group as implicit learning, and the third group as the control group. The players' ability to predict the opponent's service direction has been studied. As a result, there was a significant increase in prediction accuracy after training in the implicit learning group, but not in the explicit learning and control group[46]. As can be seen, the external focus has been more successful than the internal focus in reducing ACL injuries and increasing performance. Welling et al. in their study to prevent ACL injuries, divided individuals into external focus, internal focus, video, and control groups and evaluated their landing performance after the vertical jump[47]. Jump height was recorded as the jump performance and the Landing Error Scoring System (LESS) was used for the landing evaluation. In conclusion, it was observed that the error rate in descent techniques was greatly improved in both the video-based and external focusing groups, indicating that both techniques are of great importance in preventing ACL injury.

Based on the dynamical systems theory of learning, differential learning offers a nonlinear approach to motor learning. Learning is provided by making use of fluctuations that occur with constantly changing movements without repetitions and corrections. Contrary to known learning (linear) methods, there is no such thing as moving from simple to complex or from easy to difficult. According to this approach, (nonlinear) functional movement and to facilitate the decision-making process, the movement should continue without any interruption or restriction in constantly changing situations[48]. Similar causes do not always lead to similar results, sometimes small causes can bring big results. Schollhorn et al. aimed to investigate the acquisition and learning of two different movement techniques in football in parallel. Participants were divided into two groups, traditionally trained and differentially trained (block and random). During the ball control and shooting movements, training was given twice a week for 4 weeks. As a result of the study, it was seen that there were more significant advantages in the acquisition and learning of movement in the group given differential learning training compared to the group given traditional training [49]. As the first stage of motor learning, learning by the block can be performed. During block execution, a high number of repetitions of a single task or high-complexity models are applied in new movements to establish motion adaptation. As the motor progresses toward the associative stage of learning, serial practice is used where various movements are used in an iterative pattern. For the transition to the autonomic phase, random applications are allowed, for which multiple movements performed in an indefinite order are applied.

Conclusion

In light of these studies, programs based on motor learning principles were found to be successful by using optimal movement strategy in ACLR rehabilitation and injury prevention. Motor learning strategies can be used in acquiring skills, learning, and adapting the learned movements to sportive activities and daily life. In studies based on motor learning principles, there are not enough studies on the dosage of the treatment. Future studies should provide information on new programs and dosages based on the motor learning principle.

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Geliş tarihi/ Received: 01.09.2022
Kabul tarihi/Accepted: 01.03.2023