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WAGEMANS
MOTOR-BEHAVIORAL IMPAIRMENTS AFTER ACUTE ANKLE SPRAIN

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REVIEW

Which motor-behavioral impairments are assessed in prospective studies including patients with an acute ankle sprain

Jente WAGEMANS [1, 2] *, Kobe DECORTE [1], Helder HEYLEN [1], Michel TOBIAS [1], Jan TAEYMANS [2], Kevin KUPPENS [1, 4], Heiner BAUR [2], Dirk VISSERS [1, 2], Chris BLEAKLEY [3]

[1]Faculty of Medicine and Health Sciences, Department of Rehabilitation Sciences and Physiotherapy, University of Antwerp, Antwerp, Belgium; [2]Department of Health Professions, Bern University of Applied Sciences, Bern, Switzerland; [3]School of Health Science, Ulster University, Newtownabbey, Northern Ireland; [4]SOMT University of Physiotherapy, Amersfoort, The Netherlands

*Corresponding author: Jente Wagemans, Faculty of Medicine and Health Sciences, Department of Rehabilitation Sciences and Physiotherapy, University of Antwerp, Universiteitsplein 1, 2610, Wilrijk, Belgium. E-mail: jente.wagemans@uantwerpen.be

ABSTRACT

INTRODUCTION: Lateral ankle sprains (LAS) are one of the most common musculoskeletal injuries, with up to forty percent of patients developing chronic ankle instability (CAI). Current etiological models suggest that CAI may be underpinned by a wide variety of motor-behavioral impairments that develop after an initial LAS, but this must be validated through prospective research. The aims of this scoping review were to determine the extent to which prospective research assesses motor-behavioral impairments after LAS, and the respective measurement tools used.

EVIDENCE ACQUISITION: We searched six databases (Cochrane Library, PEDro, PubMed, Scopus, SPORTDiscus and Web of Science) for prospective studies of adults with acute LAS, incorporating at least one assessment of motor-behavioral impairment.

EVIDENCE SYNTHESIS: Six studies totaling 210 patients met the inclusion criteria. The following motor-behavioral impairments were assessed: balance (five studies), altered movement patterns (three studies), muscle strength (two studies) and reflex inhibition (one study). Balance was assessed statically and dynamically using single-limb stance and the star-excursion balance test, respectively. Movement patterns (kinematics) were recorded during a range of functional activities including, gait, going up and down stairs, drop vertical jump, and single-leg drop landing. Peak power and isometric strength were measures of muscle strength. Time to restore from sudden perturbation was used to assess reflex inhibition.

CONCLUSIONS: Motor-behavioral impairments have been prospectively assessed after LAS, but these focus primarily on measures of balance and joint kinematics. Future prospective studies must incorporate more clinically applicable outcomes to assess the entire spectrum of motor-behavioral impairments (neuromuscular inhibition, altered reflexes, muscle weakness, balance, altered movement patterns, decreased physical activity).
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Key words: Ankle joint; Sprains and strains; Athletic injuries; Gait.

Introduction

Acute lateral ankle sprains (LAS) are the most common musculoskeletal injury affecting the lower limb,[1-3] with up to 80% affecting the lateral ligaments.[4] Around 40% of LAS occur during sports,[5, 6] with the highest incidence recorded in indoor/court sports (seven sprains per 1000 athlete exposures A/E)[1] followed by field (1/1000 A/E) and outdoor sports (0.88/1000 A/E).[1, 5] Incidence also varies by sex,[7] with rates estimated at 6.94 to 13.6 ankle sprains per 1000 exposures, for males and females respectively.[5] Acute LAS can have a poor long-term prognosis with significant risk of residual symptoms and injury recurrence.[2, 7] Some of the highest re-injury rates are reported in volleyball (46%) and basketball (28%),[2] and between 30-73% of patients with LAS will develop chronic ankle instability (CAI).[8-10] This condition is characterized by pain, swelling, muscle weakness, decreased sensory motor function and perceived instability.[8, 9] CAI is also associated with deficits in physical functioning[5, 11] and decreased quality of life.[12, 13]

Establishing a clear etiology is essential for developing evidence based pathways for diagnosis and management. Contemporary etiological models suggest that CAI is a complex heterogeneous condition, underpinned by the interaction of pathomechanical, sensory-perceptual and motor-behavioral impairments.[14] Furthermore, each of these impairments have multiple constructs, and therefore cannot be quantified using a single outcome measure. Much of the evidence informing our understanding of CAI etiology uses either cross sectional or case controlled designs. Recent retrospective studies have focused primarily on the motor aspect of sensorimotor control (motor-behavioral constructs) in patients with established CAI; reporting alterations in their physical functioning,[15] altered reflexes,[16] neuromuscular inhibition in the ankle region[17] and in proximal musculature,[18] muscle weakness,[19]balance deficits,[20] altered movement patterns during walking,[21, 22] running,[23] and jump landings,[24] and reduced physical activity.[25] Much of this research (alongside expert consensus) informed the 2018 Rehabilitation-oriented assessment (ROAST) guidelines, which highlight the importance of quantifying key motor-behavioral constructs (muscle strength, static and dynamic balance, gait, activity level) periodically throughout recovery.[26]

The reliance on retrospective data has meant that the etiology of CAI has become increasingly complex over time,[27] making it more difficult for clinicians to prioritize outcome assessments, key prognostic variables and treatment rationale. Without prospective data, it is difficult to discern which of the stated motor-behavioral detriments are causative, associative or by-products of CAI. The aim of this scoping review is to identify prospective studies that have evaluated motor-behavioral impairments following acute LAS. Our key objectives are to determine which motor-behavioral impairments are most commonly assessed, and to identify the specific outcome tools and testing conditions, used in their assessment.

Evidence acquisition

Search strategy and study selection

The protocol for this scoping review was registered a priori on the international prospective register of systematic reviews (PROSPERO; registration number: CRD42022319230). This scoping review was reported according to the PRISMA extension for scoping reviews (PRISMA-ScR).[28]

Initially, PICO criteria were established, subsequently keywords and MeSH-terms were sought and inducted in a PubMed search string (Supplementary Digital Material 1: Supplementary Table I). This search string was modified as required and implemented across the following databases: Cochrane Library, Physiotherapy Evidence Database (PEDro), Scopus, SPORTDiscus and Web of Science. A hand search for additional citations was performed by going over reference lists of screened articles. The final search in all databases took place on the 30th of January 2023. All citations were imported in the Rayyan application,[29] in which duplicates were removed prior to screening. To be included in this scoping review, articles had to meet predefined eligibility criteria (Table I). Initially, three reviewers (H.H., K.D., M.T.) screened the articles blinded and independently by reading title and abstract and selected those based on the a priori set inclusion and exclusion criteria. Subsequently, a second blinded screening process was performed based on full text, for which the same allocation strategy and eligibility criteria as the first screening were used. An independent researcher (J.W.) was consulted in case of disagreement.

Data extraction

Following the selection process, the remaining articles were equally allocated to three independent reviewers (HH, KD, MT): data from each study was extracted by one reviewer, implemented in an evidence table using an Excel spreadsheet and subsequently verified by another reviewer. The following data from each study was obtained: study characteristics (author, year of publication, study design), population characteristics (number of participants, age, sex, height, weight or BMI, gradation of ankle sprain and group attributes), inclusion/exclusion criteria and time since injury (at moment of testing). As primary outcomes to this review, we extracted all outcomes quantifying motor-behavioral impairments, and the respective assessment tools used.

Evidence synthesis

Study selection

The literature search yielded 4078 unique citations. After examining all titles and abstracts, 148 citations were identified as potentially relevant. Six full texts could not be retrieved, resulting in the exclusion of these studies. Of the remaining 142 full text articles, 136 did not meet our criteria and were therefore excluded from the review. Finally, six studies met the review standards and were used for data extraction. Full details of the review process are displayed in the PRISMA flow diagram (Figure 1).

Study characteristics

Table II summarizes the study characteristics. A total of 210 patients were examined across the six included studies (57% male; 43% female). Study size varied from 17[33] to 82[30] participants. Time of follow-up ranged from 28 days[31] to 12 months.[30, 35] Participants were recruited in emergency departments, physiotherapy department or were volunteers, with time since injury at recruitment varying from 24 hours to six months post injury. All but one[34] studies assessed balance deficits; three studies involved evaluation of altered movement patterns;[30, 34, 35] two studies assessed muscle weakness;[34, 35] one study included assessment of altered reflexes.[35]

Results of individual studies

Table III summarizes the relevant outcomes and the testing conditions used in the included studies.

Balance deficits

Of the studies assessing static balance, all but one[32] involved balance in single leg stance (SLS). Two of these studies assessed balance with the participants' eyes closed,[30, 32] and one study tested the ability to perform a demi-pointe for five seconds.[35] Centre of pressure (CoP) trajectory was used in three studies[30-32] as outcome, but the reported outcome measures of CoP vary across studies. One study evaluated bipedal stance,[32] and assessed symmetry with eyes closed. Two studies included the star excursion balance test (SEBT) to assess dynamic balance; both included reaching distances as an outcome.[30, 35] Doherty et al also recorded kinetic and kinematic data during SEBT performance.[30]

Altered reflexes

Pourkazemi *et al.* investigated response to perturbations by evaluating the time to restore to baseline position after a sudden eversion perturbation.[35]

Muscle weakness

Muscle strength was evaluated using a isokinetic dynamometer to determine inversion and eversion peak power,[35] and a handheld dynamometer to determine isometric muscle strength for plantar flexion, dorsiflexion, inversion and eversion.[34]

Altered movement patterns

Two studies analyzed gait parameters using motion analysis and force plates.[30, 34] The study by Punt *et al.* assessed spatio-temporal outcome measurements and outcome measurements about dorsiflexion and plantarflexion kinematics.[34] Doherty *et al.*[30] demonstrated angular displacement of lower limb joints, ground reaction forces (GRF) and momentum during different phases of gait. Furthermore, they analyzed GRF and joint movements during a single leg drop landing and drop vertical jump. Pourkazemi *et al.* timed going up and down on stairs.[35]

Discussion

With this scoping review, we aimed to provide a summary of prospective studies which have assessed motor-behavioral impairments in adult patients with acute LAS. In conjunction with contemporary models,[14] motor-behavioral impairments were classified as: altered reflexes, neuromuscular inhibition, muscle weakness, balance deficits, altered movement patterns, reduced physical activity. Balance was the most commonly reported outcome, followed by altered movement patterns. Two studies included muscle strength and only one study tested altered reflexes. No studies evaluated neuromuscular inhibition and physical activity.

Three out of five studies evaluated balance using single-leg stance (SLS) on force plates recording different measures of postural sway: fractional dimension, excursion velocity, or proportional movement in different directions and stabilization time. As most clinicians will not have access to force plates, it is important that there are clinical alterative for quantifying balance after ankle sprain. The ROAST- guidelines suggest using the Balance Error Scoring System (BESS) and foot-lift test,[26] which quantify patient's errors or deviations during the test, without the need for technical equipment. In current review Pourkazemi *et al.* used both the foot-lift test and the participant's ability to perform a demi-pointe for five seconds.[35] The is currently data to show that BESS[36] and foot-lift test[37] are reliable to assess static balance in a population with chronic ankle instability. Whilst that the demi-pointe test described by Pourkazemi *et al.*[35] could be applicable to some populations, its reliability and validity have not been examined.

The SEBT evaluated dynamic balance, whereby the studies reported normalized reach distances in relation to lower limb length, as well as COP deviation, fractional dimension values and ankle, knee and hip joint kinematics, which were calculated by using force plates.[30] The SEBT has established clinimetric properties in a LAS population[38-43] and forms part of the ROAST guidelines.[26] Again, incorporating a force plates to calculate fractional dimensions and establish joint kinematics during the SEBT, is difficult to apply in many practices. Notwithstanding this, smartphone apps can be developed to more easily assess joint kinematics in clinical practice.[44] This may be important — and Doherty *et al.* recorded 10 salient kinematic variables for the SEBT,[30] *i.e.* variables that successfully distinguished patients with CAI and copers.

Two studies evaluated muscle weakness, using two different methods. Pourkazemi *et al.*[35] used isokinetic dynamometry to assess peak power, while Punt *et al.*[34] used handheld dynamometry to assess isometric muscle strength. Although isokinetic dynamometry is the golden standard, handheld dynamometry is feasible to apply in clinical practice and is proven reliable.[45] Both studies evaluated ankle muscle strength, whilst research has shown that impaired muscle strength also occurs more proximally up the kinetic chain: knee and hip strength differs between patients with CAI and controls.[46] Eccentric muscle strength was not addressed, while eccentric inversion strength is diminished in patients with ankle instability.[47] This was evaluated with an isokinetic dynamometer,[47] raising the question whether we can assess eccentric muscle strength in a clinically applicable manner. One could also argue that although isometric muscle strength testing is appropriate in the initial stages of rehabilitation, isokinetic muscle strength testing — *i.e.* isotonic and eccentric — is more functional and thus advocated while rehabilitation progresses. It would even be more functional if testing would occur in accordance with injury mechanics: open chain vs closed chain; movement in a single plane of motion vs multiple planes of motion; single-limb stance.[48, 49]

Only one study assessed reflexes, evaluating the time it takes to recover from a sudden inversion perturbation.[35] This test was undertaken during single limb stance,[35] and used a laboratory platform to evaluate reflex recovery. This test set up different compared to cross-sectional studies in this field, which have mostly incorporated double-limb stance, reporting delayed reaction time of the peroneus longus and brevis muscles after the inversion perturbations.[16] Evaluating reflexes is not included in the ROAST-guideline.[26] It may be challenging to incorporate this into an assessment set up that is feasible for clinicians. One alternative is electromyography,[14] which has been used to detect peroneal latency during at random perturbations while walking in patients with functional ankle instability.[50]

Altered movement patterns comprise various functional tasks: gait, running, jumping and landing, among others.[14] Two studies[30, 34] included gait, one study included walking up and down stairs and another study included a drop vertical jump and a single-leg drop landing. All studies assessing gait observed spatiotemporal gait parameters by using force plate and motion analysis systems. In addition, lower extremity kinematics were also assessed. Deviations from a normal gait function could potentially be explained by the combination of lower kinetic chain impairments after acute LAS, such as deficits in sensorimotor function, ROM, strength and the presence of pain and swelling.[7, 51] For instance, patients suffering from acute LAS showed a 13.2% decrease in gait speed, which one study theorized to be mainly related to pain and decreased ankle strength.[34] Also this is in accordance with the ROAST-guideline: the rationale for looking at gait is to evaluate antalgic gait.[26] This observation would not be objective, compared to force plates and motion analysis systems. But then again, the matter of applicability in clinical practice is raised. Smartphone applications are shown to be reliable and valid to assess gait.[52] This could be the solution for more objective evaluation of gait parameters.

Walking up and down stairs is not mentioned in the ROAST-guideline. Nevertheless, it is an activity of daily functioning. The timed up and down stairs test used by Pourkazemi *et al.*[35] has been proven reliable and applicable in clinical practice.[53] The drop vertical jump (DVJ) and single leg drop landing — or other measures of performance — are not mentioned in the ROAST-guideline either.[26] Both tests are used to measure performance in anterior cruciate ligament (ACL) injury screening[54] and rehabilitation progress.[55, 56] Current prospective ankle sprain research did not include such performance-related tests, let alone evaluate the biomechanics.

None of the included studies tested physical activity or neuromuscular inhibition. While neuromuscular inhibition may be less feasible to evaluate as it is a phenomenon that occurs at spinal level instead of the ankle,[14] physical activity can be easily included in an assessment protocol. The ROAST-guideline[26] advocates the Tenger-activity scale; one alternative is The New Activity Score, which is specifically developed for the ankle.[57] Physical activity can also be objectified alongside patient-reported outcome measures. Bleakley *et al.* used activity monitors to evaluate physical activity during their intervention period.[58]

Strengths and limitations of the study

To our knowledge, this scoping review was the first to examine which motor-behavioral impairments are assessed in prospective studies including patients with acute LAS. The research group pursued the PRISMA-ScR guidelines as required, thereby optimizing the reporting of this scoping review. The publication dates of the six included articles range from 2001 to 2018 with half of these being published after 2014, allowing us to label most studies as rather recent.[59]

There were some deviations from the a priori registered methodology: 1) we expanded our inclusion from functional impairments to motor-behavioral impairments — based on the most recent CAI model; 2) We narrowed down the inclusion of study design to prospective studies; prospective follow-up of the development of motor-behavioral impairments — and CAI as a whole — is lacking in current literature. We excluded studies with an intervention, even if they had a follow-up of their participants, due to the gap in current literature concerning the development of patients after an acute ankle sprain. Before one composes interventions, one should perform longitudinal research to substantiate future intervention studies.

Conclusions

Assessments of motor-behavioral impairments in patients with acute LAS include mostly balance testing, followed by altered movement patterns in various functional tasks (*e.g.* gait, jumping, landing). The majority of assessments concur with the content of the ROAST guidelines from the International Ankle Consortium. However, most prospective studies use laboratory test methods — force plates are ubiquitous, which is not applicable in clinical practice. Not all categories of motor-behavioral impairments are included in current literature, with an under representation of outcome measures relating to muscle strength, altered reflexes, neuromuscular inhibition and physical activity. Future research should include clinically applicable assessment methods to prospectively evaluate the entire spectrum of motor-behavioral impairments in primary care of acute LAS in adults.

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Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions

All authors read and approved the final version of the manuscript.

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Supplementary data

For supplementary materials, please see the HTML version of this article at www.minervamedica.it

Figure 1.—PRISMA flow diagram of the review process.

Table I.—Eligibility criteria.

Parameter	Inclusion	Exclusion
Population	Mean age: 18-55 years Acute ankle sprain	Previous injury <1 years Fractures Syndesmotic injuries Neurological, cardiovascular, metabolic comorbidities
Intervention	–	Surgical repair
Comparison	–	–
Outcome	Muscle reflexes, neuromuscular function, muscle strength, balance, movement, physical activity	Range of motion, swelling, pain Questionnaires, proprioception, arthrokinematics

Study design	Prospective cohort studies	Systematic review, meta-analysis, practice guideline, retrospective studies, animal studies, case report, case studies, narrative reviews, expert opinions, randomized controlled trials, cross-sectional studies

Table II.—Study characteristics.

Study	Follow-up	Participants*	Recruitment cite	Impairment assessed	Inclusion criteria
Doherty[30]	12 months	N.=82; 54-28 (66-34%) 23.78 years	ED	Balance Altered movement patterns	First-time LAS; no other severe LL injury; no fractures; no LL surgery; no neurological, vestibular or visual pathology
Evans[31]	28 days	N.=28; 11-17 (39-61%) 19.7±1.4 years	College	Balance	Grade I or II LAS; ≥2 days out; no other orthopedic injury
Genthon[32]	30 days	N.=23; 14-9 (61-39%) 29.1±7.9 years	ED	Balance	Age 18-60 years; Grade I or II LAS; ATFL or CFL injury; <48 h post injury; bipedal stance 40 s
Hertel[33]	4 weeks	N.=17; 9-8 (53-47%) 21.8±5.9 years	University	Balance	Grade I or II LAS
Punt[34]	4 weeks	N.=30; 15-15 (50-50%) 25.2±10.2 years	ED	Muscle weakness Altered movement patterns	Age 18-50 years; Grade I or II LAS
Pourkazemi[35]	12 months	N.=30; NR	University	Balance Altered reflexes Altered movement patterns Muscle weakness	Age 18-60 years; LAS <6 months

RCT: randomized controlled trial; ED: Emergency Department; LAS: lateral ankle sprain; ATFL: anterior talofibular ligament; CFL: calcaneofibular ligament; SL: single-leg; ROM: range of motion; NR: not reported; LL: lower limb.

*Total number of subjects; male-female (%); mean±SD.

Table III.—Functional impairments assessed by the included studies.

Study	Time of testing	Motor-behavioral impairment	Assessment tool (and conditions of assessment)	Specific outcome reported

Balance deficits				
Doherty[30]	2 weeks	Static and dynamic balance	Force plate SLS - Eyes closed - Eyes open SEBT	COP Fractional dimension ACMD COP Fractional dimension ACMD Ankle movement Knee movement Hip movement Anterior reaching distance Posterolateral reaching distance Posteromedial reaching distance
Evans[31]	1 day	Postural control	Force plate SLS: - Eyes open	CoP excursion velocity (cm/sec)
Genthon[32]	1 day	Postural control	Force plate bipedal stance: - Eyes closed	CoP Magnitude (RMS) CoP Shape (LR)
	1 day 10 days 30 days	Weight-bearing asymmetry	Force plate bipedal stance	Weight-bearing asymmetry D0 (%) Weight-bearing asymmetry D10 (%) Weight-bearing asymmetry D30 (%)
Hertel[33]	3 days 2 weeks 4 weeks	Postural sway	Force plate SLS Eyes open	PSLX PSLY RMS of VelX RMS of VelY
Pourkazemi[35]	NR	Static and dynamic balance	SEBT	Anterior reaching distance Posterolateral reaching distance Posteromedial reaching distance
			SLS eyes closed Demi-pointe balance test	Amount of foot lifts Ability to perform (yes/no)
Altered reflexes				
Pourkazemi[35]	NR	Response to perturbation	SLS on perturbation platform	Time to return to baseline (s)
Muscle weakness				
Pourkazemi[35]	NR	Peak power	Biodex isokinetic dynamometer	Inversion peak power [(Nm/s)/kg] - 60°/s - 90°/s - 180°/s Eversion peak power

				([Nm/s/]kg) - 60°/s - 90°/s - 180°/s
Punt[34]	4 weeks	Isometric muscle strength	Handheld dynamometer	Plantar flexion muscle strength (N) Dorsiflexion muscle strength (N) Inversion muscle strength (N) Eversion muscle strength (N)
Altered movement patterns				
Doherty[30]	<2 weeks	Gait kinematics and kinetics	Force plates Motion analysis	Angular displacement Ground reaction force Ankle movement Knee movement Hip movement
		SL drop landing	Force plates Motion analysis	Ground reaction force Ankle movement Knee movement Hip movement
		Drop vertical jump	Force plates Motion analysis	Ground reaction force Ankle movement Knee movement Hip movement
Pourkazemi[35]	NR	Functional performance	Up and down stairs	Time (s)
Punt[34]	4 weeks	Gait kinematics and kinetics	Motion analysis Force plates	Speed (m/s) Steph length (m) Single-leg support (%) Symmetry index single-leg support Maximal plantar flexion during swing (degrees) Timing of maximal plantar flexion during swing (%) Concentric dorsiflexion strength during stance (W/kg) Eccentric plantar flexion strength during stance (W/kg) Internal dorsiflexion strength moment during stance (W/kg)

NR: not reported; COP: center of pressure; ACMD: adjusted coefficient of multiple determination; RMS: root mean square; SLS: single-leg stance; LR: lengthening ratio; PSLX:

frontal plane postural sway length; PSLY: sagittal plane postural sway length; VeLX: frontal plane sway velocity; VeLY: sagittal plane sway velocity; SEBT: star excursion balance test.