SYNDESMOSIS INJURIES IN ATHLETES

RETURN TO SPORTS CONTINUUM IS LINKED TO HIGH QUALITY REHABILITATION

– Written by Pieter D'Hooghe, Qatar, Igor Tak, The Netherlands, and Alli Gokeler, The Netherlands & Germany

INTRODUCTION

Injuries to the ankle syndesmosis have demonstrated an increased prevalence among athletes of all levels. This may be the result of newer types of playing surface (i.e. artificial turf), increased load due to training and packed match programs, but increased awareness and improved diagnostics for this type of injury seem to play a vital role as well.

Syndesmotic injuries occur in athletes at an estimated incidence of 0.05 injuries per 1000 hours of exposure[1]. Specifically, impact and collision sports such as soccer, skiing, football, ice hockey, wrestling, and rugby exhibit a higher incidence of this type of injury[1]. It is widely recognized that syndesmotic injuries result in 1) substantially longer time loss from sport compared to other ankle ligament injuries, 2) are much more likely to require surgical stabilization (Figure 1), and 3) are associated with more long-term functional sequelae.

The return to sport continuum (RTS) starts immediately after injury and can be divided into (1) return to participation, (2) return to sports and finally (3) return to performance (RTP)[2]. Every step within this RTS continuum is cautiously taken, in striving to reach the pre-injury level of performance. The highest likelihood to achieve this goal is based on the prerequisite that clinicians treating these injuries have a thorough understanding of 1) pathology of syndesmotic injuries, 2) surgical procedures, and 3) deliver high-quality rehabilitation. The RTS continuum allows for individual tailoring of the content during rehabilitation but also should set boundaries, which one should not exceed. The latter is essentially relevant in the beginning to protect the surgical stabilisation to allow for the weak links to heal, which is the basis for increasing and durable load-bearing capacity over time.

In this article, we present a short overview of current surgical procedures, which is relevant for rehabilitation specialists. The main aim is to present advances and expert-opinion suggestions on the rehabilitation program within a RTS continuum after syndesmotic ankle injury.

Global Perspective

The Leg, Ankle and Foot Committee (LAF) of the International Society of Arthroscopy, Knee surgery and Orthopaedic Sports Medicine (ISAKOS) recently surveyed 742 orthopaedic surgeons specialising in ankle injuries from across the globe through ISAKOS and all major orthopaedic sports medicine societies. Survey participants answered questions focused on their indications for the treatment of syndesmotic injuries and the information that was used during their decision-making process. Each respondent's preferred technique, either suture-buttons, syndesmotic screws, or hybrid constructs for operative repair of indicated syndesmotic injuries, were also queried. Six hypothetical athlete scenarios were constructed to assess the preferred duration of rehabilitation and graduation to activity in each variation of syndesmotic injury. Flexible devices were the preferred fixation construct (47%), followed by screws (30%), hybrid fixation (18%) and other (5%). There was a higher preference for flexible devices among sports medicine trained providers (58%) relative to non-sports medicine trained providers (44%). In total, 64% of respondents noted that their rehabilitation protocols would not change for each athlete scenario. Considerable variability was present in an anticipated full

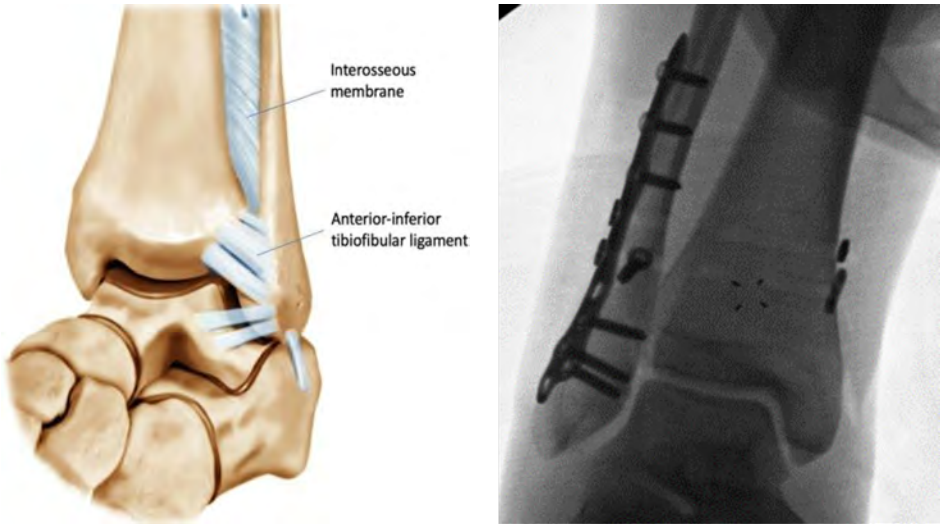

Figure 1: a) Representation of ankle syndesmosis ligaments. b) Per operative imaging of stabilisation of fibular (Weber C) fracture and syndesmosis rupture. Note the fibular plate and double flexible button fixation. Bone tunnels through the tibia and fibula are visible.

Recent insights from the ISAKOS Return to Play Survey

There is no current consensus on the timeline to be advised for athletes to return to performance following a syndesmotic injury of the ankle. D'Hooghe et al analysed both the time to return to sport-specific rehabilitation as well as the time to first participation in an official soccer match, in a large professional soccer injury registry of 110 players with Grade IIb and III syndesmotic injuries[3]. Their data revealed that the mean time to begin on-field/sport-specific rehabilitation was 37 +/- 12 days, with a mean time of 103 +/- 28 days to the first match after syndesmotic stabilization. Only 4% of the athletes returned to an official game within two months after surgery. Two important points needs to be mentioned here 1) there is a large standard deviation between players of up to 1 month to play the first match, 2) playing the first match does not mean the player has returned to the pre-injury performance level of sports. This may take substantially more time as is known from, for example, ACL injuries. This information assists clinicians in educating players and coaches and guides expectation management.

return to sport, ranging from immediately following an injury to 6 months post-op. From our survey collection, we were able to infer that regardless of the severity of the injury to the syndesmosis, device choice and return to play protocol were not consistent internationally. Thus, no consensus exists among providers treating syndesmotic injuries.

Recent anecdotal reports (NCAA) have questioned the dogma of immobilization for syndesmotic ankle injuries in athletes. These considerations have ignited a renewed discussion on accelerated rehabilitation and consequently brought more awareness to the flexible device techniques. The LAF survey also indicated that there is substantial variability in return to sport protocols. This information taken altogether highlights the need for specific attention on how to design an optimal post-operative rehabilitation pathway.

REHABILITATION

Although there are clear differences in aetiology and mechanism of injury between lateral ligament ankle injuries and syndesmotic injuries, rehabilitation of most syndesmotic ankle sprains is still performed according to "classic" ankle sprain treatment regimes. To improve our understanding in syndesmotic injury rehabilitation, there is a need for high quality rehabilitation. In this article, we will provide a scientific basis for the rationale behind our rehabilitation program following syndesmotic stabilisation. We will first discuss healing in relation to loading in the early phase after surgical stabilisation. Following, we present a novel framework of our rehabilitation program.

General considerations

A syndesmotic injury is commonly regarded as a biomechanical injury and treated as such. This is for sure a correct approach, certainly in the early and intermediate stages of healing. Protection of the surgical stabilisation is essential, yet at the same time early ankle loading is advocated. Hence, rehabilitation should take place within the boundaries of early protection, whilst early loading and restoring functions needed for e.g. ADL. The rehabilitation after surgical stabilization of syndesmotic injury is organized in four phases. Progression from one phase to the next more demanding phase is primarily based on meeting criteria, the time factor is used as a gauge to determine whether an injured athlete is progressing as expected based on data from the entire population of injured players.

In this section we present the early stage of the rehabilitation options and restrictions. For the later phases, we will introduce a comprehensive multimodal rehabilitation model.

Balancing between early loading yet protecting the surgical stabilization

In Figure 2 we present guidelines regarding load (A) and range of movement (B) of the ankle in the early phase. Note that exercising without a boot or walker in the 1st phase is advised to improve ankle ROM and activate muscles of the lower leg.

A medially oriented and circular sport tape supports the ankle and the reconstructed syndesmosis[4]. Additionally, this type of rigid tape increased posteromedial ankle stability during a Y-balance task, more than kinesiotape or no tape at all[4,5]. Medial support and circular rigid taping seem valid ways to protect the ankle syndesmosis in the early phase of rehab.

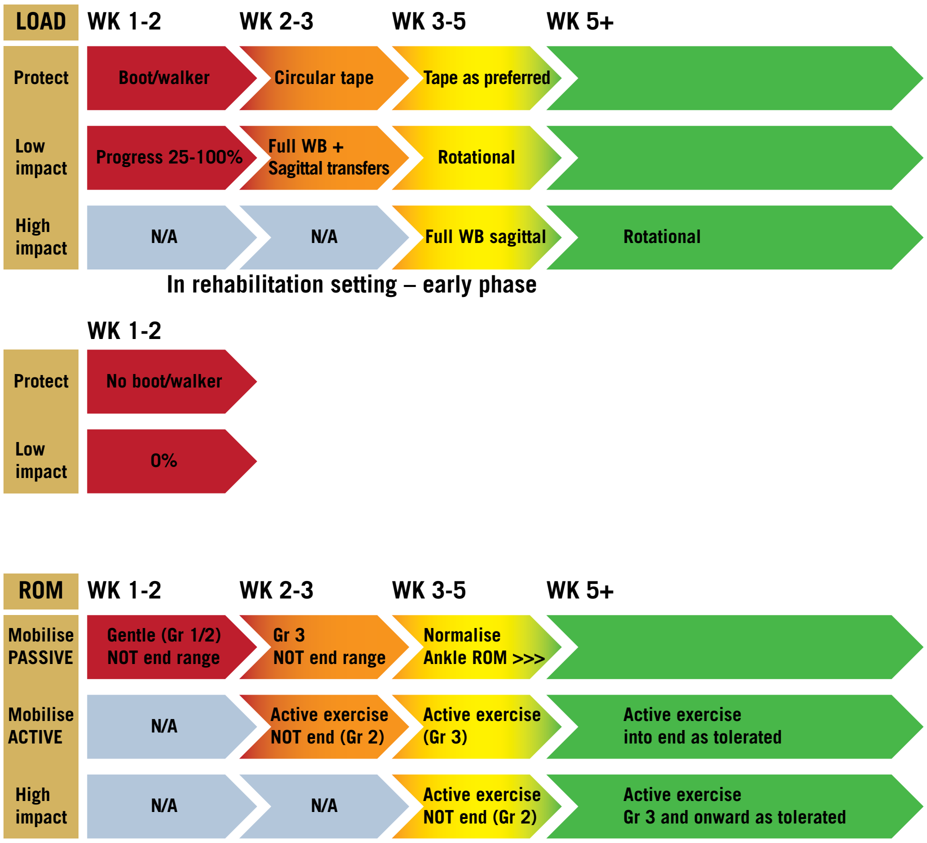

Figure 2: Progression of loading and range of movement (ROM) allowed is presented at 2a and 2b respectively. Note that there is some overlap in weeks as the clinical picture may allow advances without crossing the strict timeframe borders.

First phase: (0-2 weeks)

- Activation of the proximal global movement chain.
- Isometric activation and increasing facilitation of (deep) calf musculature & intrinsic foot musculature (plantar and dorsal flexors and evertors and invertors as well as deep foot flexors and extensors).
- Apply neurophysiological training principles: cross education of the non-injured side.
- Improve hip mobility and activity: hip extension & external rotation / abduction.
- Gait training within limits of allowed weight bearing.

Framework rehabilitation: time for a paradigm change

Acknowledge neurophysiological and neurocognitive changes

It is apparent that traditional rehabilitation does not restore normal sensorimotor function in all patients after syndesmotic injury and necessitates the need to appraise their components. These entail a combination of exercises to restore range of motion and improve muscle strength, basic neuromuscular function and endurance. Although we acknowledge the importance of addressing these factors, there is a clear need for improvement in the light of RTP whilst reducing re-injury risk and early onset of osteoarthritis.

Figure 3: Examples of exercises with increasing load and different stimuli per the different phases. Colors as presented in figure to depict different phases. Phase 1: a) unloaded muscle activation of calf and intrinsic foot. Phase 1 onwards to phase 2: b-d) partially loaded muscle activation within range.

Emerging evidence indicates the large cascade of neurophysiological and neurocognitive alterations that occur after ankle injury[6]. A unilateral ankle injury induces bilateral lower extremity dysfunction, with sensory information deficits across the whole spectrum of the sensorimotor system[7].

The sensorimotor system incorporates all the afferent, efferent, and central integration and processing components involved in maintaining functional joint stability while performing a task. Gibson[8] posited that sensory information from the environment provides movement affordances and movement provides sensory information. In ecological dynamics approach, the perceptual (based on sensory information), neurocognition and action "systems" are deeply intertwined in their activity, functioning as continuously integrated and highly coupled systems[9]. This interaction is presented in Figure 4.

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 a syndesmotic injury as a combined biomechanical-neurophysiological-neurocognitive injury. Adopting this more comprehensive approach is likely to improve outcomes.

For purposes of comprehensive post-operative syndesmosis injury rehabilitation, a model that integrates function in subsystems of motor tasks, sensory (based on CNS changes) and neurocognition serves as the foundation (Figure 5). The model is a modified version previously published by Baumeister[11] who presented a sensorimotor control model that integrates sensory information, subsequent processing in the brain and the resultant motor action. 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 motor-sensory and neurocognitive function and the relationship between them is examined. As discussed before, the components of motor function, sensory system and neurocognition should not be viewed in isolation as these subsystems are intertwined. Knowledge however, has been obtained from e.g. complex neurophysiological studies, leaving clinicians with the question how to assess this in a clinical setting.

Gold standard

Pain is your guide both during and after loading. For many this is a difficult topic and therefore we propose the following:
<u>No acute, sharp pain</u> > 4/10 VAS during exercises. Pain should subside within 2-3 hours after exercise (thus <u>not accumulate</u> over multiple days). There should be <u>no increase in swelling</u> the day after exercise.

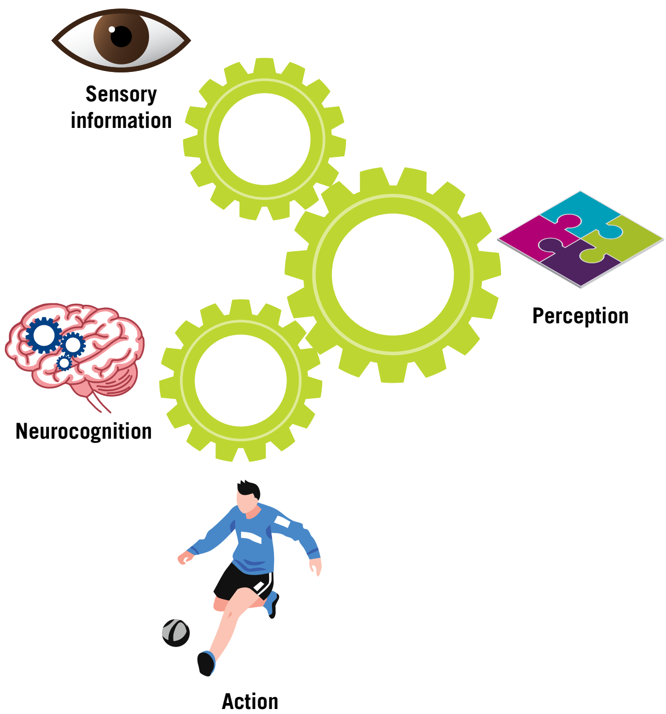

Figure 4: Model displaying the intertwined process from perceiving information from the environment, processing this information and selecting a motor action[10].

The objective of the model is to assist clinicians with a framework on how manipulations within the subsystems (motor, sensory, neurocognitive) influence the 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[12]. 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, added neurocognitive load to change of direction or jump-landing tasks elicit movement patterns that may increase lower extremity injury risk[13–16].

How can we use the model for assessment?
First, we need to establish a baseline condition. Obviously, a test that has demonstrated satisfactory reliability and clinical relevance should be chosen. In this example we will use the modified Star Excursion Balance test (mSEBT) serving as a baseline reference test. The scoring is done according to recent guidelines[17]. In addition to the standard scoring we also employ sensor technology to assess the movement coordination during the task. This allows us to measure kinematics of the trunk and lower extremities. In the example, we use added neurocognitive load to a balance motor task to illustrate the potential effect on movement coordination e.g. 'kinematics lower extremity' and the effect on performance 'reach on the mSEBT'. A schematic overview is presented in Figure 5 a and b. The coordination and performance can manifest itself in various ways:

1. the athlete, under increasing neurocognitive load, demonstrates good coordination and performance
2. the athlete, under increasing neurocognitive load, demonstrates poor coordination but good performance
3. the athlete, under increasing neurocognitive load, demonstrates good coordination but poor performance
4. the athlete, under increasing neurocognitive load, demonstrates poor coordination and poor performance

Second phase: (2-3 weeks)

- Full weight bearing
- Active mobilisation (Gr II) + manual passive ROM of the ankle (gr III allowed)
- Improve proximal control with weight bearing exercises
- Intrinsic foot & calf muscle activation while weight bearing
- Gait training with real time video feedback or sensor technology
- Corrective frontal & sagittal weight transfer exercises.
- Implementation of the somatosensory model of training to integrate sensory and neurocognitive function to motor tasks to enhance neuroplasticity.

Third phase: (3-5 weeks)

- Active mobilisation exercises and integration of ankle rotation with progressive resistance. Integrate rotations and variations with a fixed talus: forefoot - mid foot.
- Passive ROM with mobilisation towards full ankle ROM
- If a normal gait pattern has been

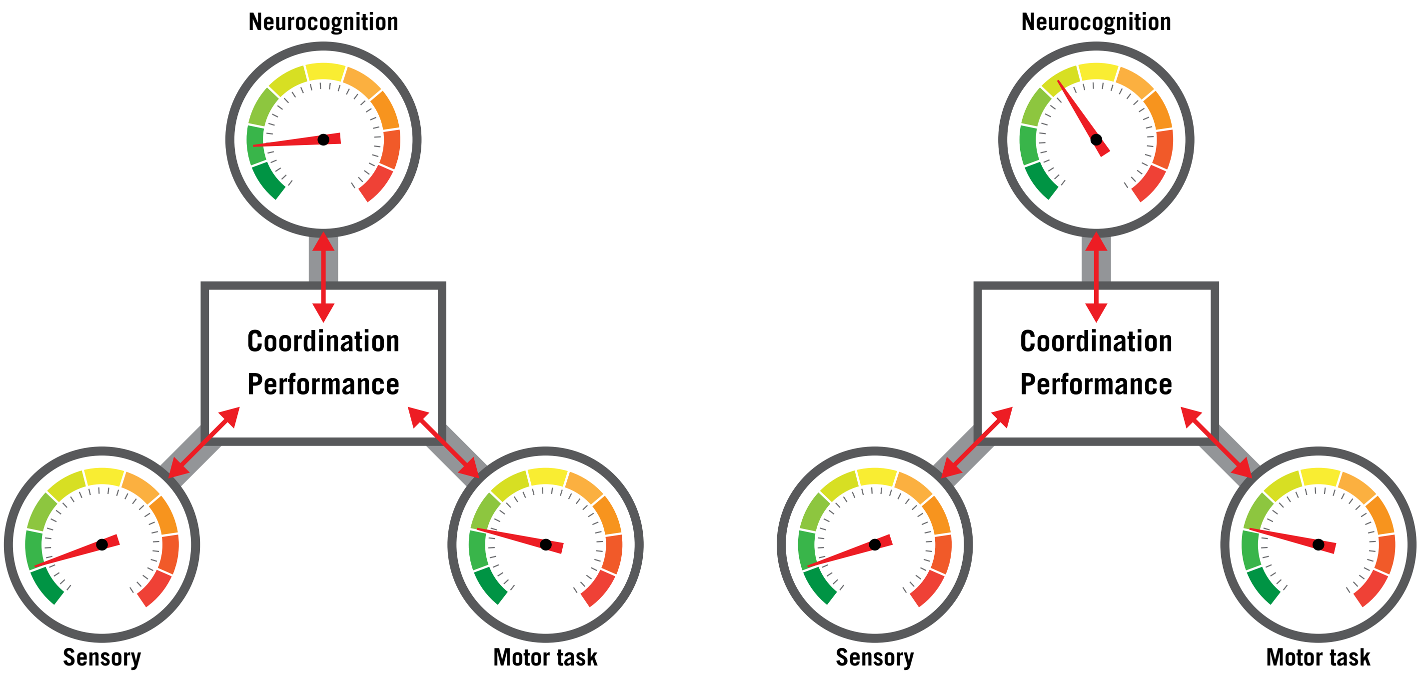

Figure 5 (above): a) This model shows how motor task, sensory and neurocognition can be manipulated for testing and subsequent tailored rehabilitation. b) The same motor task is performed as in Figure 5a, but now with higher concurrent neurocognitive load.

Figure 6 (left): Athlete initially performs the modified Star Excursion Balance test (mSEBT). The reach distance in the three directions is measured. In addition, movement analysis of the pelvis, hip, knee and ankle is simultaneously done with inertial measurement units (Sportslapp, The Netherlands). After the baseline mSEBT, additional sensory and neurocognitive load (dual motor-motor and dual motor-cognitive task) is added and its effect on the reach distance and/or movements of lower extremity is determined. In addition, the cognitive performance is assessed.

established and pain; start basic running drills (tripling, skipping etc) keeping pain < 2/10. Progress to straight line running if tolerated
- Conduct running motion analysis (2D video or sensor technology). Check for proper alignment in the sagittal plane and ROM ankle dorsiflexion (left-right).
- Improving proximal control in impact situations
- Intrinsic muscle activation with eccentric exercise (eg. backward walking/ jumping / running).
- Continued sensorimotor training principles: add variations in neurocognitive (e.g. dual-tasking) and sensory (e.g. stroboscopic glasses to target visual dependency, even/uneven surface, barefoot/with sport shoes) load to the exercises
- Use the functional task environment principles to plan and organise the exercise program. All high impact exercises in the third phase of rehabilitation should be confounded to the strategic phase (Figure 12).

Gold standard

No syndesmotic stress exercises with full weight bearing

Figure 7: Athlete responding to visual stimuli. Note the response is either done with the hand or the foot but not simultaneously indicating the difficulty to respond to multiple ad random stimuli.

Gold standard

Correct frontal & sagittal & rotational weight transfer with higher impact. (correct = full control of active movement through range.)

Fourth phase: (5 weeks +)
- Focus towards RTS, changes in shoe/ boot & surfaces.
- High impact movements (multidimensional).
- Rotation exercises with resistance
- Start from eversion ankle position, then implement stress & rotation exercises from this position.
- Increase the load slowly (ligaments are adaptive to load).
- Implement deceleration exercises and forces
- Implement full impact strength exercises
- Implement multi-coordination exercises
- Continue to use the functional task environment principles. Progress from strategic to the tactical and finally reactive phase. Criteria for progression are based on movement competence and assure that the athlete can cope with the psychological stress when exposed to higher sport-specific demands. In addition, and as in previous phases, monitor for adverse reactions like increased pain and swelling, as this would preclude progression.

Clinical tests and milestones

Considerations
- Increased BMI has a higher injury risk[18].
- Ankle ROM should be restored to full as ROM deficits pose a risk factor for recurrent injury
- Hip external rotation ROM should be restored as lower hip ROM results in more external rotation in the ankle. This foot position plays a key role in the mechanism of (re-) injury.
- Lack of hip extension.
- End-range extension testing (active + passive) of the first toe. Limited function results in medially collapsed and externally oriented foot being related to a syndesmosis injury
- Balance testing:
  - modified Star excursion balance test
  - Single-leg step down: Hip flexion/ knee flexion/ ankle dorsiflexion in the sagittal plane.
  - Alignment adjustments with focus on the frontal plane.
- Drop jump - landing pattern LESS score:
  - Hip flexion/ knee flexion/ ankle dorsiflexion in sagittal plane.

  - Alignment adjustments with focus on the frontal plane.
- Hop test (e.g. single hop test and triple hop test distance):
  - Exclude a potential stiff knee pattern
  - Ankle dorsiflexion angle analysis by landing: injured - non-injured side
  - Landing and push off equally forceful from similar biomechanics/ kinetics
  - LSI 100%
  - Absolute jump distance compared to pre-injury, if not available use non-injured side or normative data healthy controls
  - Use sensor technology for quantitative and qualitative analysis
- Sensorimotor multidirectional hop test. Outcome measures: jump distance and height, movement quality, correct response and reaction time. Use systems like SwitchedOn, Fitlight, Blazepod or Smartgoals
  - medial / lateral triple hop for distance
  - 90 medial / lateral rotational hop for distance
  - vertical hop
  - combinations of the above in a random (unexpected) order
- Change of direction test
  - T-test
  - Illinois test
- Rotation stress exercise:
  - Smooth knee flexion to achieve
  - Painfree ankle / knee rotation stress to achieve
  - Symmetrical ankle dorsiflexion

In rehabilitation of syndesmosis injuries, often pre-planned motor tasks such as landing from a jump or cutting is used to identify high-risk lower extremity biomechanics[19]. The traditional RTS test employing single controlled and specific tasks (jumping, cutting, etc.) that allow full attention to motor control (including maximal pre-task planning and preparation) may not adequately detect those that would present with higher injury risk movement on the field of play when attention is diverted. We propose an approach from an 'ecological dynamics' perspective that considers the human body as a complex adaptive system that interacts with its environment, which is best studied at the athlete-environment level of analysis[12].

Figure 8: a) Athlete performing a soccer dribble task with additional cognitive load to respond to the representative colour of the ball as shown on the TV screen. b) The same dribble task is done; however visual information is distorted as the athlete wears stroboscopic glasses.

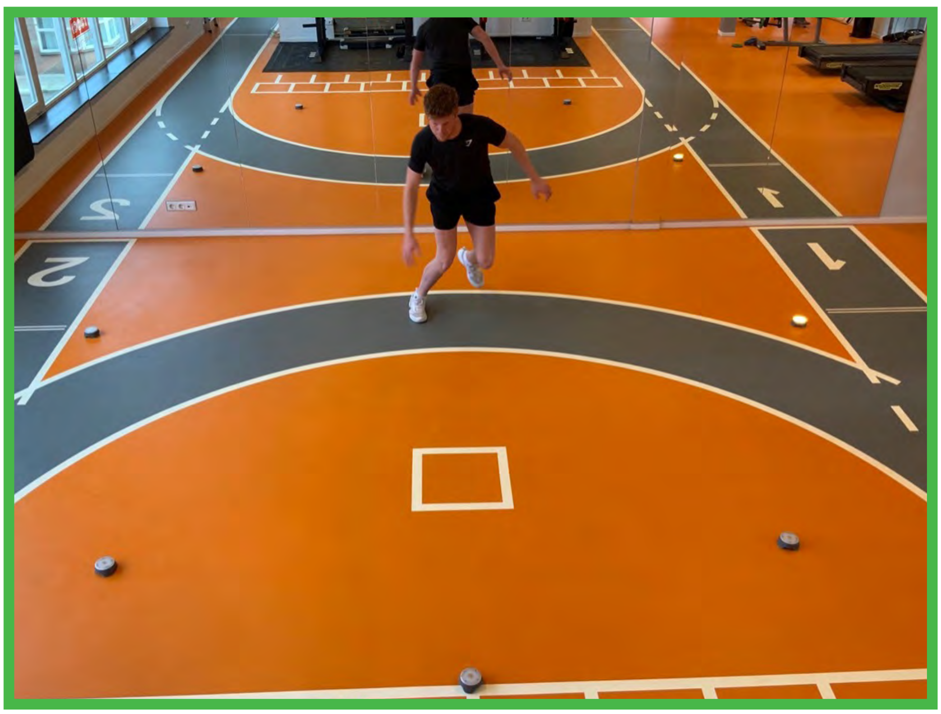

Figure 9: Ahtlete performs multidirectional (medialleteral triple hop, diagonal medial/lateral rotational single leg hop and triple single leg hops) based on the Go stimulus presented with light system placed on the floor. The stimuli are presented in a random to facilitate the athlete to scan the entire field.

Current rehabilitation and return to sports (RTS) often leans towards methods with the following limitation: 1) a poor preservation of the above mentioned player-environment relationship that limits the validity and thus generalizability of results.

This reductionist analysis neglects profound information regarding human movement. More specifically, a 1-dimensional test (i.e. only considering an athlete's biomechanical profile as a risk factor) for secondary prevention purposes may not be useful if we accept that syndesmosis injury is multifactorial by nature.

In the following we discuss relevant organizational principles and decision making for progression that clinicians should consider when outlining a rehabilitation program for athletes after syndesmotic ankle injury.

How to organise the rehabilitation? Create a functional task environment

Gokeler et al[20] have recently presented a model on how perceptual-cognitive training 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. As stated earlier, the moment-to-moment interaction between the athlete pursuing a particular goal in sport situations is defined as the functional task environment[20].

To enhance motor skill acquisition, clinicians should be cognizant of the constant interaction among the athlete, task, and environmental constraints of the functional task environment in the situations where decisions and movements are made. For example, among the goals in current rehabilitation programs is that the athlete learns movement competence such as jumping and landing with "feet shoulder width apart" and "land on your forefoot"[12]. Any deviation is deemed an error and is corrected. In many sports, although basic movement competence needs to be acquired, there is no ideal movement pattern because relatively unique functional movement solutions emerge from the interaction of task and environmental constraints in the sport situation. Hence, movement variability increases the adaptability of athletes to handle complex situations as they emerge on the field. In rehabilitation, rather than pushing an athlete toward an

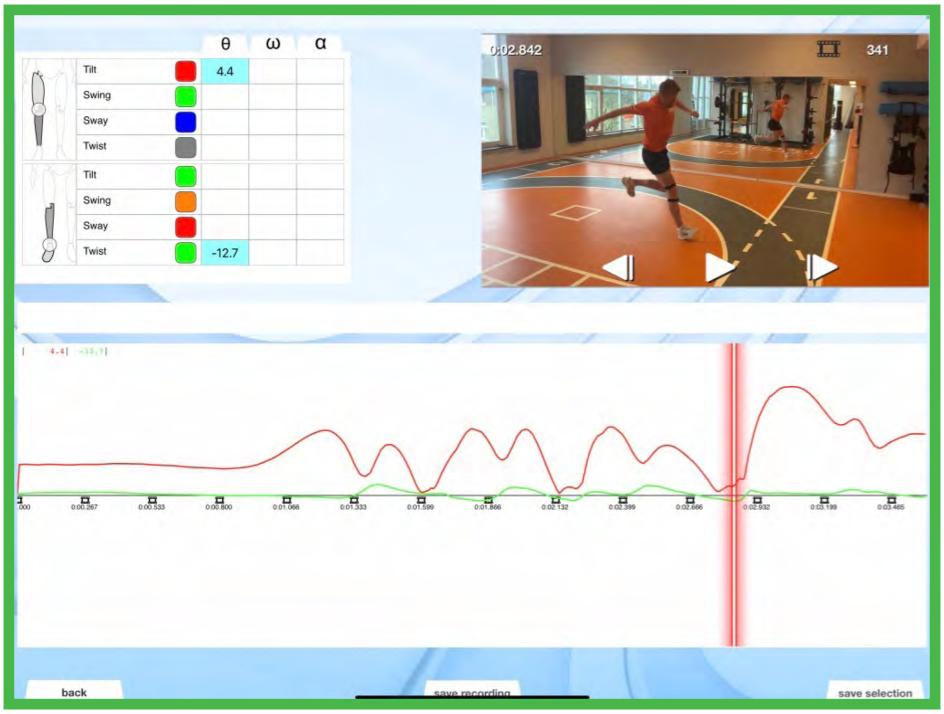

Figure 10: Limb symmetry assessment for distance and kinematics (ROM, angular velocity for different segments.

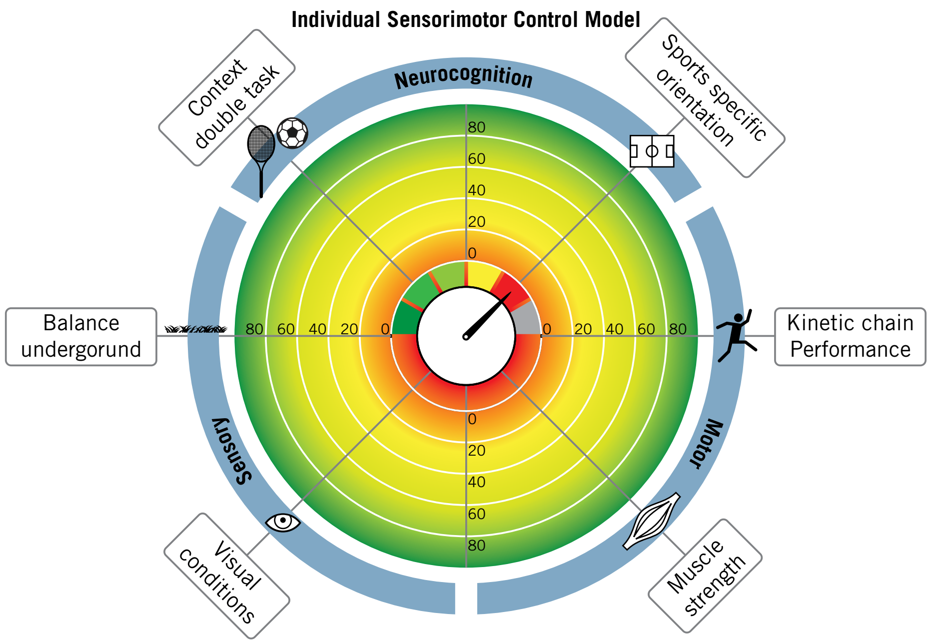

Figure 11: This sensorimotor control model assists clinicians in specifically targeting different components of sensorimotor control. It shows in which domain (motor, sensory and/or neurocognitive deficits may remain after injury which, when not targeted in rehabilitation, likely results in non-optimal performance and a higher residual risk for recurrence.

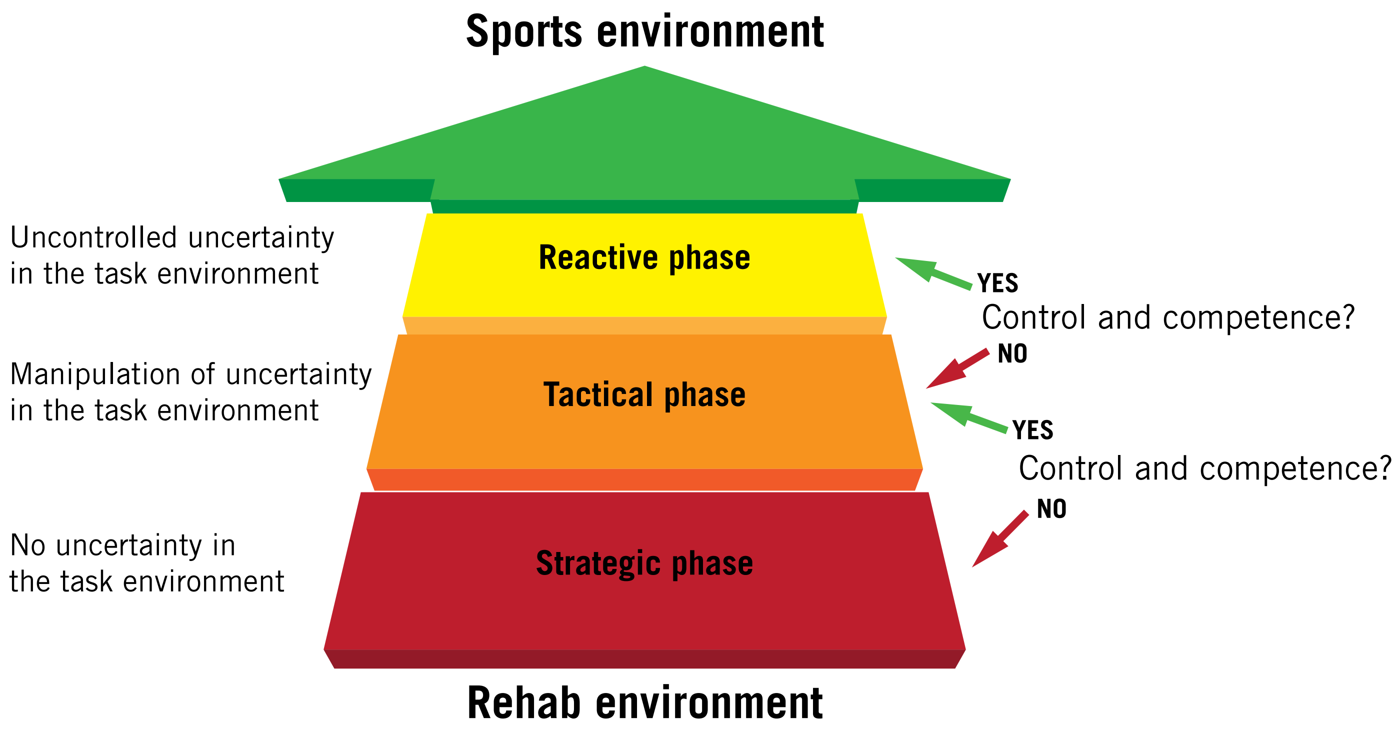

Figure 12: Functional task environment[20].

"ideal" movement pattern, it is important to consider how the task and environment constraints can be manipulated to optimize movement solutions within an acceptable bandwidth of movement variability[12].

The ability to quickly and accurately adjust lower extremity movements in response to an external (unexpected) stimulus is a key demand for athletic performance and injury prevention[10,15,21]. To sufficiently execute such open skill tasks, athletes need to perceive and process a stimulus (i.e. visual sensory uptake) and subsequently select and execute a movement as fast and accurately as possible. It has been suggested that motor performance as well as task related perceptual and cognitive abilities are highly relevant for successfully performing complex motor tasks[15].

The perceptual capacities of an athlete play an important role in team ball sports. This interpretation and the following (subconscious) decision, must be made quickly and be re-evaluated depending on the demands on the field. This process is further compounded by game rules, time requirements, intrinsic and extrinsic distractors, and interactions during play.

The unpredictable and constantly evolving sports environment presents athletes with a myriad of stimuli across different mediums (e.g. visual, auditory, haptic).

Consideration

The rehabilitation principles presented in this manuscript all relate to a framework based on recent insights developed in optimising motor learning and rehabilitation outcomes. This framework is now elaborated upon for ankle syndesmotic injury, thoroughly defining phases of protected yet optimal loading and careful workup towards return to sport, addressing all dimensions of the sensorimotor control model. We propose the sports rehabilitation community apply this for every MSK injury.

CONCLUSION

Syndesmotic injuries are increasingly common in the field and court sports. Our approach to these athletes has changed considerably, even in the last decade. While there is an on-going need for additional science to support new surgical stabilization constructs and accelerated return to sport protocols, the current management ethos has evolved toward flexible fixation device constructs and accelerated return to sport protocols. Recent data provide a clearer outlook on RTS most often not being reached within 8 weeks post operatively. Perhaps the most valuable tools to inform our understanding of the results of evolving treatment strategies are time-based data collection of functional recovery aspects and sport registries which offer guidance for treatment protocols for athletes. Whilst yet not broadly available, we currently should rely on reports of outcomes from a rapidly evolving treatment landscape.

References

1. *Lubberts, B.; D'Hooghe, P.; Bengtsson, H.; DiGiovanni, C.W.; Calder, J.; Ekstrand, J. Epidemiology and return to play following isolated syndesmotic injuries of the ankle: a prospective cohort study of 3677 male professional footballers in the UEFA Elite Club Injury Study. Br. J. Sports Med. 2019, 53, 959–964, doi:10.1136/bjsports-2017-097710.*
2. *Ardern, C.L.; Glasgow, P.; Schneiders, A.; Witvrouw, E.; Clarsen, B.; Cools, A.; Gojanovic, B.; Griffin, S.; Khan, K.M.; Moksnes, H.; et al. 2016 Consensus statement on return to sport from the First World Congress in Sports Physical Therapy, Bern. Br. J. Sports Med. 2016, 50, 853–64, doi:10.1136/bjsports-2016-096278.*
3. *D'Hooghe, P.; Grassi, A.; Alkhelaifi, K.; Calder, J.; Baltes, T.P.A.; Zaffagnini, S.; Ekstrand, J. Return to play after surgery for isolated unstable syndesmotic ankle injuries (West Point grade IIB and III) in 110 male professional football players: a retrospective cohort study. Br. J. Sports Med. 2020, 54, 1168–1173, doi:10.1136/bjsports-2018-100298.*
4. *Wilkerson, G.B. Biomechanical and neuromuscular effects of ankle taping and bracing. J. Athl. Train. 2002, 37, 436–445.*
5. *Andreo, P.; Khalaf, K.; Heale, L.; Jelinek, H.F.; Donnan, L. Effects of kinesiology tape on non-linear center of mass dispersion during the y balance test. Front. Physiol. 2018, 9, 1–8, doi:10.3389/fphys.2018.01527.*
6. *Needle, A.R.; Kaminski, T.W.; Baumeister, J.; Higginson, J.S.; Farquhar, W.B.; Swanik, C.B. The Relationship Between Joint Stiffness and Muscle Activity in Unstable Ankles and Copers. J. Sport Rehabil. 2017, 26, 15–25, doi:10.1123/jsr.2015-0061.*
7. *Burcal, C.J.; Needle, A.R.; Custer, L.; Rosen, A.B. The Effects of Cognitive Loading on Motor Behavior in Injured Individuals: A Systematic Review. Sport. Med. 2019, doi:10.1007/s40279-019-01116-7.*
8. *Gibson, J.J. The senses considered as perceptual systems; Houghton Mifflin: Boston, 1966;*
9. *Renshaw, I.; Davids, K.; Araújo, D.; Lucas, A.; Roberts, W.M.; Newcombe, D.J.; Franks, B. Evaluating weaknesses of "perceptual-cognitive training" and "brain training" methods in sport: An ecological dynamics critique. Front. Psychol. 2019, 9, doi:10.3389/fpsyg.2018.02468.*
10. *Gokeler, A.; Benjaminse, A.; Della Villa, F.; Tosarelli, F.; Verhagen, E.; Baumeister, J. Anterior cruciate ligament injury mechanisms through a neurocognition lens: implications for injury screening. BMJ Open Sport Exerc. Med. 2021, 7, e001091, doi:10.1136/bmjsem-2021-001091.*
11. *Baumeister, J. Sensorimotor Control and Associated Brain Activity in Sports Medicine Research, 2013.*
12. *Bolt, R.; Heuvelmans, P.; Benjaminse, A.; Robinson, M.A.; Gokeler, A. An ecological dynamics approach to ACL injury risk research: a current opinion. Sport. Biomech. 2021, 00, 1–14, doi:10.1080/14763141.2021.1960419.*
13. *Almonroeder, T.G.; Kernozek, T.; Cobb, S.; Slavens, B.; Wang, J.; Huddleston, W. Cognitive demands influence lower extremity mechanics during a drop vertical jump task in female athletes. J. Orthop. Sports Phys. Ther. 2018, 48, 381–387, doi:10.2519/jospt.2018.7739.*
14. *Hughes, G.; Dai, B. The influence of decision making and divided attention on lower limb biomechanics associated with anterior cruciate ligament injury: a narrative review. Sport. Biomech. 2021, 00, 1–16, doi:10.1080/14763141.2021.1898671.*
15. *Giesche, F.; Stief, F.; Groneberg, D.A.; Wilke, J. Effect of unplanned athletic movement on knee mechanics: a systematic review with multilevel meta-analysis. Br. J. Sports Med. 2021, bjsports-2021-103933, doi:10.1136/bjsports-2021-103933.*
16. *Schnittjer, A.; Simon, J.E.; Yom, J.; Grooms, D.R. The Effects of a Cognitive Dual Task on Jump-landing Movement Quality. Int. J. Sports Med. 2021, 42, 90–95, doi:10.1055/a-1195-2700.*
17. *Picot, B.; Terrier, R.; Forestier, N.; Fourchet, F.; McKeon, P.O. The Star Excursion Balance Test: An Update Review and Practical Guidelines. Int. J. Athl. Ther. Train. 2021, 26, 285–293, doi:10.1123/ijatt.2020-0106.*
18. *Waterman, B.R.; Belmont, P.J.; Cameron, K.L.; Svoboda, S.J.; Alitz, C.J.; Owens, B.D. Risk factors for syndesmotic and medial ankle sprain: role of sex, sport, and level of competition. Am. J. Sports Med. 2011, 39, 992–8, doi:10.1177/0363546510391462.*
19. *Dos'Santos, T.; Thomas, C.; McBurnie, A.; Comfort, P.; Jones, P.A. Biomechanical Determinants of Performance and Injury Risk During Cutting: A Performance-Injury Conflict? Sport. Med. 2021, doi:10.1007/s40279-021-01448-3.*
20. *Gokeler, A.; McKeon, P.O.; Hoch, M.C. Shaping the Functional Task Environment in Sports Injury Rehabilitation: A Framework to Integrate Perceptual-Cognitive Training in Rehabilitation. Athl. Train. Sport. Heal. Care 2020, 12, 283–292, doi:10.3928/19425864-20201016-01.*
21. *Wilke, J.; Giesche, F.; Niederer, D.; Engeroff, T.; Barabas, S.; Tröller, S.; Vogt, L.; Banzer, W. Increased visual distraction can impair landing biomechanics. Biol. Sport 2021, 38, 123–127, doi:10.5114/BIOLSPORT.2020.97070.*

Pieter D'Hooghe M.D., Ph.D.[1]
Orthopaedic Surgeon
Chief Medical Officer

Igor Tak Ph.D., P.T.[2,3]
Post-Doctoral Researcher

Alli Gokeler Ph.D., P.T.[3,4]
Post-Doctoral Researcher

[1] Department of Orthopaedic Surgery
Aspetar Orthopaedic and Sports Medicine Hospital
Doha, Qatar

[2] Manual Therapy and Sports Rehabilitation
Physiotherapy Utrecht Oost
Utrecht, The Netherlands

[3] Amsterdam Collaboration for Health and Safety in Sports
Department of Public and Occupational Health, Amsterdam Movement Sciences
VU University Medical Center
Amsterdam, The Netherlands

[4] Exercise Science and Neuroscience Unit
Department Exercise & Health, Faculty of Science
University of Paderborn
Paderborn, Germany

Contact: pieter.dhooghe@aspetar.com