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SYSTEMATIC REVIEW

Criteria-Based Return to Sport Decision-Making Following Lateral Ankle Sprain Injury: a Systematic Review and Narrative Synthesis

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Abstract
Objective The aim of this systematic review was to identify prospective studies that used a criteria-based return to sport (RTS) decision-making process for patients with lateral ankle sprain (LAS) injury.
Design Systematic review and narrative synthesis.
Data sources The PubMed (MEDLINE), Web of Science, PEDro, Cochrane Library, SPORTDiscus (EBSCO), ScienceDirect, and Scopus databases were searched to 23 November 2018.
Eligibility criteria for selecting studies Studies were included if they prospectively applied a criteria-based RTS decision-making process for patients with LAS injury, but were excluded if they merely gathered outcome measures at the RTS time point. Studies were also excluded if patients were recovering from ankle fracture, high ankle sprain, medial ankle sprain, chronic ankle instability or complex ankle injury.
Results No studies were identified that used a criteria-based RTS decision-making process for patients with LAS injury. We were unable to conduct a quantitative synthesis or meta-analysis, therefore we provide a narrative synthesis of relevant questionnaires, as well as clinical and functional assessments commonly used in studies retrieved in the search.
Conclusion There are currently no published evidence-based criteria to inform RTS decisions for patients with an LAS injury. Based on our narrative synthesis, we propose a number of variables that could be used to develop a criteria-based RTS decision paradigm. Future research should aim to reach consensus on these variables and apply them to actual RTS decisions within prospective study designs. Furthermore, we suggest that complex systems theory and the RTS continuum could be used to inform the development of an RTS decision-making paradigm for athletes with LAS injury.

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Key Points

No published evidence-based criteria exist to inform return to sport decisions for patients following lateral ankle sprain (LAS) injury.

Return to sport decisions following LAS injury are generally time-based.

We propose that complex systems theory and the return to sport continuum could be used to inform the development of a criteria-based return to sport paradigm to bridge the gap between research and clinical practice.

1 Introduction

Lateral ankle sprains (LAS) are one of the most frequently incurred musculoskeletal injuries in individuals participating in recreational and competitive sports [1–7]. During the 12-month time period following a first-time LAS injury, athletes have a significantly increased risk of re-injury (risk ratio in the first 6 months after first-time LAS = 9.8; risk ratio from 6 months to 1 year after first-time LAS = 5.6) in comparison with athletes who have never incurred an LAS injury [8–10]. The recurrence rate of LAS injury is one of the highest among all musculoskeletal injuries [10–14]. A high proportion of individuals who incur an LAS injury develop chronic ankle instability (CAI) [15–17], which can initiate the onset of post-traumatic osteoarthritis and ultimately culminate in the development of both physical and psychological impairments [18–20].

In 2012, evidence-based clinical guidelines published by Kerkhoffs and colleagues [21] identified that a wide variety of efficacious treatment options exist for individuals with an acute LAS injury. In spite of this, LAS injury is still typically regarded as an innocuous injury and, even today, individuals with an acute LAS injury do not consistently seek or receive appropriate medical treatment and patient-centred rehabilitation [22–25]. Recently, an update of these evidence-based clinical guidelines (2018) [26] recommended that in order to facilitate a faster return to sport (RTS) for individuals with an acute LAS injury, clinicians should implement a multifaceted, exercised-based rehabilitation programme (e.g. proprioception, strength, coordination) [26, 27].

Clinically, LAS injury management and RTS decisions are typically informed by fundamental and anecdotal evidence, as well as the experience and clinical reasoning of the clinician who is managing the injury. Oftentimes, emphasis is placed on an expedient return to activity, with the time to RTS being used as a surrogate measure of rehabilitation success; however, such an approach can be counterproductive, as evidenced by the high recurrence rate of LAS injuries. This high recurrence rate is hypothesised to be mainly caused by an increased re-injury risk due to previous LAS, the persistence of sensorimotor impairments, and premature RTS clearance [13, 22, 28–31]. Therefore, there is a need to develop and implement evidence-based progressive rehabilitation programmes, as well as specific evidence-based criteria to guide RTS decisions for individuals with acute LAS injury.

To initiate the development of a criteria-based RTS decision paradigm for acute LAS injury patients, variables, cut-offs and ranges of criteria to be included in this paradigm need to be determined and evaluated. Injury-specific, criteria-based RTS decision paradigms exist for anterior cruciate ligament reconstruction (ACLR) and hamstring strain injury (HSI); these have been informed by critical [32], scoping [33] and systematic reviews [34, 35].

To our knowledge, no systematic reviews have been published on the topic of criteria-based RTS decision-making for individuals with acute LAS injury. Therefore, the aim of this systematic review was to identify and discuss the results of prospective studies that used a criteria-based RTS decision-making process for patients with acute LAS injury, with the objective of identifying suitable criteria to inform this complex clinical process.

2 Methods

The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) and was developed in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P) [36]. The review protocol can be accessed via PROSPERO (http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42017060910) [37].

2.1 Information Sources

The PubMed (MEDLINE), Web of Science, PEDro, Cochrane Library, SPORTDiscus (EBSCO), ScienceDirect, and Scopus databases were searched to collate published articles from the dates of inception of these databases to 23 November 2018.

2.2 Eligibility Criteria

Studies were included if they prospectively applied a criteria-based RTS decision-making process for patients (adults aged > 18 years) who had incurred an LAS injury; however, studies that merely gathered outcome measures at the time point that corresponded to RTS were excluded. RTS criteria encompassed any criteria that were used to guide the RTS decision-making processes [38]. LAS injury was defined in accordance with the definition advocated by the International Ankle Consortium: "an acute traumatic injury to the lateral ligament complex of the ankle joint as a result of excessive inversion of the rear foot or a combined plantar flexion and adduction of the foot" [15, 39–41]. Studies were also excluded if patients were recovering from ankle fracture, high ankle sprain, medial ankle sprain, CAI or complex ankle injury.

2.3 Search Strategy

The search strategy was developed by two authors (BT, JV) and encompassed three term sets that were combined with 'AND'. The term sets included words for ankle injuries (e.g. 'ankle injuries' or 'ankle sprain'), criteria and tests (e.g. 'test', 'measurement' or 'criteria'), and outcomes (e.g. 'return to sport', 'match fitness'). The words within each term were separated by 'OR'. The specialised and detailed search strategy for each database can be found in electronic supplementary material (ESM) Table S1. Return to work and return to duty were deemed beyond the scope of this review and were not included in the systematic search strategy. Reference lists of included articles, relevant reviews and meta-analyses were screened to identify possible additional articles.

2.4 Study Selection and Assessment of Risk of Bias

All databases were searched by one author (BT). Next, all retrieved titles, abstracts, full texts and citations were aggregated in the Rayyan web application (https://rayyan.qcri.org) [42]. Publications were independently screened for inclusion by two authors (BT, JV) using a staged process of reviewing titles and abstracts, and eventually reviewing the remaining full texts. Only published articles in peer-reviewed journals were considered for full-text inclusion. If no full text was available, corresponding authors were contacted. If no full text could be supplied after contacting the corresponding authors, the full text was ordered via the library of the Vrije Universiteit Brussel. Inclusion and exclusion decisions were recorded via the Rayyan web application. Differences in the decision to include or exclude articles were settled through discussion. If agreement could not be reached through discussion, a third author (RM) was consulted in order to reach consensus. Depending on the design of the study, appropriate checklists for the assessment of risk of bias were selected, i.e. Cochrane Collaboration's tool (randomised controlled trials) and National Institute for Health and Care Excellence (NICE) guidelines (wide scope of study designs).

2.5 Data Extraction and Synthesis

To answer the research question, questionnaires and tests for which the outcome was a priori identified as an RTS criterion by the original studies were extracted from included full texts. Furthermore, when screening abstracts and full texts, two authors (BT, JV) systematically extracted questionnaires, clinical and functional tests and criteria in ankle sprain populations, to build a test inventory used in ankle sprain populations. These extracted measures did not have to be linked to RTS, but were collated to give an indication of objective rehabilitation parameters in LAS. For studies included in the systematic review, criteria that were used to make the RTS decision were defined as cut-off values or ranges that were applied to the corresponding questionnaires and tests (e.g. limb symmetry index ≥ 90% on a single-leg hop for distance test).

3 Results

3.1 Study Collection

A total of 948 articles were identified and screened for inclusion using title and abstract. After exclusion of nonrelevant articles ($n = 915$), 33 full-text articles were assessed for eligibility and their reference lists checked for possible additional relevant articles. Finally, no studies could be included in this systematic review as not one prospective study using a criteria-based RTS decision-making approach for patients who had incurred an LAS injury was retrieved. The selection process can be found in Fig. 1.

3.2 Test Inventory Created During the Data Collection and Extraction Processes

A total of 47 questionnaires, 45 clinical assessment measures and/or functional performance tests, as well as four criteria that were used in ankle sprain, LAS, mechanical ankle instability and functional ankle instability populations were identified during the screening of abstracts and full texts, prior to the inclusion of studies in the systematic review.

3.2.1 Questionnaires

In total, 37 questionnaires were extracted from the reviews by Haywood et al. [43], Donahue et al. [44], Simon et al. [45] and Jia et al. [46], as well as the study by Da Cunha et al. [47]. We recommend that readers who are interested in implementing patient-reported outcome measures (PROMs) questionnaires for ankle injury patients should consult these papers. Furthermore, seven additional questionnaires (Ankle Rehabilitation Checklist [ARC] [48], Chamorro Assisted

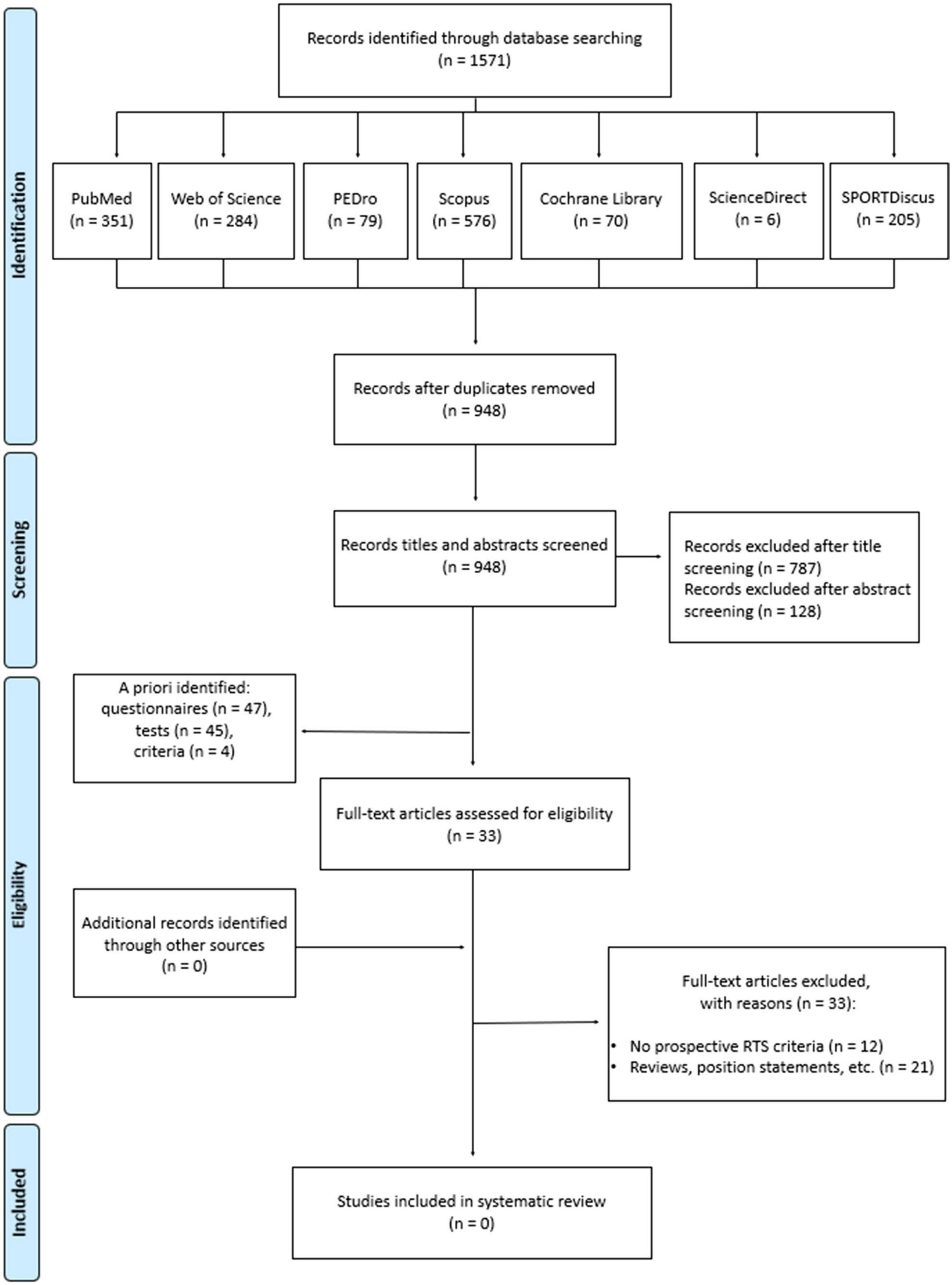

Fig. 1 Study selection process. *RTS* return to sport

Gait Scale [CHAGS] [49], Health-Related Quality of Life [HR-QOL] [50, 51], Lower Extremity Functional Scale [LEFS] [52, 53], Lower Limb Task Questionnaire [LLTQ] [54], Sports Ankle Rating System [SARS] [55, 56], and Short Form-36 [SF-36] [50, 57–59]) were identified.

Two narrative reviews [60, 61] suggested the use of questionnaires to measure psychological readiness to RTS ($n=3$), namely the Injury-Psychological Readiness to Return to Sport Scale (I-PRRS) [62], Trait Sport Confidence Inventory (TSCI) [63, 64] and State Sport Confidence Inventory (SSCI) [64]. However, no prospective studies were identified that used psychological readiness to RTS after acute LAS injury as a primary or secondary outcome measure.

3.2.2 Clinical Assessment Measures and Functional Performance Tests

A wide spectrum of clinical assessment measures and functional performance tests were reported for evaluating an ankle sprain as well as a patient's rehabilitation progress and physical performance. An overview of these tests with their corresponding references can be found in ESM Tables S2 and S3.

Clinical assessment measures for ankle sprains were assigned to the following categories: swelling ($n=1$), ligamentous laxity ($n=7$) and range of motion ($n=2$). For the functional performance tests, we identified the following categories: proprioception ($n=1$), hopping and jumping ($n=14$), range of motion ($n=1$), balance ($n=6$), agility/speed ($n=9$) and strength ($n=4$). Although an extensive range of clinical assessment measures and functional performance tests were identified, no consistency in their use across studies could be identified. Some important gaps in the testing spectrum were identified as some constructs remain to be investigated (e.g. movement quality). These are discussed in Sect. 4.2.3 (bullet point 5) and Sect. 4.3.

3.2.3 Criteria

Only one study applied a set of criteria to determine acceptable RTS [65]. These criteria encompassed a limb symmetry index (≥ 80% to compare the injured and uninjured limbs) when performing both a triple forward hop for distance and a triple lateral hop for distance, an absence of pain and no loss of function rated on 10-point scales. These criteria were not used to determine whether an ankle sprain patient was ready to RTS or not, but rather to give the patient an acceptable or unacceptable RTS score after 6 weeks and 6 months when the patient had already resumed his or her sport. Given this time-contingent RTS decision, this study was excluded from the systematic review, with the result that no studies could be included to answer the research question.

4 Discussion

Since the predetermined research question could not be answered due to a lack of available literature, a narrative synthesis was written to address (1) the use of the outcome 'time to return to play, sport or work'; (2) rationales and considerations for RTS decision making following LAS injury; and (3) directions for future research. The objective of this narrative synthesis was to aid the building of a solid base for objective, evidence-founded, scalable, safe, and sustainable RTS decisions for athletes with an acute LAS injury. The inventory of reported tests (ESM Tables S2 and S3) identified across studies was used alongside the general findings from the data collection and extraction phases to substantiate these suggestions.

4.1 Use of the Outcome "Time to Return to Play, Sport or Work"

The outcome time to RTS, work or play was frequently represented among the screened articles [66–78]. Based on the extensive use of this outcome [66–78] and the lack of prospectively determined RTS criteria throughout the ankle sprain injury literature, it is reasonable to infer that ankle rehabilitation, both in clinical practice and research, is still firmly anchored in time-contingent protocols and decision making. This underscores the need to develop phase-sensitive and -specific RTS assessment clusters and criteria in order to help clinicians determine which athlete is ready to proceed to a certain RTS phase and which athlete is not. In addition to assessing rehabilitation progress and performance, these assessment clusters and criteria should give clinicians insight into the athletes' re-injury risk [8–10, 79, 80]. It is important to not confound the phases of rehabilitation with phase-dependent criteria. The phases of rehabilitation are often tailored to injury and the phases of tissue repair, and mainly include goal setting, therapy content, and tests to monitor the progression of the patient. However, phase-dependent criteria are tailored to the athlete and are not always in line with these phases of rehabilitation, and mainly serve the purpose of supporting clinicians in making RTS decisions. In the ACLR [32, 33, 81–85] and HSI [34, 35, 86–89] domains, researchers and clinicians are currently undertaking steps to develop this relatively new criteria-based approach. Therefore, it is logical that such an approach should be developed for LAS injury patients.

4.2 Rationales and Considerations for RTS Decision Making Following Acute LAS Injury

4.2.1 Is It Time to Implement Complex Systems Theory into the RTS Decision-Making Paradigm?

Recently, the fields of sports medicine and sports science have shown an increased re-interest in the complexity sciences' paradigm in order to bridge the gap between research and clinical practice [90–102]. An interesting feature of complex adaptive systems (CAS) is that studying or collecting discrete variables, components or subparts of CAS does not automatically lead to the understanding of the emergent behaviour at a higher level of such systems. To put it in the words of Douglas Adams: "If you try and take a cat apart to see how it works, the first thing you have on your hands is a nonworking cat" [103]. In living systems, a multilevel hierarchical organisation is suggested where various processes operating across different time scales dynamically interact in nonlinear ways and lead to the emergence of new components and properties through self-organisation [99, 100]. This is why patients can and should also be considered as CAS [104]. For example, patients with a perfectly recovered ankle without any residual complaints but high fear of re-injury could be delayed in resuming their sport, while patients with some residual complaints and better coping skills might RTS sooner.

Since athletes and patients can be considered as CAS [104], decision-making models with a reductionist approach might not be suited to substantiate sustainable and responsible decisions along the RTS continuum. Moreover, making RTS decisions is both a complex and complicated affair due to the many intrinsic (e.g. risk factors, physiology, coping strategy) and extrinsic (e.g. social support, playing position, stakeholders) variables interacting with each other at different time scales (e.g. molecular, organism and social levels) via both bottom-up and top-down processes. The goal of complexity research is to focus on a more holistic approach, with the objective of determining how these constraints interact with and influence the emergent behaviour of the patient. The International Classification of Functioning, Disability and Health model, the Strategic Assessment of Risk and Risk Tolerance (StARRT) framework and the concept of patient-centred care align with this complexity paradigm as they focus on the individual, its subsystems and interactions with the environment, and not solely on the injured body tissue. Concentrating on LAS injury research, complexity science has only been evaluated in an implicit form and is not currently being explicitly explored. One article suggested the use of a constraints-led approach to better understand and treat LAS patients [105], while other studies have applied some (mainly non-linear) complexity principles in LAS [106–110] and CAI [111–115] populations.

This implies that both research and clinical practice are currently continuing the evolution towards a more holistic view of rehabilitation and that we are gradually moving away from deterministic concepts and models of risk, and reductionistic assessment. It also necessitates the further development of phase-sensitive and -specific multifactorial assessments and decision-making models that accommodate these insights and are based on the interactions of their components in order to create a dynamic RTS clearance profile for each patient. Eventually, this adaptable RTS clearance profile could be used by clinicians to allow each patient to make safe and evidence-informed phase transitions along the RTS continuum. If we consider an RTS decision model after acute LAS injury as a CAS, the RTS decision would be the emergence of behaviour based on the interactions of multiple factors (e.g. questionnaires, clinical assessments and functional tests, and stakeholders) that are both dynamic and temporal by nature. This supports the use of complex systems theory throughout the RTS decision-making paradigm.

4.2.2 Defining the RTS Continuum

First and foremost, distinct and well-described phases have to be demarcated along the RTS continuum in order to build a dynamic RTS decision-making model that guides clinicians through the rehabilitation journey. Therefore, we adopted the continuum and definitions from the 2016 Consensus statement on RTS [38]:

1. *Return to participation (RTPa)* The athlete may be participating in rehabilitation, training (modified or unrestricted) or sport, but at a level lower than his or her RTS goal. The athlete is physically active, but not yet 'ready' (medically, physically and/or psychologically) to RTS. It is possible to train to perform, but this does not automatically mean RTS.
2. *RTS* The athlete has returned to his or her defined sport but is not performing at his or her desired performance level. Some athletes may be satisfied with reaching this stage, and this can represent successful RTS for that individual.
3. *Return to performance (RTPf)* This extends on the RTS phase. The athlete has returned to his or her defined sport and is performing at or above his or her pre-injury level. For some athletes, this stage may be characterised by personal best performance or expected personal growth as it relates to performance.

For an injured athlete to be able to successfully RTPf, all stakeholders (athlete, medical staff, coaches, etc.) should participate actively in managing the dynamic, but delicate, balance between rehabilitation, training and re-injury prevention. Therefore, the shared RTS management and decision-making processes should combine aspects of clinical and psychological state, risk and performance assessment along the continuum and emerge in a dynamic RTS clearance profile. Therefore, we advocate the use of the definitions of the consensus statement in future research and clinical practice instead of the ambiguous return to play/activity/work outcomes.

4.2.3 Which Variables Can We Consider for Building a Dynamic RTS Clearance Profile?

Shrier and colleagues performed an exploratory study on the differences in professionals' (clinicians and non-clinicians) opinions about which criteria should be used to guide RTS decisions and who is best able to evaluate these decisions [116]. They concluded that both injury-related and non-injury-related risk assessment criteria should be included and that non-clinicians (e.g. coaches) should participate actively in the RTS decision-making process. We advocate that injury-related and non-injury-related variables should be considered in the development of a criteria-based RTS decision-making paradigm for acute LAS injury patients.

- Time to Return to Full Activity Coupled with Grading of the LAS Injury: A Thing of the Past?

  Historically, acute LAS injuries have been categorized in terms of severity by a three-tiered grading system [117]. A grade I LAS injury is characterized by some torn ligamentous fibres with negligible haemorrhage. Normally, no ligamentous laxity or residual instability is present [118, 119]. A grade II, or moderate, LAS injury involves an incomplete tear of the ligament with subsequent mild ligamentous laxity and residual instability, minor reduction in function, possible decrease in strength, and the potential for loss of proprioception [118]. A grade III, or severe, LAS injury is characterized by complete rupture of the ligament with substantial ligamentous laxity and concomitant instability, and possibly a complete loss of function, strength, and proprioception [117, 120–122]. Textbooks published between the 1950s and 1990s suggested time frames to RTS based on the severity (or grade) of the injury (i.e. up to 12 days for a grade I injury, 2–6 weeks for a grade II injury, and up to 26 weeks for a grade III injury) [117–122]. While these time-contingent return to activity statements provided clinicians with an estimate as to when athletes could return to activity, we consider that these are outdated and do not reflect the clinical symptoms, resolution of impairments or the ability of the athlete.

  A 2014 study on time to RTS in high-school athletes observed that a 95% probability exists for full return to sports participation within 10 days after a first-time ankle sprain injury [123]. However, an even more recent study (2018) reported that individuals who sustained an LAS injury still exhibited increased ankle ligamentous laxity, reduced self-reported function, restriction of dorsiflexion range of motion, and impaired dynamic postural balance at the RTS time point (mean ± standard deviation 12.7 ± 10.0 days) [124]. Consequently, these authors suggested that athletes with an LAS injury require more extensive care to resolve impairments before they should be allowed to RTS [124]. This is a 'wake-up call' for researchers and clinicians to develop and implement criteria-based RTS decisions following acute LAS injury in order to reduce the number of patients who RTS with residual impairments and to decrease the risk of re-injury. We therefore advocate that time should not be included as a variable in a dynamic criteria-based RTS decision framework. However, we do acknowledge that time to RTS will always be present in the background since the RTS team (e.g. athlete, medical staff, coaches) desires the athlete to RTS as fast as possible.

- Predisposing Factors Increasing the (Re-)Injury Risk and Prognostic Factors Increasing the Risk of Developing CAI

  We briefly summarize the most relevant modifiable risk factors, both intrinsic and extrinsic, that can aid clinicians in assessing an individual's risk of LAS (re-)injury. Regarding intrinsic risk factors for (re-)injury, clinicians should be attentive to reduced ankle dorsiflexion range of motion [125–127], decreased proprioception, reduced static and dynamic postural balance [126, 128–136], poor neuromuscular control and running technique (high plantar pressure during running) [135, 137], reduced ankle muscle strength [126, 132, 134, 138], reduced cardiorespiratory endurance [135] and delayed peroneus brevis reaction time [134]. These intrinsic modifiable risk factors could be targeted by the appropriate prescription of exercises. Regarding extrinsic risk factors, clinicians should be cognizant of type of sport (e.g. basketball, volleyball) [3, 5, 139], position played (e.g. centre in basketball) [140, 141], athlete exposure [3, 5, 139], landing after a jump [9, 139], stepping on an opponent's foot [142], and playing surface [143–145]. While some of these extrinsic risk factors are potentially modifiable, it is highly unlikely that many of them would be altered (e.g. changing a player's field position). Nevertheless, these extrinsic risk factors may have a role in the RTS decision-making process (e.g. volleyball athlete vs. long-distance runner).

  Since up to 40% of individuals who incur a first-time LAS injury will develop CAI within a 1-year time frame [146], it is important for clinicians to identify possible prognostic factors for developing CAI. These encompass the inability to perform a jump landing (drop land or drop vertical jump) within 2 weeks after first-time LAS injury

[26], impaired postural balance [146, 147], impaired lower limb kinematics [146, 148], increased ankle laxity after 8 weeks [149, 150], and lower perceived activities of daily living function [146]. Integrating these insights into rehabilitation may be important to prevent the development of CAI.

Clinicians should be aware of these interacting factors and act accordingly throughout rehabilitation. For a complete overview of risk factors and prognostic factors, we suggest the recently published consensus statement (2018) on the diagnosis, treatment and prevention of ankle sprains [26].

- Ligament Healing, Ankle Laxity and Arthrokinematics

  The anterior talofibular ligament and calcaneofibular ligament are the most commonly injured ankle ligaments, and tissue damage of these ligaments can result in ankle joint laxity and arthrokinematic alterations [151, 152]. To check ligament healing, ankle laxity and arthrokinematics, clinicians often use the same clinical assessment measures they use for grading the LAS injury. Ligament healing is distinctly demarcated into inflammatory (3–5 days), proliferative (3–21 days) and remodelling (14–28 days) phases [153]. However, the exact time an ankle ligament needs to heal and when/if ankle laxity is resolved after an acute LAS injury is unknown. Significant improvements in mechanical stability are often observed from 6 weeks to 3 months post-injury, but mechanical laxity remains present in a vast number of patients [70]. Remarkably, recovery of mechanical laxity does not coincide with the 'end' of the remodelling phase, nor do either of these coincide with the aforementioned typical timeframe of RTS (10–12 days post-injury). Although some theoretical hypotheses exist on this matter, this discrepancy is still poorly understood. Moreover, mechanical laxity and the characteristic features of CAI remain present for up to 1 year in a significant subset of individuals who have incurred an LAS injury, even upon RTS [70, 154]. Since ligament damage is associated with mechanical and sensorimotor changes, it is important to obtain an impression of ligament healing via relevant clinical assessment measures (e.g. anterior drawer, talar tilt, posterior talar glide test) [154–156]; however, ligament damage is not limited only to the talocrural joint. Despite the lack of consistency in scientific literature, one could consider the subtalar joint and the other foot joints as these can also contribute to LAS injury and the development of CAI [135, 157, 158]. Although impairments in ankle joint arthrokinematics are regularly identified in individuals with CAI, clinical assessment measures have limited predictive value for CAI when conducted in the acute phase of a first-time LAS injury [159]. However, if increased ankle laxity following first-time LAS is still present after 8 weeks, there is an increased risk of developing CAI [149, 150]. Therefore, we advocate the utilisation of clinical assessments of ankle ligamentous laxity and support their inclusion in a multifactorial, criteria-based RTS decision framework.

- Clinical Tests and PROMs: Application of the 2019 Consensus Statement and Recommendations of the International Ankle Consortium [156]

  For the assessment of ankle pain (e.g. Numeric Pain Rating Scale, Foot and Ankle Disability Index), swelling (e.g. figure of eight test), range of motion (e.g. weight-bearing lunge tests, goniometer, inclinometer), muscle strength (e.g. hand-held dynamometry) and PROMs (e.g. Foot and Ankle Disability Index, Foot and Ankle Ability Measure), we refer to this consensus statement [156]. The authors built their recommendations on scientific evidence and after completion of a modified Delphi process [156]. We advocate including these suggested components into the criteria-based RTS decision paradigm as they gather information on the initial state of the CAS and can be used to evaluate the efficacy of the treatment implemented, monitor the progress of the patient and guide the rehabilitation process.

- Functional and Sport-Specific Performance Tests

  For high-performance athletes, sport and athlete analyses are warranted to determine relevant functional and sport-specific tests to guide rehabilitation and RTS. Subsets of these analyses should contain the sport-specific exercise physiological profile, biomechanical profile (e.g. kinetics, kinematics, movement sequences of relevant movement patterns), muscle–tendon functioning profile (e.g. energy absorption, energy transfer), and skill profile (e.g. environment stability, size of the movement). In light of different requirements, this will be unique for each sport. For example, a football player will have different, as well as some overlapping, needs in all four subsets when compared with a marathon runner.

  The rationale for the use of functional performance tests is to assess possible impairments that need to be addressed in rehabilitation and to form an impression as to whether an athlete is ready to start working towards performance enhancement [160–162]. Such tests often encompass more generic movements (e.g. walking, hopping) or simpler tasks (e.g. unilateral leg stance) than sport-specific tests. The main goal of sport-specific tests (e.g. reactive agility, linear speed) is to measure the athlete's current performance level and provide performance-specific training goals for both the athlete and the coaching staff. Quantitative and/or qualitative impairments of the human movement system can also be identified during sport-specific tests and can be used to guide the rehabilitation process.

  In individuals with LAS injury and CAI, impairments are exposed during static (e.g. balance error scoring system, foot lift test) and dynamic (e.g. star excursion balance test) postural balance tests and hopping [147, 163–171]. Bilateral deficits in postural balance have been observed following acute unilateral LAS injury, suggesting a central impairment in neuromuscular control and supporting the hypothesis of central nervous system (CNS) reorganization as a contributing mechanism to persistent neuromuscular deficits [172]. Recent research has shown that alterations in movement strategies during simple (e.g. walking, single limb stance) and more difficult tasks (e.g. dynamic balance, drop vertical jump, hopping) are present immediately and 6 months after an acute LAS and in CAI populations [109, 112, 147, 148, 163, 173–182]. These alterations in sensorimotor control might reduce an athlete's ability to adequately react, adapt or respond to unexpected external stimuli [183, 184], as is the case in open-skill sports. Therefore, it is warranted to further explore and implement various 'new' motor learning methods in rehabilitation (e.g. constraints-led approach, differential training, contextual interference). These methods, which consider the complexity of the sensorimotor system, have been shown to be more beneficial than traditional motor learning methods (e.g. repetitive practice, methodological series of exercises) for injury prevention, rehabilitation and performance training [185–190].

Furthermore, as higher injury rates have been reported towards the end of a game [140], fatigue should also be considered and utilized within the functional and sport-specific testing paradigm as part of the RTS decision-making process. Fatigue during exercise or sport competition manifests itself in multiple ways (e.g. decrease in performance, alteration of movement patterns, slower decision making) and is the result of multiple and complex interactions of both bottom-up and top-down processes [191]. Therefore, it can also be considered as a constraint interacting with the injured sensorimotor system. Clinicians can use various kinds of fatigue (e.g. peripheral fatigue, mental fatigue) to challenge the human movement system [191–195].

These insights highlight the importance of functional and sport-specific testing of athletes after LAS injury, with consideration of the CAS nature of the sensorimotor system. In summary, we suggest use of the following:

(a) quantitative performance analysis;
(b) movement quality assessment evaluating generic and sport-specific movement focusing on both the end result performance and applied movement strategy;
(c) acute fatigue as a constraint and extra criterion in performance testing.

- Load Monitoring (the Acute:Chronic Workload Ratio)

  In light of evidence that poor load management is a major threat for athletes to develop an injury [196], the International Olympic Committee (IOC) published a two-part consensus statement on load in sport and risk of injury and illness [196, 197]. They provided practical guidelines to manage load in sport to enable practitioners to prescribe scientifically founded training and competition loads. These guidelines provide suggestions about how to monitor training, competition and psychological load, athlete well-being, and injury. Poor load management can either mean exposing an athlete to loads that are too high, thus increasing the risk of (re-)injury, or exposing an athlete to loads that are too low and do not prepare him/her for when RTS or RTPf clearance is given [198]. This was suggested and visualised in the workload–injury aetiology model by Windt and Gabbett [199]. Therefore, the calculation of the acute:chronic workload ratio throughout the RTS decision-making process is advised as it permits clinicians to quantify a player's risk of subsequent injury [200] and to monitor training loads so training errors and unfavourable fatigue can be avoided.

- Psychological and Psychosocial Factors

  The importance of psychological factors for a successful RTS has been proven in the ACLR domain [201–203]. Readiness to RTS after ACLR was most affected by fear of re-injury, emotional disturbance, and lack of motivation, self-esteem, confidence in the injured limb, locus of control and self-efficacy [201–203]. Two narrative reviews on RTS after LAS [60, 61] suggest the use of questionnaires to measure psychological readiness to RTS, specifically the I-PRRS [62], TSCI [63, 64], and SSCI [64]. While direct evidence to support the role of these psychological and psychosocial factors is currently lacking, general insights support them. Therefore, we advise the inclusion of the assessment of psychological and psychosocial factors as variables in the dynamic criteria-based RTS decision paradigm after LAS injury.

  We advise readers to consult the narrative review by Podlog and colleagues on the psychosocial factors in sports injury rehabilitation and RTS [204], and invite researchers in the sports science domain to start collaborating with, or further involve, psychologists in the multidisciplinary domain of RTS following LAS injury.

- Decision Modifying Variables

  To support the CAS nature of an RTS decision, the authors would like to suggest the following variables could be added to the dynamic criteria-based RTS decision framework: quality of the communication and consensus of opinion between all stakeholders; stress [205]; sleep [206]; socioeconomic status of the athlete [116]; social support of the athlete (e.g. family, friends, fans) [204]; risk of injury to team members or opponents [116]; and short-term and long-term financial burden [116]. Note that the inclusion or exclusion of some variables (e.g. socioeconomic status, financial burden) would result in a more idealistic versus a more realistic perspective on the RTS decision clearance profile. All of the aforementioned variables need to be considered when developing a dynamic RTS clearance profile, with each variable having its own calculated weight, while interacting with the other determined RTS variables. To our knowledge, the main variables have been discussed above, although we would like to invite researchers, clinicians, coaches, athletes and students to further complement these variables in order to gain further insights and to build a more comprehensive model.

- Summary

  We have identified clinical, functional, sport-specific, psychosocial and decision-modifying variables as part of the RTS decision paradigm. Inclusion of a time-contingent approach in this RTS decision paradigm is not advised. The weight of each variable can change as the patient moves through the RTS continuum. For instance, the weight of sport-specific tests may be less in the dynamic RTS clearance profile when making RTPa decisions, but will be of great importance when considering RTS or RTPf decisions. Future research should try to determine relevant interactions, the weight of each variable in the RTS decision matrix, and objective criteria to make correct RTS decisions following acute LAS injury.

The authors would like to suggest a phenomenological framework and components for a dynamic RTS decision-making paradigm along the RTS continuum (see Figs. 2 and 3). With respect to content (questionnaires, tests, criteria), no suggestions will be formulated since there is no rigorous evidence to fill in this framework. Hopefully, the aforementioned rationales and considerations for building a dynamic criteria-based RTS decision-making paradigm can inspire researchers, clinicians and trainers. Assuming control theory as a metaphor, four general requirements have to be met for the control of any system (even a dynamic system for decision-making): (1) there has to be a goal (the goal condition = RTPf); (2) one has to be able to determine the state of the system (the observability condition = biopsychosocial assessment); (3) it has to be possible to affect the state of the system (the action condition = the athlete or patient); and (4) there needs to be a model of the system (the model condition = RTS clearance profile) [207]. Before such a

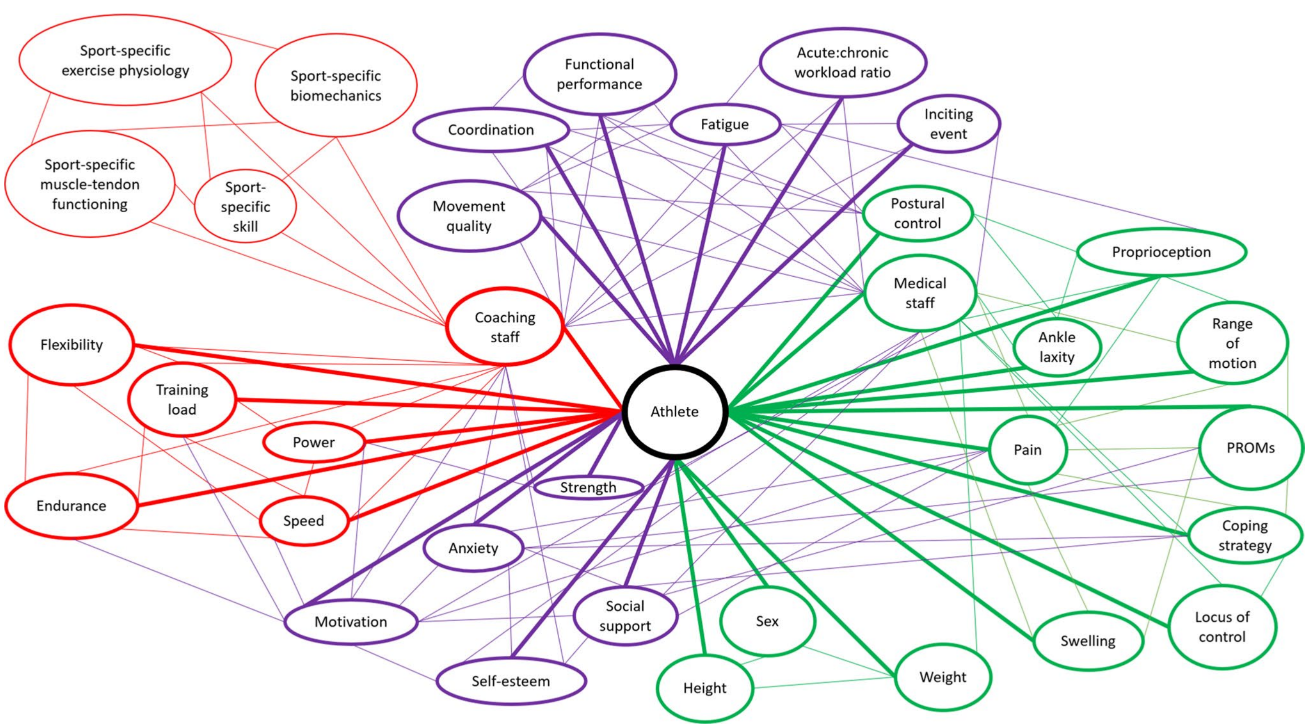

Fig. 2 Example of a dynamic RTS profile. Note that most of the variables discussed in Sect. 4.2.3 were included. Thick lines indicate variables directly related to an athlete. Such a profile would further depict possible correlations and interactions between variables (thin lines). The emergence of an RTPa, RTS or RTPf decision can arise due to the dynamic and nonlinear changes in, and interactions between, these constantly fluctuating variables. The different colours are an illustration of possible variables related to a certain stakeholder group (green = medical staff; red = coaching staff; purple = medical and coaching staff). *RTPa* return to participation, *RTS* return to sport, *RTPf* return to performance, *PROMs* patient-reported outcome measures

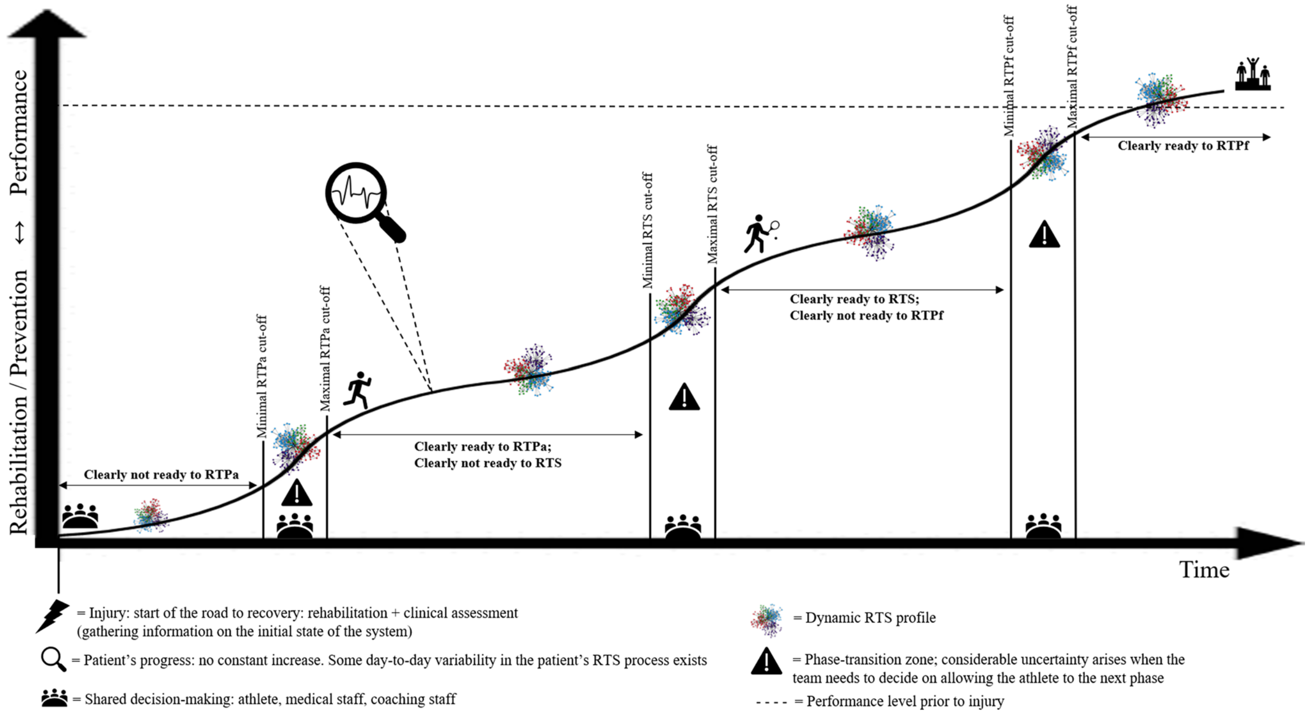

Fig. 3 Road to recovery along the RTS continuum. The *x*-axis denotes 'time', and the *y*-axis denotes the constant field of tension between rehabilitation/prevention and performance along the RTS continuum. While RTPf is a nonlinear process, Fig. 3 depicts a more or less ideal course. The progress curve emerges due to the dynamic RTS profile (see Fig. 2) over time. An example of the interpretation of minimal and maximal cut-offs for RTS decisions can be as follows: athletes with a lower re-injury risk but who are less advanced in their rehabilitation can possibly progress earlier to the next phase, while athletes with a higher re-injury risk could benefit from making further progress in their rehabilitation before being allowed to the next phase. Furthermore, (elite) athletes can benefit from pre-injury load monitoring since this would yield additional information on the previous state of the system and help in determining goals for rehabilitation, prevention and training. *RTPa* return to participation, *RTS* return to sport, *RTPf* return to performance

dynamic criteria-based RTS decision-making paradigm can be created, consensus on its variables needs to be found among clinicians, researchers and coaches.

4.3 Directions for Future Research

Future research should explore substantiating and establishing a solid management pathway, together with a dynamic criteria-based RTS decision-making paradigm along the RTS continuum, with clear cut-off values and ranges for individuals recovering from acute LAS injury. We hope this review can guide researchers in selecting RTS criteria to investigate. This is a crucial first step that needs to be progressed with scientific research and supported by clinicians in the field. Prospective studies that use a criteria-based approach for the RTS decision-making process, combined with adequate follow-up measures to determine the success rate of this RTS decision, are needed to develop an evidence-informed management pathway following LAS injury. In addition, defining 'successful' RTS decisions along the RTS continuum is warranted in order to objectively measure success or failure. For example, a successful RTPf decision should not only be characterised by an athlete returning to his or her defined sport and performing at or above his or her pre-injury level but also by the fact that the athlete does not incur a re-injury in the following months or years. This is especially important with injuries that have high recurrence rates, as is the case for acute LAS injury. These prospective, criteria-based study designs, defining successful RTPa, RTS and RTPf, are a crucial first step that needs to be initiated in scientific research to aid clinicians in the RTS decision-making process, as well as to aid researchers in developing evidence-informed guidelines and approaches in the RTS decision-making process after LAS injury.

Therefore, an international multidisciplinary enterprise has to be undertaken to connect both researchers and clinicians to the goal of bridging the gap between research and clinical practice and developing international consensus to select the best possible criteria that can be used throughout LAS injury management and decision-making processes. A modified Delphi process has been carried out for the clinical assessment following LAS injury and has already lead to some promising first results [156, 208, 209]. The Delphi process and corresponding consensus statements could form the first step to align practitioners and inspire researchers to develop and implement dynamic RTS clearance profiles that capture all relevant biopsychosocial aspects of a patient with an LAS injury. Inspiration for this continuing process can possibly be found in other domains, such as injury prevention and health promotion research (e.g. Reach, Effectiveness, Adoption, Implementation, and Maintenance (RE-AIM) model, Translating Research into Injury Prevention Practice (TRIPP) framework, six-stage operational framework for individualising injury risk management in sport) [210–213]. Using a knowledge transfer scheme to make the gap between science and practice smaller could provide valuable input for this ongoing process [214]. If these steps are successful, on field results can be evaluated through epidemiological research on re-injury rates, and short- and long-term cost effectiveness analyses can be undertaken.

Other areas that require further investigation are the clinical assessment, functional and sport-specific performance testing domains. It should be the objective of researchers to provide or advise relevant tests that can be performed clinically and that are able to identify the current progress of a patient or athlete through the RTS continuum after LAS injury. A good starting point would be to map the clinimetric characteristics (e.g. reliability, predictive values, specificity, likelihood ratios) of proposed tests. This could identify gaps within available tests and open the possibility for the development of new tests. Since humans can be considered as CAS, quantitative data will not always expose inefficiencies in movement patterns as the system can look for alternative solutions to maintain performance (even though significant deficits could exist). Thus, tests assessing both quantitative performance data and movement quality should be integrated within the RTS decision-making continuum.

A more daunting challenge for future research is to determine how clinicians would most benefit from this complexity science paradigm, and also how it would create high-quality and clinician friendly treatments and assessments based on the principles and concepts of CAS. The most important CAS within this framework is the patient. Future prospective studies should therefore include psychological, behavioural and social factors related to RTS in LAS and CAI patients in order to gain valuable insights into how these constraints interact with the progression of the patient along the rehabilitation and RTS continuum. These perspectives will help us to look beyond the injured joint and treat patients in a more holistic way.

While most of the sports medicine and sports science world is shifting its focus towards the exploration and utilisation of complexity science in research, major incentives for high-quality reductionist research have to keep being created (e.g. isolated factors, differences in isolated treatment strategies). This final comment is of great importance as both paradigms reinforce each other and can symbiotically co-exist.

4.4 Limitations

The biggest limitation of this review is that no direct evidence was available regarding the prospective use of RTS tests and criteria. For this reason, a narrative synthesis was written based on the findings of the search process of the systematic review. The RTS variables suggested in this review are a theoretical description based on empirical research that is linked to relevant tests in ankle rehabilitation throughout the RTS continuum. These variables need to be applied to actual RTS decisions within prospective research designs to evaluate their relevance. We realize that the perfect decision-making model with the perfect measurements and perfect criteria does not exist due to the ubiquitous nature of complexity. However, this should not keep us from striving towards a best-care model, and reminds us of the beauty of our work that combines rigorous science and the delicate art of guiding injured athletes back to their pre-injury level and beyond. Awareness was also raised in the LAS and CAI literature to not oversimplify the multidimensional problems and consequences faced by LAS and CAI patients [209, 215]. It was not our intention to provide a static framework, but to suggest possible rationales and considerations for a future dynamic criteria-based RTS decision-making paradigm. Hence, the principle of self-organization will automatically ensure that what is deemed useful or relevant is adopted by the (healthcare) system, and what seems implausible or too controversial is automatically ignored or rejected. This is an important consideration as the road from research to implementation is a rocky one and barriers to implementation need to be identified [216]. For example, will athletes, coaches, clubs and fans accept the criteria-based approach if it takes athletes longer to RTS, while currently a (very) fast RTS is possible even though a greater risk of re-injury and long-term sequalae exist? With this paper, we aspired to stimulate the debate on RTS in LAS (and adjacent CAI) by fuelling critical thinking, contributing to the development process of a criteria-based decision-making approach in this population, and, at best, to inspire researchers, practitioners and students. Finally, Goodhart's law cautions that the more an evaluation of performance becomes an expectation, the poorer it becomes as a discriminator of individual performances. In other words, "When a measure becomes a target, it ceases to be a good measure" [217]. Therefore, we advocate for a sensible approach in establishing, implementing and applying any criteria-based RTS decision-making paradigm in clinical practice and research. The goal should always be to assess whether athletes are truly ready to safely resume sports or not, instead of training them to pass the predetermined criteria without them actually being ready for RTS.

5 Conclusions

No studies were identified that used a criteria-based RTS decision-making process for patients with LAS injury. Therefore, we provided the reader with an overview of relevant retrieved questionnaires, clinical assessment measures, functional and sport-specific performance tests within ankle sprain populations, and proposed RTS variables based on empirical research throughout the RTS continuum. This narrative synthesis encompasses rationales and considerations for RTS decision making following LAS injury. We advocate for the implementation of complex systems theory into the RTS decision-making paradigm, and the utilisation of the RTS continuum by the 2016 Consensus statement on RTS [38]. In order to develop and implement a criteria-based and evidence-founded RTS clearance profile following LAS injury, these variables need to be applied to actual RTS decisions within future prospective research designs to evaluate their significance. The aims of future research should be to reach consensus on the 'to be included' variables, the cut-offs and ranges of these variables that would serve as criteria, and to conduct rigorous scientific evaluation of these criteria. In short, it is time to develop a criteria-based RTS decision-making paradigm for acute LAS injury.

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Compliance with Ethical Standards

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Conflicts of interest Bruno Tassignon, Jo Verschueren, Eamonn Delahunt, Michelle Smith, Bill Vicenzino, Evert Verhagen and Romain Meeusen declare that they have no conflicts of interest relevant to the content of this review.

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Electronic Supplementary Material Table S1. Search strategies for all databases

Database	***Keywords***
PubMed	("Ankle Injuries"[Mesh] OR "ankle injury" OR "ankle sprain" OR "lateral ankle sprain" OR "ankle inversion trauma") AND (test OR "functional test" OR "functional tests" OR "functional testing" OR "static test" OR "mechanical test" OR "clinical test" OR "measurement" OR "criteria") AND ("Return to sport"[MeSH] OR "Reproducibility of results"[MeSH] OR "Sensitivity and Specificity"[MeSH] OR "Limit of detection"[MeSH] OR "return to sports" OR "return to play" OR "return to participation" OR "return to action" OR "return to sporting activities" OR "return to activity" OR "return to competition" OR "return to training" OR "sports participation" OR "return to performance" OR "return to level" OR "match fitness" OR "training fitness" OR "full fitness" OR "repetitive injury" OR "recurrent injury" OR "reinjury risk" OR "reinjury" OR "reinjury rate" OR "re-injury" OR "re-injury rate" OR validity OR reliability OR specificity OR sensitivity OR "repetitive sprain" OR "recurrent sprain")
Web of Science	("Ankle Injuries" OR "ankle injury" OR "ankle sprain" OR "lateral ankle sprain" OR "ankle inversion trauma") **AND** (test OR "functional test" OR "functional tests" OR "functional testing" OR "static test" OR "mechanical test" OR "clinical test" OR "measurement" OR "criteria") **AND** ("Return to sport" OR "Reproducibility of results" OR "Limit of detection" OR "return to sports" OR "return to play" OR "return to participation" OR "return to action" OR "return to sporting activities" OR "return to activity" OR "return to competition" OR "return to training" OR "sports participation" OR "return to performance" OR "return to level" OR "match fitness" OR "training fitness" OR "full fitness" OR "repetitive injury" OR "recurrent injury" OR "reinjury risk" OR "reinjury" OR "reinjury rate" OR "re-injury" OR "re-injury rate" OR validity OR reliability OR specificity OR sensitivity OR "repetitive sprain" OR "recurrent sprain")
PEDro	Ankle **AND** return
Scopus	TITLE-ABS-KEY (("ankle injuries" OR "ankle sprain" OR "ankle inversion trauma") **AND** (test OR measurement OR criteria) **AND** ("return to sport" OR fitness OR play OR reinjury OR re-injury OR validity OR reliability OR sensitivity OR specificity OR "recurent sprain")) AND DOCTYPE (ar OR re)
Cochrane Library	("Ankle Injuries" OR "ankle injury" OR "ankle sprain" OR "lateral ankle sprain" OR "ankle inversion trauma") **AND** (test OR "functional test" OR "functional tests" OR "functional testing" OR "static test" OR "mechanical test" OR "clinical test" OR "measurement" OR "criteria") **AND** ("Return to sport" OR "Reproducibility of results" OR "Limit of detection" OR "return to sports" OR "return to play" OR "return to participation" OR "return to action" OR "return to sporting activities" OR "return to activity" OR "return to competition" OR "return to training" OR "sports participation" OR "return to performance" OR "return to level" OR "match fitness" OR "training fitness" OR "full fitness" OR "repetitive injury" OR "recurrent injury" OR "reinjury risk" OR "reinjury" OR "reinjury rate" OR "re-injury" OR "re-injury rate" OR validity OR reliability OR specificity OR sensitivity OR "repetitive sprain" OR "recurrent sprain")
Science Direct	("ankle injuries" or "ankle sprain" or "ankle inversion trauma") **AND** (test OR measurement OR criteria) **AND** ("return to" OR reinjury OR re-injury OR validity OR reliability OR sensitivity OR specificity OR "recurrent sprain" OR fitness OR sport)
SPORTDiscus	("Ankle Injuries" OR "ankle injury" OR "ankle sprain" OR "lateral ankle sprain" OR "ankle inversion trauma") **AND** (test OR "functional test" OR "functional tests" OR "functional testing" OR "static test" OR "mechanical test" OR "clinical test" OR "measurement" OR "criteria") **AND** ("Return to sport" OR "Reproducibility of results" OR "Limit of detection" OR "return to sports" OR "return to play" OR "return to participation" OR "return to action" OR "return to sporting activities" OR "return to activity" OR "return to competition" OR "return to training" OR "sports participation" OR "return to performance" OR "return to level" OR "match fitness" OR "training fitness" OR "full fitness" OR "repetitive injury" OR "recurrent injury" OR "reinjury risk" OR "reinjury" OR "reinjury rate" OR "re-injury" OR "re-injury rate" OR validity OR reliability OR specificity OR sensitivity OR "repetitive sprain" OR "recurrent sprain")

Electronic Supplementary Material Table S2. Clinical assessment tests

Category	Test/Test battery/Guideline/Index	References
Swelling	Figure-of-eight method	[1, 2]
Ligamentous laxity	Anterior drawer test	[2-6]
	Talar tilt test	[2, 4]
	Inversion tilt	[4]
	Medial subtalar glide test	[7]
	Talar glide test	[2]
	Posterior-talar glide test	[2]
	Distal fibular position	[5]
Range of motion	Inclinometer	[7]
	Goniometer	[7]

Electronic Supplementary Material Table S3. Functional tests

Category	Test/Test battery/Guideline/Index	References
Proprioception	Biodex systems (joint reposition sense, sense of resistance, sense of kinaesthesia)	[8]
Hopping and jumping	One-legged hop	[8-11]
	Square hop test	[12]
	6 meter crossover hop	[12]
	Stairs hop	[11, 13]
	Triple hop for distance	[11, 13]
	Figure-8 hop	[10, 12]
	Side-to-side hop	[10, 12]
	Triple-crossover hop for distance	[8, 10]
	Single limb hopping course	[8]
	6 meter hop for distance	[8]
	6 meter hop for time	[8]
	Single-legged jump-landing	[14]
	Vertical jump test	[15]
	Vertical drop jump	[16]
Range of motion	Knee-to-wall test (goniometer); weight bearing lunge test	[2, 6]

Electronic Supplementary Material Table S3. Functional tests – continued

Category	Test/Test battery/Guideline/Index	References
Postural balance	Single-legged postural equilibrium test / Foot lift test / Time in balance test	[6, 8, 9]
	Balance test on a computerized board	[9, 17]
	Spring test on an electronic contact platform	[9]
	One-legged balance test on a square beam	[9]
	Star excursion balance test	[6, 18]
	Balance error scoring system	[19]
Agility / speed	Zig zag run	[16]
	Shuttle run with side steps	[16]
	Agility t-test	[15]
	40-meter walk	[11, 13]
	40-meter run	[11, 13]
	Timed up-and-down stair test	[6, 9]
	Modified figure-of-8 running test	[9]
	Running in a figure-of-8 test	[9, 11, 13]
	Walking down a staircase	[9]
Strength	Isometric dynamometer (invertor – evertor)	[20]
	Isokinetic dynamometer (invertor – evertor)	[6, 8]
	One-legged rising on heels	[9]
	One-legged rising on toes	[9]

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