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Clinical Commentary/Current Concept Review

Neurocognitive & Ecological Motor Learning Considerations for the 11+ ACL Injury Prevention Program: A Commentary

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The 11+ is a structured warm-up program designed to prevent injuries in soccer players, but has proven efficacy in many populations, settings and sports. It consists of 15 exercises that target the most common injury sites, such as the knee, ankle, and groin. However, the implementation and adherence of the 11+ remain suboptimal, and recent compelling data indicates underlying mechanisms of injury risk related to neural control of movement may not be adequately targeted. Updates to the 11+ considering practical implications of neurocognitive and ecological motor learning may be warranted for coaches and practitioners. We review the evidence on how an updated 11+ may influence the cognitive and perceptual processes involved in motor control and learning, such as attention, anticipation, decision making, and feedback. How the 11+ can be adapted to the ecological constraints and affordances of the football (soccer) environment is also discussed, including the task, the individual, and the context. By considering these factors, the 11+ can be more effective, engaging, and enjoyable for the players, and thus improve its adoption and compliance. The 11+ has the capability to not only a physical warm-up, but also a neurocognitive and ecological preparation for the game. Therefore, the purpose of this manuscript is to describe the conceptual design of a new ecological neurocognitively enriched 11+, that builds on the strong foundation of the original intervention with considerations for the newly discovered potential neural control of movement risk factors.

INTRODUCTION

OVERVIEW OF THE ORIGINAL 11+

Over the last 20 years, injury prevention has received well deserved attention in the sports medicine community and by sports governing bodies. To illustrate this point, the protection of the athlete's health has become one of the declared objectives of the International Olympic Committee.[1] Football (soccer) is the most popular sport worldwide, and it is played on an amateur or recreational level by almost 300 million people.[2] While soccer can be considered a healthy leisure activity, soccer as a contact team sport, also entails a risk of injury.[3] The medical treatment of soccer-related injuries can have a significant socio-economic impact in terms of related healthcare costs.[4] In 1994 the Fédération Internationale de Football Association (FIFA) created its Medical Assessment and Research Centre (F-MARC) with the aim "to prevent football injuries and to promote football as a health-enhancing leisure activity, improving social behaviour".[5,6]

F-MARC in collaboration the Oslo Sports Trauma Research Center and the Santa Monica Orthopaedic and Sports Medicine Research Foundation developed and tested the injury prevention program (IPP) "11+" (also called "FIFA 11+") in numerous scientific studies, demonstrating how a simple exercise-based program can significantly decrease the incidence of all soccer related injuries in amateur players.[7-14] Additional research has further confirmed the preventive benefits of 11+ and have evaluated its performance effects in amateur soccer players.[15-21] From 2009 to 2016, FIFA has promoted and disseminated the 11+ IPP among its Member Associations and at numerous events/conferences worldwide (until the termination of F-MARC in November 2016). "The 11+" is a complete warm-up IPP with running exercises in the beginning and at the end to activate the cardiovascular system, and specific preventive exercises focusing on core, trunk and leg strength and sta-

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bility, balance, proprioception, and changes of direction, with each exercise providing three levels of increasing difficulty (to allow for variation and progression). It takes about 15-22 minutes to be completed and requires minimal equipment: a set of cones and balls.[2]

Since 2007, different research groups have evaluated the preventive and performance effects of the 11+, making it the most studied IPP worldwide. A significant injury reduction (up to 40- 50%) has been found in female and male players in large RCTs, when the warm-up exercises were performed at least twice a week.[7,10,11,22] These four RCTs impressively showed how a basic injury prevention program, with proper player and team compliance and program fidelity, significantly reduces injuries both in female and male amateur soccer. However, the role of compliance/adherence has been well documented, showing a further reduction of injury risk in those players with higher adherence to the program.[23-25] A recent systematic review and meta-analysis concluded that the 11+ has a substantial, 39% injury reduction effect in recreational/sub-elite soccer, reducing the risk of hamstring, hip/groin, knee and ankle injuries.[26]

Despite the effectiveness of the 11+ in controlled situations, injuries are still increasing across many sports and especially young women's soccer.[27] Several barriers mitigate the pragmatic translation of these controlled study findings to the field, including low compliance, poor program implementation and adoption. While contextual and socioecological factors are the major barrier to implementation,[28,29] they are not easily within the scope of the sports medicine clinician to resolve. A potential avenue to increase compliance and efficacy of the original 11+ is to consider that 20 years have passed since the original program development and emerging fields in relation to ACL injury, such as motor learning, ecological psychology, and neurocognition/neuroplasticity have demonstrated the potential to improve IPP's.[30-39] Updating the 11+ to increase ecological validity and preserve the athlete-environment relationship may aid in overcoming adoption barriers by better linking exercises with training and player performance goals.[40] In light of these advances, it is pertinent to consider an update of the 11+ program based on this emerging evidence.

NEXT GENERATION UPDATES TO THE 11+

While the 11+ program has certainly been effective to reduce injury-risk when implemented with high compliance, non-contact ACL injuries still occur in the intervention group.[26] As non-contact injuries are considered "preventable", this indicates that aspects of physiology that contribute to injury risk are not being trained in the traditional 11+ injury prevention program.[36,37] Recent data indicating that neurocognitive errors precede ACL injury events[41] and deficits in neural connectivity might be a risk factor for primary ACL injury[42-44] pointing to neurophysiology and the neural control of movement under intensive neurocognitive conditions (sport) as a potential missing link to enhance the efficacy of injury prevention training.

Addressing neurophysiology in clinical injury prevention training may at first seem challenging. However, one does not require expensive neuroimaging technology to consider the underlying neural contributors to injury risk. Based on the data available, clinicians can start to augment their practice to not only address physical attribute such as strength, coordination, and dynamic stability, but ensure those capabilities persist in the neurocognitively demanding sport environment. By building on the foundational exercises of the 11+ with selective additions of a neurocognitive challenge and ecological motor learning principles, the program can target not only the well-known musculoskeletal risk factors, but the potential neurological ones as well. Therefore, the purpose of this manuscript is to describe the conceptual design of a new ecological neurocognitively enriched 11+, that builds on the strong foundation of the original intervention with considerations for the newly discovered potential neural control of movement risk factors.

INTEGRATED ECOLOGICAL & NEUROCOGNITIVE CONSIDERATIONS

Performance in sport is a combination of physical and perceptual-cognitive skills that require the athlete to rapidly locate, identify, and process information and coordinate appropriate actions. The traditional sports medicine approach has been to focus on the physical, with an emphasis on biomechanical risk factors.[45-49] While the focus on observable biomechanics proved essential to initial understanding, there is still a substantial amount of unexplained variance for primary injury risk.[50] The authors' contend that a portion of that unexplained injury risk variance not addressed with current IPPs is related to neurocognition and neural control of movement.[33,41] As the neural data for IPP design is being considered, it is vital to maintain as much ecological validity as possible. As framework for ecological integration is Newell's constraints-led approach in which the relations between the person, task and environment explain performance.[51] In high ACL injury risk sports, athletes are under considerable task-environmental demand to perceive, anticipate and respond to a quickly changing environment. This, in-turn, requires considerable neurocognitive resources to interpret the relevant contextual information and prepare appropriate motor responses.[40] Any deficit or delay in sensory or attentional processing reduces available time for motor coordination and corrections, increasing probability of coordination errors that result in high-risk knee movements.[52]

Neurocognitive abilities are typically conceptualized as lower- and higher order (presented in column 5 in Tables 1, 2 and 3). Lower-order cognitive abilities associated with injury risk include visual attention, processing speed (e.g. reaction time) and simple dual-tasking.[53-55] Higher-order cognitive skills are executive functions of working memory, inhibitory control, and cognitive flexibility.[53] While lower-order abilities enable the detection and instigation of movement plans, higher order abilities enable athletes to accommodate to changing situational cues, problem solve, maintain vigilance, switch attention and generate motor corrections.[56] For example, defenders are required predict the outcome of offensive players movements with limited information required constant extrapolations, attention shifts and motor refinements. This may pose a challenge for a defender, who is pressing and anticipating a particular direction of the ball, but at the last moment, the attacker is faking his action. In a fraction of a second, the defender must change the movement quickly which poses a significant challenge for the motor system to change an already planned or initiated movement (response inhibition).[41]

INJURY PREVENTION TRAINING THAT PREPARES FOR SPORT

Given the intensive neurocognitive demand of sport, it is essential to expose athletes to challenging, unpredictable environments during preventative training.[30] This so called "repetition without repetition" makes it necessary to train adaptable movement solutions instead of one 'ideal' movement technique. To achieve such variability in the regulation of movement coordination, the authors' suggest clinicians leverage challenges in the task, person, or environment via implicit motor learning strategies that encourage creativity, self-exploration, and cognitive flexibility during IPPs. Implicit learning methods aim to minimize declarative (explicit) knowledge about movement execution during learning.[57] For this purpose, implicit learning can be induced by providing external focus instructions or analogies rather than explicit instructions during motor skill acquisition.[32] Implicit learning reduces the reliance on the working memory for movement coordination, freeing up those resources for sport engagement.[58] As competitive sports require elevated task complexity under intensive psychological pressure, the likelihood of a decision-making error increases when executing motor skills that require high levels of working memory.[59] Implicit motor learning has been shown to reduce working memory demands and be more sustainable in situations with physical[60-62] or mental pressure[63-66] providing a trainable pathway to enhance IPP effect transfer to sport.

Traditionally, the instructions in the 11+ program have included explicit wording, such as "bend your hips and knees". However, an external focus of attention can lead to improved movement form and result in safer landing mechanics, compared to an internal focus of attention with explicit wording.[67] A literature review on jump and landing technique showed that an external focus of attention (e.g. "make as little noise as possible when landing") improves movement with greater knee flexion angles, greater center of mass displacement, lower peak vertical ground reaction force , and improved neuromuscular coordination, while maintaining or improving performance (i.e., jump height or distance) as compared to an internal focus of attention.[67] The subtle instruction can promote implicit learning so that attention is directed to one's intended effect of the movement (goal-directed attention), in contrast to paying attention to one's own body movements (i.e., internal focus of attention or self-directed attention).[34] This implicit learning centers on the ability to engage both the perceptual-cognitive and physical performance factors in the functional task environment.[68] Implicit learning with instructions and feedback to direct the attention to one's intended effect of the movement can be promoted by using an external focus of attention (e.g. 'make as little noise as possible when landing') or an analogy (e.g. "pretend you are landing in a puddle of water, don't splash it too much!") (see column 6 and 7 in Tables 1, 2 and 3).

FRAMEWORK FOR INTEGRATION OF ECOLOGICAL NEUROCOGNITIVE PROGRESSIONS

The authors' have proposed that a combination of situational awareness theory, ecological neurocognitive challenges and implicit motor learning be integrated to provide three layers of 11+ "augmented" exercise progression across strategic, tactical, and reactive layers.[69-71] Strategic control is used when decisions are not time dependent.[68] The athlete has plenty of time to explore and coordinate potential movement solutions. Athletes have the time to become familiar with a specific activity, progress at their own pace, and refine their movement patterns in a safe and certain functional task environment. Tactical control takes place when perceptual-cognitive and physical performance demands are compressed into a time-dependent situation with increasing uncertainty. Tactical control is typically incorporated into sport drills and maneuvers in which athletes work on their performance during changing sport situations in a relatively controlled functional task environment. The tactical control phase shifts the focus from simple physical performance to time-dependent decision-making and physical performance.[68]

When uncertainty continues to increase and time for decision-making decreases, the athlete may shift to reactive control where there is limited or no time to explore the functional task environment.[68] In reactive control, an athlete may first enter a "panic" style of coordination. Panic in this context represents the breakdown in the ability to meaningfully link the perceptual-cognitive (anticipation and control) and physical (movement competence and functional variability) factors for successfully attaining a particular goal, which ultimately increases the risk for compromised performance. This is typically when we may see an athlete freeze up or perform dangerous movements that are not linked to safe performance in sport situations. Exercises with this uncontrolled uncertainty should be practiced until control and competence is reached.[68]

DISCUSSION

The main objective of the new program is to address the *neural aspects* of ACL injury prevention, which have been largely overlooked in traditional interventions. The new program incorporates exercises that challenge the integration of neuromuscular and neurocognitive abilities. These newly "augmented" exercises aim to improve the neural control of movement, the ability to anticipate and react to changing situations, and the integration of sensory and motor information. By enhancing these abilities, the new program may reduce the risk of ACL injury by preventing or correcting faulty movement patterns, improving joint sta-

Table 1. Example exercise modifications incorporating Neurocognitive and Ecological Challenges

Exercise	Neurocognitive load	Strategic (no / low uncertainty in task-environment)	Tactical (manipulation of uncertainty in the task-environment)	Reactive (uncontrolled uncertainty in the task-environment)	Instruction / feedback to improve knee flexion
Single leg balance	Lower order: [1]visual attention,[2]processing speed, [3]reaction time, [4]decision making, [5]dual tasking. Higher order: [6]inhibitory control, [7]working memory	1) Maintain balance while moving your arms sideways, forward, backward, up, together or alternating. 2) Swing your leg forward, backward, sideways. 3) Perform single leg squats, while moving your arms.[2,5]	1) Toss a ball against a wall with a self-chosen speed, height, direction, and catch it with two hands or one hand. 2) Perform single leg squats while tossing. 3) While tossing, attend to visual cues from a board, cards, screen, or hand signals to engage in counting or arithmetic or word games or identification. 4) If visual display is unavailable, count down from 100 with subtractions of 7 or multiply by 3 starting from 2.[1,2,5]	Perform tossing a ball with a partner. Your partner chooses the speed, height and direction of the ball. 1) When ball is in the air your partner calls '1' of '2' or 'left' or 'right' to indicate how you will catch the ball.[1,3-5] 2) Your partner calls different numbers, such as 1 or 2, and you perform a simple action as quickly as possible, such as clapping or snapping before catching the ball, according to the number that you hear. Switch legs and cues regularly. To make it harder, use numbers or arithmetic that are more complex.[1,3-5] 3) Your partner holds a red and green ball. When you see the red ball, you do perform a single leg squat, when you see the green ball, you just hold balance.[1,3,5,6] 4) Your partner calls or displays a series of numbers or signals, each number representing a certain task. You perform the tasks subsequently as quickly as possible.[1,3-5,7]	"While squatting, pretend you are going to sit on a chair." **Instruction / feedback to reduce knee abduction** "Pretend you have headlights in your knees and point them forward." "Make sure the tip of your shoes point forward when you land."

Table 2. Example exercise modifications incorporating Neurocognitive and Ecological Challenges

Exercise	Neurocognitive load	Strategic (no / low uncertainty in task-environment)	Tactical (manipulation of uncertainty in the task-environment)	Reactive (uncontrolled uncertainty in the task-environment)	Instruction / feedback to improve knee flexion	Instruction / feedback to reduce knee abduction
Box jumps.	Lower order: [1]visual attention,[2]processing speed, [3]reaction time, [4]decision making, [5]dual tasking. Higher order: [6]inhibitory control, [7]working memory	Stand sideways in one of the quadrants of a square. Jump quickly along the course with self-chosen speed, height, direction, and turns.[2] Options can include lateral, medial, forward, backward.	Stand sideways in one of the quadrants of a square. Jump along the course with self-chosen speed, height, direction, and turns.[2] 1) While doing this, throw and catch or dribble with a ball.[5] 1) While doing this, alternate between two legs and one leg.	You and your partner are both in your own quadrant. 1) Your partner indicates different directions, turns, heights and speeds and you mimic your partner.[1,2,4] 2) Give each quadrant a number. Hop forward on one leg from one number to another, following a sequence that your partner calls out, such as 4-1-3-2.[2] The call can be either before[7] or while[4] jumping. If possible do as a group with a visual cue. Can use visual cue patterns to indicate box jump pattern. 3) Hop forward on one leg. Look at your partner who is holding up a ball of a certain size (S/L) and side (L/R) quickly after each of your landings and immediately say the size and jump the direction indicated as quickly as possible.[1,3,4]	"Land as softly as you can." "Pretend you are going to sit on a chair when landing." "Make as less noise as possible when landing." "Pretend someone is sleeping next to you, don't wake him up when you land!" "Pretend you are landing in a puddle of water, don't splash it too much!"	"Pretend you have headlights in your knees and point them forward." "Make sure the tip of your shoes point forward when you land." "Land on the targets on the floor."

Table 3. Example exercise modifications incorporating Neurocognitive and Ecological Challenges

Exercise	Neurocognitive load	Strategic (no / low uncertainty in task-environment)	Tactical (manipulation of uncertainty in the task-environment)	Reactive (uncontrolled uncertainty in the task-environment)	Instruction / feedback to improve knee flexion	Instruction / feedback to reduce knee abduction
Run along a marked course with several changes of directions	Lower order: [1]visual attention,[2]processing speed, [3]reaction time, [4]decision making, [5]dual tasking. Higher order: [6]inhibitory control, [7]working memory	Run quickly along the course with self-chosen speed and angles.[2]	Run along the course with self-chosen speed and angles,[2] while dribbling a ball.[5]	Run towards a partner along the course. If done as a group\ team use visual cues, arrows or colors or hand signals to indicate direction, and speed changes 1) When together, the partner cuts to the left or right (with possibly a fake move), you cut the opposite direction.[1,2,4,6] 2) Your partner approaches you dribbling with a ball and when together, the partner decides to cut to the left or right with ball (with possibly a fake move), you cut and try to intercept the ball as quickly as possible.[1,3-7] 3) Your partner approaches you dribbling with a ball and when together, s/he will pass a ball (direction and speed self-chosen) and you have to change direction to chase for the ball.[1,2,4,5,7]	"When making the cut, push yourself off of the ground as hard as possible." "When making the cut, I want to see your cleats in the grass." "When making the cut, accelerate like a rocket."	"Point the logo of your shirt towards the new running direction." "Pretend your knee in a headlight, direct it to the new running direction."

bility and muscle activation, and increasing the adaptability and resilience of the soccer players to different scenarios and environments. The new program is presented to provide suggestions on how to augment ACL injury prevention exercises, these are not set in stone. Clinicians are encouraged to use their own creativity by modifying the presented ideas or use other ideas, with the same underlying principles.

One of the important directions for future research is to explore the mechanisms and pathways by which the new program may influence the neural aspects of ACL injury prevention. A conceptual framework for clinical practice could be developed based on the evidence from this research, which would guide the selection, progression, and adaptation of the exercises according to the individual needs and goals of the soccer players. Additionally, policy implications could be considered, such as the feasibility, acceptability, and cost-effectiveness of the new program in different settings and populations, and the potential barriers and facilitators for its implementation and evaluation. These recommendations and suggestions would help to advance the knowledge and practice of ACL injury prevention, and to promote the new program as a novel and promising approach that integrates the neuromuscular and neurocognitive dimensions.

CONCLUSION

The 11+ continues to be the most studied injury prevention program worldwide. While its injury reduction efficacy in controlled studies has been repeatedly confirmed, showing an overall 40% reduction rate of lower extremity injuries, the time has come to reflect after all these years. Reflection is an essential step in any journey (the ACL injury prevention journey, in this case), and it should allow incorporate of new data, specifically here the neurocognitive and ecological motor learning principles into the 11+ program. By recognizing the evolving research in ACL neuroscience and motor learning, this current knowledge should be integrated in the further dissemination and implementation of the 11+. Considering the strong foundation of the 11+, there is great potential to maximize the effectiveness of a reframed 11+ based on the latest neuroscience knowledge in further reducing lower extremity injuries, and particularly ACL injuries.

The authors encourage our colleagues PTs, ATCs, coaches and other personnel working in soccer to implement (even partially) this proposed "11+ augmented", with the hope of stimulating new research in this emerging area. As researchers and clinicians, it is the responsibility and duty of all practitioners to (or try to) bring this framework to the field, for the health of all young athletes playing soccer, the most popular sport in the world.

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