Bang for your buck: the clinical assessment and rehabilitation of postural balance impairments

Professor Eamonn Delahunt

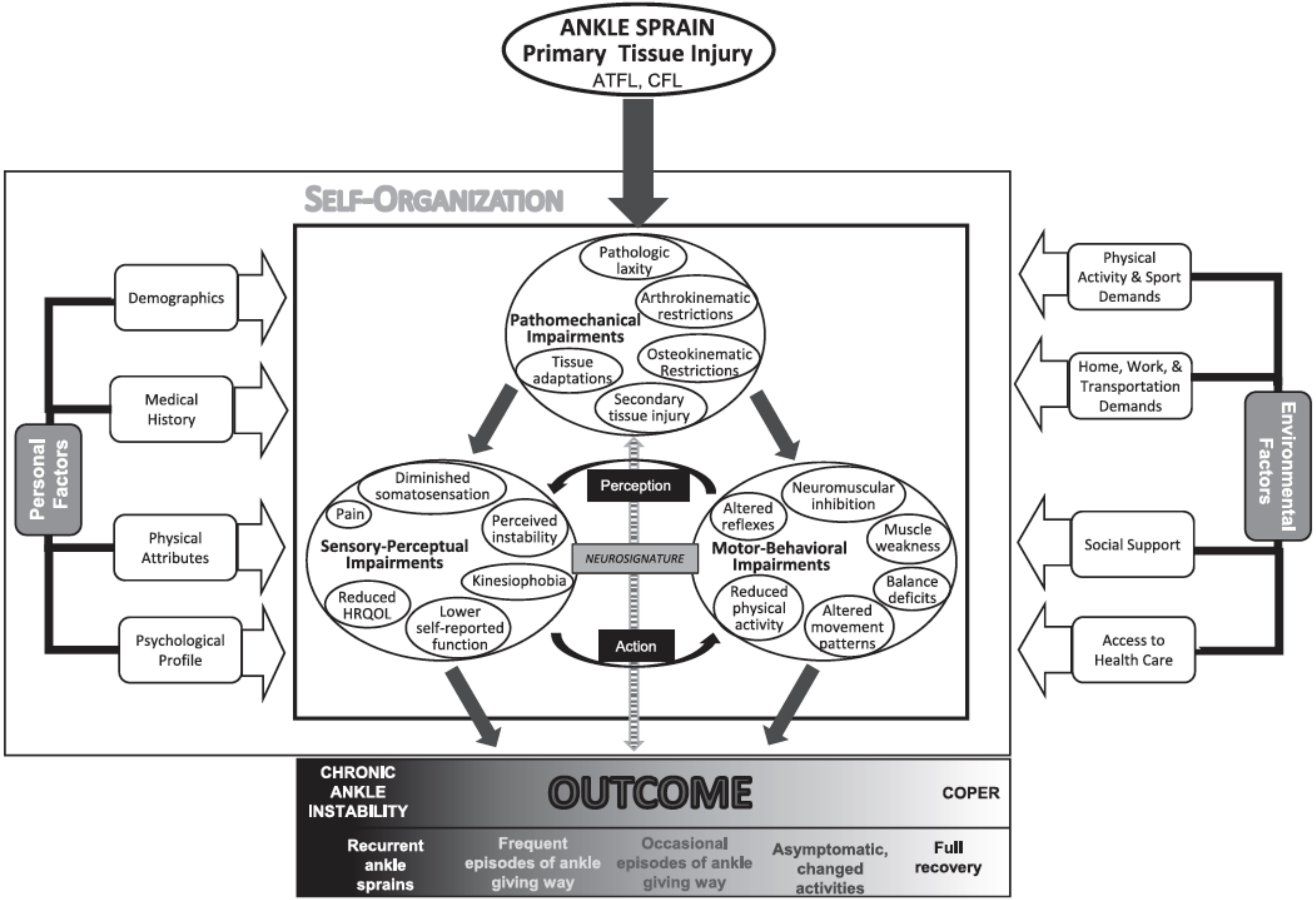


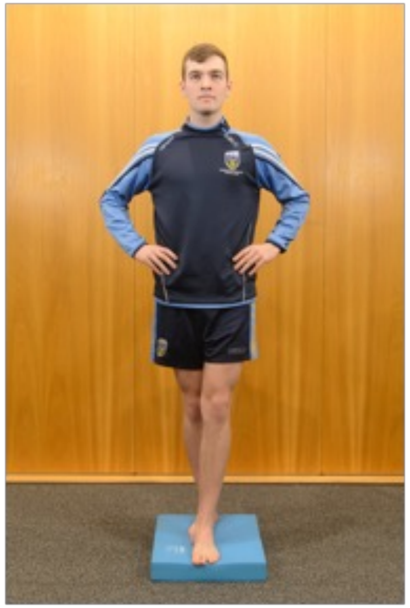
Figure 1. The updated model of chronic ankle instability (CAI). The outcome is determined at least 12 months after the initial ankle sprain. Abbreviations: ATFL, anterior talofibular ligament; CFL, calcaneofibular ligament; HRQOL, health-related quality of life.

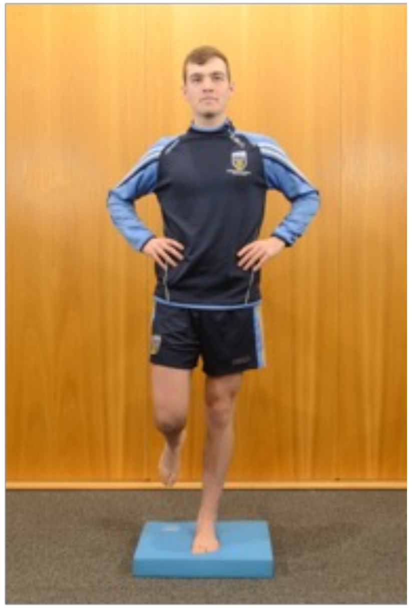

Double leg stance (firm surface)


Tandem stance (firm surface)


Single leg stance (firm surface)


Double leg stance (foam surface)


Tandem stance (foam surface)


Single leg stance (foam surface)

All tests are initiated and lasts for 20 seconds when the patients closes his/her eyes.

Double leg stance (firm surface)

Errors

[1] Moving the hands off the hips
[2] Opening the eyes
[3] Step, stumble, or fall
[4] Abduction or flexion of the hip >30 degrees
[5] Lifting the forefoot or heel off the testing surface
[6] Remaining out of the proper test position for >5 seconds

Tandem stance (firm surface)

Errors

[1] Moving the hands off the hips
[2] Opening the eyes
[3] Step, stumble, or fall
[4] Abduction or flexion of the hip >30 degrees
[5] Lifting the forefoot or heel off the testing surface
[6] Remaining out of the proper test position for >5 seconds

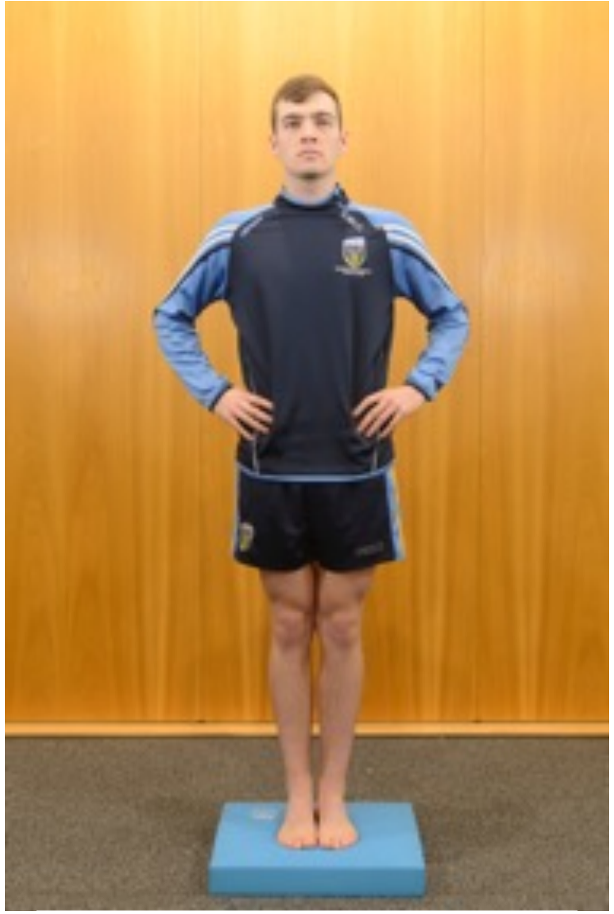
Single leg stance (firm surface)

Errors

[1] Moving the hands off the hips
[2] Opening the eyes
[3] Step, stumble, or fall
[4] Abduction or flexion of the hip >30 degrees
[5] Lifting the forefoot or heel off the testing surface
[6] Remaining out of the proper test position for >5 seconds

Errors

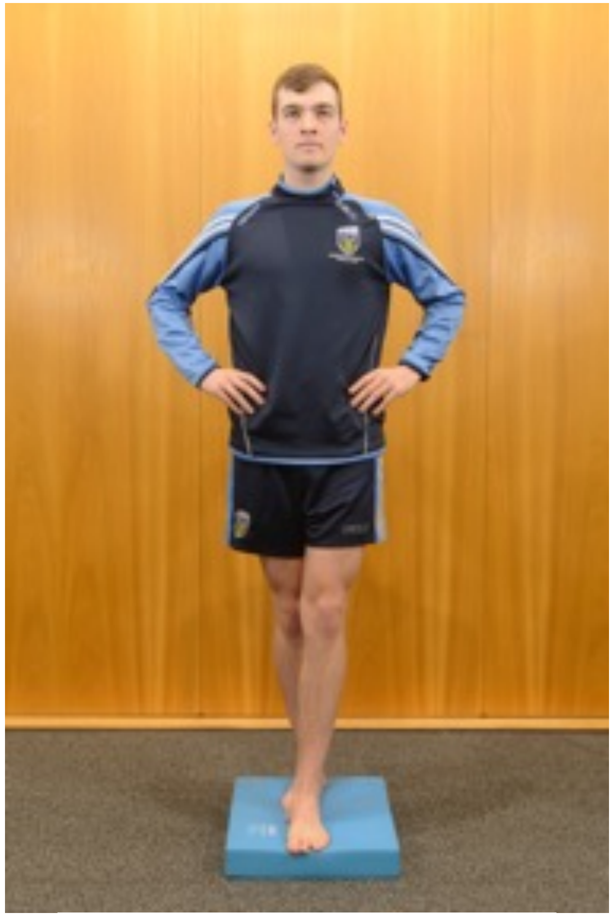
[1] Moving the hands off the hips
[2] Opening the eyes
[3] Step, stumble, or fall
[4] Abduction or flexion of the hip >30 degrees
[5] Lifting the forefoot or heel off the testing surface
[6] Remaining out of the proper test position for >5 seconds



Double leg stance (foam surface)

Errors

[1] Moving the hands off the hips
[2] Opening the eyes
[3] Step, stumble, or fall
[4] Abduction or flexion of the hip >30 degrees
[5] Lifting the forefoot or heel off the testing surface
[6] Remaining out of the proper test position for >5 seconds



Tandem stance (foam surface)


AIREX

Errors

[1] Moving the hands off the hips
[2] Opening the eyes
[3] Step, stumble, or fall
[4] Abduction or flexion of the hip >30 degrees
[5] Lifting the forefoot or heel off the testing surface
[6] Remaining out of the proper test position for >5 seconds

Single leg stance (foam surface)


AIREX
BeBalanced!
Balance-pad
www.bebalanced.net

	Double leg stance (firm surface)	Tandem stance (firm surface)	Single leg stance (firm surface)	Double leg stance (foam surface)	Tandem stance (foam surface)	Single leg stance (foam surface)
Errors	0	2	5	2	5	10

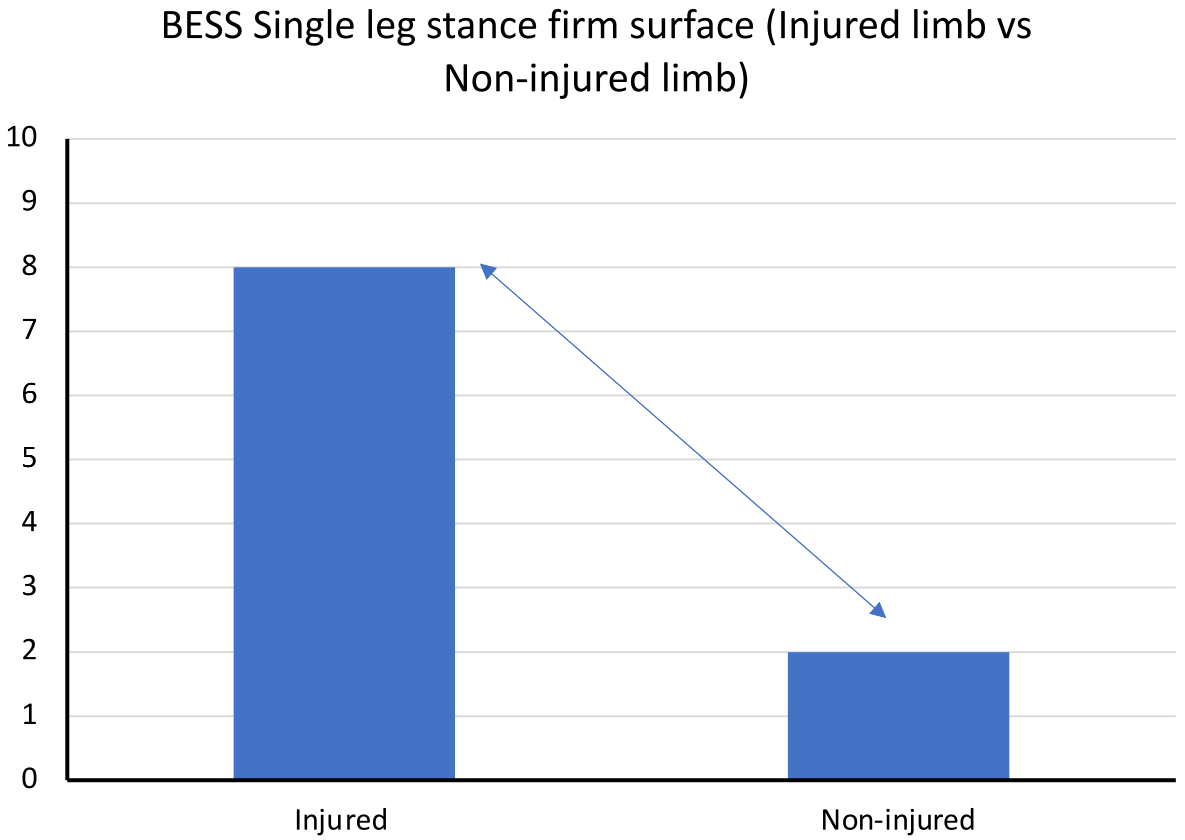
Balance errors made by *Player A* as assessed via performance on the Balance Error Scoring System.

No errors were made by *Player A* when completing the double leg stance (firm surface) task. Hence, this task will not challenge the sensorimotor system and its incorporation into a rehabilitation programme would be **redundant**.

Player A made 2 errors whilst completing the tandem stance (firm surface) task and the double leg stance (foam surface) task. This low number of errors would suggest that these tasks should only constitute **a minority component** (i.e. small percentage) of the total time devoted to postural balance exercises.

Player A made 5 errors whilst completing the single leg stance (firm surface) task and the tandem stance (foam surface) task. This is a substantial number of errors for each of these tasks and suggests that they are **appropriately challenging** the sensorimotor system; they are not so easy such that he can complete them with minimal errors, whilst they are not so difficult such that he cannot complete them at all. Therefore, it would be prudent to include these tasks as key exercises of the postural balance component of his rehabilitation programme.

Player A made 10 errors (i.e. the maximum number of errors) whilst completing the single leg stance (foam surface) task. This suggests that this task is **too challenging (at this time point)** for the sensorimotor system and should not be included as an initial exercise of the postural balance component of his rehabilitation programme.



Concept of limb asymmetry

Applicable to:

[1] BESS Tandem stance (firm surface)
[2] BESS Single leg stance (firm surface)
[3] BESS Tandem stance (foam surface)
[4] BESS Single leg stance (foam surface)

Nashner and McCollum were the first to propose the existence of two postural control strategies that can be used either independently or in conjunction by the central motor programme based on the feedback received from sensory afferents in order to achieve adaptable control of the COP within the supporting base (Nashner and McCollum, 1985):

the synchronous exploitation of torques around the ankle joint that constitutes the **‘ankle strategy’** is appropriate for subtle changes in postural control while a **‘hip strategy’**, which generates shear forces around the hip joint, compensates for more substantial disturbances in equilibrium (Hwang et al., 2009; Nashner and McCollum, 1985).

Clinical Biomechanics 29 (2014) 643–649

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Postural control strategies during single limb stance following acute lateral ankle sprain

Cailbhe Doherty [a,*], Chris Bleakley [c], Jay Hertel [d], Brian Caulfield [a], John Ryan [e], Eamonn Delahunt [a,b]

[a] School of Public Health, Physiotherapy and Population Science, University College Dublin, Dublin, Ireland
[b] Institute for Sport and Health, University College Dublin, Dublin, Ireland
[c] Sport and Exercise Sciences Research Institute, Ulster Sports Academy, University of Ulster, Newtownabbey, Co. Antrim, Northern Ireland, United Kingdom
[d] Department of Kinesiology, University of Virginia, Charlottesville, VA, United States
[e] St. Vincent's University Hospital, Dublin, Ireland

A R T I C L E   I N F O

Article history:
Received 20 February 2014
Accepted 24 April 2014

Keywords:
Ankle joint [MEsH]
Biomechanics [MEsH]
Kinematics [MEsH]
Kinetics [MEsH]
Postural balance [MEsH]

A B S T R A C T

Background: Single-limb stance is maintained via the integration of visual, vestibular and somatosensory afferents. Musculoskeletal injury challenges the somatosensory system to reweight distorted sensory afferents. This investigation supplements kinetic analysis of eyes-open and eyes-closed single-limb stance tasks with a kinematic profile of lower limb postural orientation in an acute lateral ankle sprain group to assess the adaptive capacity of the sensorimotor system to injury.

Methods: Sixty-six participants with first-time acute lateral ankle sprain completed a 20 second eyes-open single-limb stance task on their injured and non-injured limbs (task 1). Twenty-three of these participants successfully completed the same 20 second single-limb stance task with their eyes closed (task 2). A non-injured control group of 19 participants completed task 1, with 16 completing task 2. 3-dimensional kinematics of the hip, knee and ankle joints, as well as associated fractal dimension of the center-of-pressure path were determined for each limb during these tasks.

Findings: Between trial analyses revealed significant differences in stance limb kinematics and fractal dimension of the center-of-pressure path for task 2 only. The control group bilaterally assumed a position of greater hip flexion compared to injured participants on their side-matched "involved"(7.41 [6.1°] vs 1.44 [4.8]°; $\eta^2 = .34$) and "uninvolved" (9.59 [8.5°] vs 2.16 [5.6°]; $\eta^2 = .31$) limbs, with a greater fractal dimension of the center-of-pressure path (involved limb = 1.39 [0.16°] vs 1.25 [0.14°]; uninvolved limb = 1.37 [0.21°] vs 1.23 [0.14°]).

Interpretation: Bilateral impairment in postural control strategies present following a first time acute lateral ankle sprain.

1. Introduction

Balance is a generic term describing the dynamics of body posture to prevent falling (Winter, 1995). Information about body posture in single-limb stance (SLS) with respect to the force of gravity is provided to the central nervous system by vestibular, visual and somatosensory afferents (McCollum et al., 1996). Redundancies between structurally different sensory afferents [otherwise known as 'degeneracies' (Glazier and Davids 2009)] can combine in a variety of ways to produce similar efferent motor responses; this allows the sensorimotor system to simplify a task within a limited number of movement strategies (Nashner, 1979). Selective reweighting of these degeneracies by the central nervous system is then based on the availability of reliable information (McKeon et al., 2012). As a result, it is possible for the functioning somatosensory system to produce a motor output contingent with maintaining balance in the presence of altered visual, vestibular and/or somatosensory signals (McCollum et al., 1996). Despite this, some deterioration in the efferent response may become evident in simple postural control tasks when sensorimotor afferents are compromised (Winter, 1995).

Kinematic (Huurnink et al., 2014; Liu et al., 2012) and center of pressure (COP) (Prieto et al., 1996) analyses have been previously used to quantify the motor response associated with distorted sensory environments during single limb stance in a variety of populations. The underlying premise of these investigations is that in instances of sensorimotor compromise, the motor apparatus is organized in such a way as to adopt suitable compensatory postural orientation strategies (Pintsaar et al., 1996) which are reflected in the COP path trajectory features. A number of measures are currently available with which to characterize the COP path trajectory. However, traditional measures such as

---

* Corresponding author at: A101, School of Public Health, Physiotherapy and Population Science, University College Dublin, Health Sciences Centre, Belfield, Dublin 4, Ireland.
E-mail address: cailbhe.doherty@ucdconnect.ie (C. Doherty).

http://dx.doi.org/10.1016/j.clinbiomech.2014.04.012
0268-0033/© 2014 Elsevier Ltd. All rights reserved.

Clinical Biomechanics 30 (2015) 129–135

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Inter-joint coordination strategies during unilateral stance 6-months following first-time lateral ankle sprain

Cailbhe Doherty [a,*], Chris Bleakley [c], Jay Hertel [d], Brian Caulfield [a], John Ryan [e], Kevin Sweeney [a], Eamonn Delahunt [a,b]

[a] School of Public Health, Physiotherapy and Population Science University College Dublin, Dublin, Ireland
[b] Institute for Sport and Health, University College Dublin, Dublin, Ireland
[c] Sport and Exercise Sciences Research Institute, Ulster Sports Academy, University of Ulster, Newtownabbey, Co. Antrim, United Kingdom
[d] Department of Kinesiology, University of Virginia, Charlottesville, VA, United States
[e] St. Vincent's University Hospital, Dublin, Ireland

ARTICLE INFO

Article history:
Received 8 June 2014
Accepted 18 December 2014

Keywords:
Ankle joint [MeSH]
Biomechanical phenomena [MeSH]
Kinematics [MeSH]
Kinetics [MeSH]
Postural balance [MeSH]

ABSTRACT

Background: Longitudinal analyses of participants with a history of lateral ankle sprain are lacking. This investigation combined measures of inter-joint coordination and stabilometry to evaluate eyes-open (condition 1) and eyes-closed (condition 2) static unilateral stance performance in a group of participants, 6-months after they sustained an acute, first-time lateral ankle sprain in comparison to a control group.

Methods: Sixty-nine participants with a 6-month history of first-time lateral ankle sprain and 20 non-injured controls completed three 20-second unilateral stance task trials in conditions 1 and 2. An adjusted coefficient of multiple determination statistic was used to compare stance limb 3-dimensional kinematic data for similarity in the aim of establishing patterns of lower-limb inter-joint coordination. The fractal dimension of the stance limb centre of pressure path was also calculated.

Findings: Between-group analyses revealed significant differences in stance limb inter-joint coordination strategies for conditions 1 and 2, and in the fractal dimension of the centre-of-pressure path for condition 2 only. Injured participants displayed increases in ankle–hip linked coordination compared to controls in condition 1 (sagittal/frontal plane: 0.15 [0.14] vs 0.06 [0.04]; $\eta^2 = .19$; sagittal/transverse plane: 0.14 [0.11] vs 0.09 [0.05]; $\eta^2 = 0.14$) and condition 2 (sagittal/frontal plane: 0.15 [0.12] vs 0.08 [0.06]; $\eta^2 = 0.23$), with an associated decrease in the fractal dimension of the centre-of-pressure path (injured limb: 1.23 [0.13] vs 1.36 [0.13]; $\eta^2 = 0.20$).

Interpretation: Participants with a 6-month history of first-time lateral ankle sprain exhibit a hip-dominant coordination strategy for static unilateral stance compared to non-injured controls.

1. Introduction

The high prevalence of lateral ankle sprain (LAS) in a wide variety of activity types (Doherty et al., 2014a) has motivated a large body of research designed to evaluate the movement patterns which develop as a consequence of this acute injury. These movement patterns are typically assessed by means of laboratory analyses of prescribed tasks such as static unilateral stance, whereby kinematic and stabilometric measures are utilised to quantify postural control (Doherty et al., 2014b,c; Evans et al., 2004; Hertel et al., 2001).

Postural control during unilateral stance emerges from a dynamic interaction between feedback mechanisms and a central motor programme (McCollum et al., 1996). Feedback mechanisms originate as sensory afferents which include visual, vestibular and somatosensory components (McCollum et al., 1996). A decay in somatosensory afferents, as may occur with acute LAS injury (Freeman, 1965), combined with loss of visual input, has previously been shown to challenge the ability of the central nervous system to reweight available information with an appropriated postural control response (Evans et al., 2004; McKeon et al., 2012). With respect to acute LAS, it has been reported that this manifests as a deterioration of eyes-closed unilateral standing balance capability, with less effective utilisation of the supporting base and an altered kinematical orientation, on both the injured and non-injured limbs (Doherty et al., 2014c).

The high potential for patients with a history of LAS to suffer recurrence (Anandacoomarasamy and Barnsley, 2005; Konradsen et al., 2002) has prompted researchers to theorise that recovery or the onset of chronicity following this injury is dependent on the type of postural control strategies adopted in the year following the acute injury (Wikstrom et al., 2010, 2012); patients who subjectively report the continuum of residual symptoms collectively labelled 'chronic ankle instability' (CAI) (Delahunt et al., 2010), or those 'copers' who recover with no

---

[*] Corresponding author at: A101, School of Public Health, Physiotherapy and Population Science, University College Dublin, Health Sciences Centre, Belfield, Dublin 4, Ireland.
E-mail address: cailbhe.doherty@ucdconnect.ie (C. Doherty).

http://dx.doi.org/10.1016/j.clinbiomech.2014.12.011
0268-0033/© 2014 Elsevier Ltd. All rights reserved.

Lower Limb Interjoint Postural Coordination One Year after First-Time Lateral Ankle Sprain

CAILBHE DOHERTY[1], CHRIS BLEAKLEY[2], JAY HERTEL[3], BRIAN CAULFIELD[1], JOHN RYAN[4], KEVIN SWEENEY[5], MATTHEW R. PATTERSON[5], and EAMONN DELAHUNT[1,6]

[1]School of Public Health, Physiotherapy and Population Science, University College Dublin, Dublin, IRELAND; [2]Sport and Exercise Sciences Research Institute, Ulster Sports Academy, University of Ulster, Newtownabbey, County Antrim, UNITED KINGDOM; [3]Department of Kinesiology, University of Virginia, Charlottesville, VA; [4]Emergency Department, St. Vincent's University Hospital, Dublin, IRELAND; [5]Insight Centre for Data Analytics, University College Dublin, Dublin, IRELAND; and [6]Institute for Sport and Health, University College Dublin, Dublin, IRELAND

ABSTRACT

DOHERTY, C., C. BLEAKLEY, J. HERTEL, B. CAULFIELD, J. RYAN, K. SWEENEY, M. R. PATTERSON, and E. DELAHUNT. Lower Limb Interjoint Postural Coordination One Year after First-Time Lateral Ankle Sprain. *Med. Sci. Sports Exerc.*, Vol. 47, No. 11, pp. 2398–2405, 2015. **Introduction**: Longitudinal analyses of participants with a history of lateral ankle sprain are lacking. This investigation combined measures of lower limb interjoint coordination and stabilometry to evaluate static unipedal stance with the eyes open (condition 1) and closed (condition 2) in a group of participants with chronic ankle instability (CAI) compared to lateral ankle sprain "copers" (both recruited 12 months after sustaining an acute first-time lateral ankle sprain) and a group of noninjured controls. **Methods**: Twenty-eight participants with CAI, 42 lateral ankle sprain "copers," and 20 noninjured controls completed three 20-s single-limb stance trials in conditions 1 and 2. An adjusted coefficient of multiple determination statistic was used to compare stance limb three-dimensional kinematic data for similarity to establish patterns of interjoint coordination. The fractal dimension of the stance limb center of pressure path was also calculated. **Results**: Between-group analyses revealed that participants with CAI displayed notable increases in ankle–hip linked coordination compared with both lateral ankle sprain "copers" (−0.52 (1.05) vs 0.28 (0.9), $P = 0.007$) and controls (−0.52 (1.05) vs 0.63 (0.64), $P = 0.006$) in condition 1 and compared with controls only (0.62 (1.92) vs 0.1 (1.0) $P = 0.002$) in condition 2. Participants with CAI also exhibited a decrease in the fractal dimension of the center-of-pressure path during condition 2 compared with both controls and lateral ankle sprain "copers." **Conclusions**: Participants with CAI present with a hip-dominant strategy of eyes-open and eyes-closed static unipedal stance. This coincided with reduced complexity of the stance limb center of pressure path in the eyes-closed condition.

Key Words: ANKLE JOINT, BIOMECHANICAL PHENOMENA, KINEMATICS, KINETICS, POSTURAL BALANCE, JOINT INSTABILITY

Lateral ankle sprain (LAS) injury pervades a variety of activities, with between 0.88 (95% confidence interval (CI), 0.73–1.02) and seven (95% CI, 6.82–7.18) injury events occurring per 1000 exposures depending on the activity type (11). The prevalence of this injury in a wide range of sports and activities is further complicated by its capacity to deteriorate into an array of chronic sequelae and injury recurrence, collectively termed *chronic ankle instability* (CAI) (7,15–17), which has been linked to limitations in future physical activity participation (1).

Although CAI is considered a multifaceted condition with a range of consequences, persistent deficits in single-limb stance (SLS) postural control strategies are well established in individuals with CAI (18,26,36) and may be consequent upon a change in neural signaling after the initial ankle joint trauma (14). This theory has since been tested in previous studies comparing individuals with history of LAS with noninjured controls (13), with a new hypothesis emerging whereby the long-term outcome after LAS is dependent on the success or failure of the newly adopted post-LAS postural control strategies (34,35). This has yet to be confirmed however, as there is currently an absence of longitudinal investigations, which prospectively track the restoration or degradation of postural control strategies after an initial LAS.

More recently, LAS "copers," who have history of LAS and have experienced a restoration of preinjury levels of function in the year after initial injury (15–17,34), have been compared with individuals with CAI during SLS (36); this is considered to provide a stronger, more relevant comparison in laying the foundation for longitudinal analyses and the development of clinical outcome models for the CAI paradigm

---

Address for correspondence: Cailbhe Doherty, B.Sc., A101 School of Public Health, Physiotherapy and Population Science, University College Dublin, Health Sciences Centre, Belfield Dublin 4, Ireland; E-mail: cailbhe.doherty@ucdconnect.ie.

Submitted for publication November 2014.
Accepted for publication March 2015.

0195-9131/15/4711-2398/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000000673

A deterioration in ankle joint function following LAS impairs the sensorimotor system's ability to maintain unilateral stance balance using ankle-dominant strategies of postural control.

The primary implication of the current findings for clinicians is that postural control strategies continue to be altered 6-months following acute ankle sprain injury, with the hip seemingly playing a significant compensatory role for the injured ankle.

Re-weighted dominance on hip joint strategies may have a local ‘detraining’ effect at the ankle. If the ankle is then unable to fulfil its primary role in completing the local movement subtleties required for normal unperturbed standing balance (Nashner and McCollum, 1985), this may contribute to instability.

Clinicians must devise rehabilitation protocols with these issues in mind, and must consider the importance of administering these protocols in the months following the injury if self-reported functional deficits persist.

Participants with chronic ankle instability present with a hip-dominant strategy of eyes-open and eyes-closed static unipedal stance.

This coincided with reduced complexity of the stance-limb centre of pressure path in the eyes-closed condition.

Clinical Pearl #1:

'Unfreeze' the foot and ankle to help restore "ankle strategy"

Clinical Biomechanics 29 (2014) 643–649

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Postural control strategies during single limb stance following acute lateral ankle sprain

Cailbhe Doherty [a,*], Chris Bleakley [c], Jay Hertel [d], Brian Caulfield [a], John Ryan [e], Eamonn Delahunt [a,b]

[a] School of Public Health, Physiotherapy and Population Science, University College Dublin, Dublin, Ireland
[b] Institute for Sport and Health, University College Dublin, Dublin, Ireland
[c] Sport and Exercise Sciences Research Institute, Ulster Sports Academy, University of Ulster, Newtownabbey, Co. Antrim, Northern Ireland, United Kingdom
[d] Department of Kinesiology, University of Virginia, Charlottesville, VA, United States
[e] St. Vincent's University Hospital, Dublin, Ireland

ARTICLE INFO

Article history:
Received 20 February 2014
Accepted 24 April 2014

Keywords:
Ankle joint [MEsH]
Biomechanics [MEsH]
Kinematics [MEsH]
Kinetics [MEsH]
Postural balance [MEsH]

ABSTRACT

Background: Single-limb stance is maintained via the integration of visual, vestibular and somatosensory afferents. Musculoskeletal injury challenges the somatosensory system to reweight distorted sensory afferents. This investigation supplements kinetic analysis of eyes-open and eyes-closed single-limb stance tasks with a kinematic profile of lower limb postural orientation in an acute lateral ankle sprain group to assess the adaptive capacity of the sensorimotor system to injury.
Methods: Sixty-six participants with first-time acute lateral ankle sprain completed a 20 second eyes-open single-limb stance task on their injured and non-injured limbs (task 1). Twenty-three of these participants successfully completed the same 20 second single-limb stance task with their eyes closed (task 2). A non-injured control group of 19 participants completed task 1, with 16 completing task 2. 3-dimensional kinematics of the hip, knee and ankle joints, as well as associated fractal dimension of the center-of-pressure path were determined for each limb during these tasks.
Findings: Between trial analyses revealed significant differences in stance limb kinematics and fractal dimension of the center-of-pressure path for task 2 only. The control group bilaterally assumed a position of greater hip flexion compared to injured participants on their side-matched "involved"(7.41 [6.1°] vs 1.44 [4.8]°; $\eta^2 = .34$) and "uninvolved" (9.59 [8.5°] vs 2.16 [5.6°]; $\eta^2 = .31$) limbs, with a greater fractal dimension of the center-of-pressure path (involved limb = 1.39 [0.16°] vs 1.25 [0.14°]; uninvolved limb = 1.37 [0.21°] vs 1.23 [0.14°]).
Interpretation: Bilateral impairment in postural control strategies present following a first time acute lateral ankle sprain.

1. Introduction

Balance is a generic term describing the dynamics of body posture to prevent falling (Winter, 1995). Information about body posture in single-limb stance (SLS) with respect to the force of gravity is provided to the central nervous system by vestibular, visual and somatosensory afferents (McCollum et al., 1996). Redundancies between structurally different sensory afferents [otherwise known as 'degeneracies' (Glazier and Davids 2009)] can combine in a variety of ways to produce similar efferent motor responses; this allows the sensorimotor system to simplify a task within a limited number of movement strategies (Nashner, 1979). Selective reweighting of these degeneracies by the central nervous system is then based on the availability of reliable information (McKeon et al., 2012). As a result, it is possible for the functioning somatosensory system to produce a motor output contingent with maintaining balance in the presence of altered visual, vestibular and/or somatosensory signals (McCollum et al., 1996). Despite this, some deterioration in the efferent response may become evident in simple postural control tasks when sensorimotor afferents are compromised (Winter, 1995).

Kinematic (Huurnink et al., 2014; Liu et al., 2012) and center of pressure (COP) (Prieto et al., 1996) analyses have been previously used to quantify the motor response associated with distorted sensory environments during single limb stance in a variety of populations. The underlying premise of these investigations is that in instances of sensorimotor compromise, the motor apparatus is organized in such a way as to adopt suitable compensatory postural orientation strategies (Pintsaar et al., 1996) which are reflected in the COP path trajectory features. A number of measures are currently available with which to characterize the COP path trajectory. However, traditional measures such as

---

[*] Corresponding author at: A101, School of Public Health, Physiotherapy and Population Science, University College Dublin, Health Sciences Centre, Belfield, Dublin 4, Ireland.
E-mail address: cailbhe.doherty@ucdconnect.ie (C. Doherty).

http://dx.doi.org/10.1016/j.clinbiomech.2014.04.012
0268-0033/

Clinical Pearl #2:

Ensure adequate hip strength

Lower Limb Interjoint Postural Coordination One Year after First-Time Lateral Ankle Sprain

CAILBHE DOHERTY[1], CHRIS BLEAKLEY[2], JAY HERTEL[3], BRIAN CAULFIELD[1], JOHN RYAN[4], KEVIN SWEENEY[5], MATTHEW R. PATTERSON[5], and EAMONN DELAHUNT[1,6]

[1]*School of Public Health, Physiotherapy and Population Science, University College Dublin, Dublin, IRELAND;* [2]*Sport and Exercise Sciences Research Institute, Ulster Sports Academy, University of Ulster, Newtownabbey, County Antrim, UNITED KINGDOM;* [3]*Department of Kinesiology, University of Virginia, Charlottesville, VA;* [4]*Emergency Department, St. Vincent's University Hospital, Dublin, IRELAND;* [5]*Insight Centre for Data Analytics, University College Dublin, Dublin, IRELAND; and* [6]*Institute for Sport and Health, University College Dublin, Dublin, IRELAND*

ABSTRACT

DOHERTY, C., C. BLEAKLEY, J. HERTEL, B. CAULFIELD, J. RYAN, K. SWEENEY, M. R. PATTERSON, and E. DELAHUNT. Lower Limb Interjoint Postural Coordination One Year after First-Time Lateral Ankle Sprain. *Med. Sci. Sports Exerc.*, Vol. 47, No. 11, pp. 2398–2405, 2015. **Introduction**: Longitudinal analyses of participants with a history of lateral ankle sprain are lacking. This investigation combined measures of lower limb interjoint coordination and stabilometry to evaluate static unipedal stance with the eyes open (condition 1) and closed (condition 2) in a group of participants with chronic ankle instability (CAI) compared to lateral ankle sprain "copers" (both recruited 12 months after sustaining an acute first-time lateral ankle sprain) and a group of noninjured controls. **Methods**: Twenty-eight participants with CAI, 42 lateral ankle sprain "copers," and 20 noninjured controls completed three 20-s single-limb stance trials in conditions 1 and 2. An adjusted coefficient of multiple determination statistic was used to compare stance limb three-dimensional kinematic data for similarity to establish patterns of interjoint coordination. The fractal dimension of the stance limb center of pressure path was also calculated. **Results**: Between-group analyses revealed that participants with CAI displayed notable increases in ankle–hip linked coordination compared with both lateral ankle sprain "copers" (−0.52 (1.05) vs 0.28 (0.9), $P = 0.007$) and controls (−0.52 (1.05) vs 0.63 (0.64), $P = 0.006$) in condition 1 and compared with controls only (0.62 (1.92) vs 0.1 (1.0) $P = 0.002$) in condition 2. Participants with CAI also exhibited a decrease in the fractal dimension of the center-of-pressure path during condition 2 compared with both controls and lateral ankle sprain "copers." **Conclusions**: Participants with CAI present with a hip-dominant strategy of eyes-open and eyes-closed static unipedal stance. This coincided with reduced complexity of the stance limb center of pressure path in the eyes-closed condition. **Key Words:** ANKLE JOINT, BIOMECHANICAL PHENOMENA, KINEMATICS, KINETICS, POSTURAL BALANCE, JOINT INSTABILITY

Lateral ankle sprain (LAS) injury pervades a variety of activities, with between 0.88 (95% confidence interval (CI), 0.73–1.02) and seven (95% CI, 6.82–7.18) injury events occurring per 1000 exposures depending on the activity type (11). The prevalence of this injury in a wide range of sports and activities is further complicated by its capacity to deteriorate into an array of chronic sequelae and injury recurrence, collectively termed *chronic ankle instability* (CAI) (7,15–17), which has been linked to limitations in future physical activity participation (1).

Although CAI is considered a multifaceted condition with a range of consequences, persistent deficits in single-limb stance (SLS) postural control strategies are well established in individuals with CAI (18,26,36) and may be consequent upon a change in neural signaling after the initial ankle joint trauma (14). This theory has since been tested in previous studies comparing individuals with history of LAS with noninjured controls (13), with a new hypothesis emerging whereby the long-term outcome after LAS is dependent on the success or failure of the newly adopted post-LAS postural control strategies (34,35). This has yet to be confirmed however, as there is currently an absence of longitudinal investigations, which prospectively track the restoration or degradation of postural control strategies after an initial LAS.

More recently, LAS "copers," who have history of LAS and have experienced a restoration of preinjury levels of function in the year after initial injury (15–17,34), have been compared with individuals with CAI during SLS (36); this is considered to provide a stronger, more relevant comparison in laying the foundation for longitudinal analyses and the development of clinical outcome models for the CAI paradigm

---

Address for correspondence: Cailbhe Doherty, B.Sc., A101 School of Public Health, Physiotherapy and Population Science, University College Dublin, Health Sciences Centre, Belfield Dublin 4, Ireland; E-mail: cailbhe.doherty@ucdconnect.ie.

Submitted for publication November 2014.
Accepted for publication March 2015.

0195-9131/15/4711-2398/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000000673

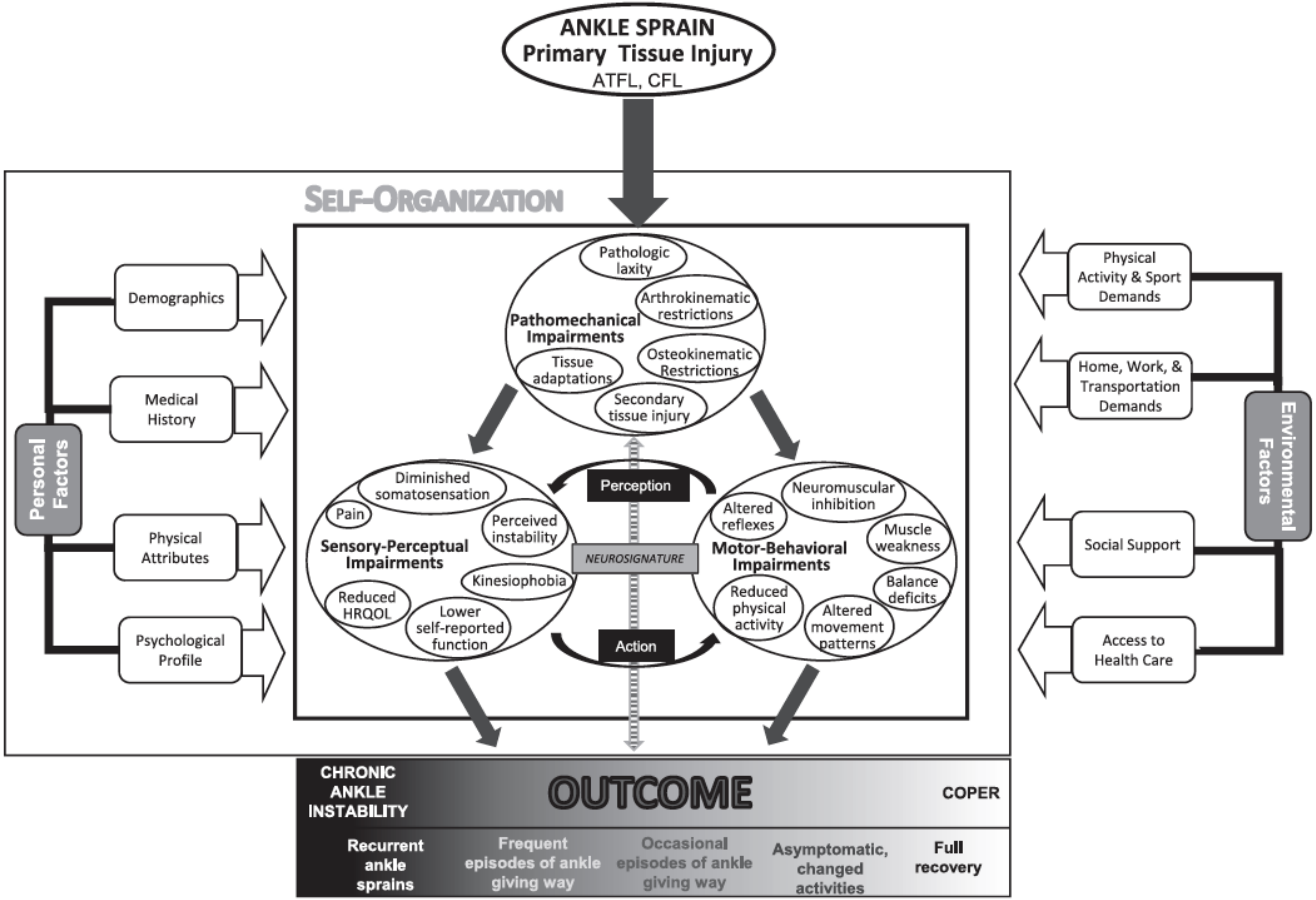


Figure 1. The updated model of chronic ankle instability (CAI). The outcome is determined at least 12 months after the initial ankle sprain. Abbreviations: ATFL, anterior talofibular ligament; CFL, calcaneofibular ligament; HRQOL, health-related quality of life.

Journal of Athletic Training 2012;47(3):339–357
doi: 10.4085/1062-6050-47.3.08
© by the National Athletic Trainers' Association, Inc
http://www.nata.org/journal-of-athletic-training

systematic review

Using the Star Excursion Balance Test to Assess Dynamic Postural-Control Deficits and Outcomes in Lower Extremity Injury: A Literature and Systematic Review

Phillip A. Gribble, PhD, ATC*; Jay Hertel, PhD, ATC, FNATA, FACSM†; Phil Plisky, DSc, PT, OCS, ATC‡

*University of Toledo, OH; †University of Virginia, Charlottesville; ‡University of Evansville, IN

Context: A dynamic postural-control task that has gained notoriety in the clinical and research settings is the Star Excursion Balance Test (SEBT). Researchers have suggested that, with appropriate instruction and practice by the individual and normalization of the reaching distances, the SEBT can be used to provide objective measures to differentiate deficits and improvements in dynamic postural-control related to lower extremity injury and induced fatigue, and it has the potential to predict lower extremity injury. However, no one has reviewed this body of literature to determine the usefulness of the SEBT in clinical applications.

Objective: To provide a narrative review of the SEBT and its implementation and the known contributions to task performance and to systematically review the associated literature to address the SEBT's usefulness as a clinical tool for the quantification of dynamic postural-control deficits from lower extremity impairment.

Data Sources: Databases used to locate peer-reviewed articles published from 1980 and 2010 included Derwent Innovations Index, BIOSIS Previews, Journal Citation Reports, and MEDLINE.

Study Selection: The criteria for article selection were (1) The study was original research. (2) The study was written in English. (3) The SEBT was used as a measurement tool.

Data Extraction: Specific data extracted from the articles included the ability of the SEBT to differentiate pathologic conditions of the lower extremity, the effects of external influences and interventions, and outcomes from exercise intervention and to predict lower extremity injury.

Data Synthesis: More than a decade of research findings has established a comprehensive portfolio of validity for the SEBT, and it should be considered a highly representative, noninstrumented dynamic balance test for physically active individuals. The SEBT has been shown to be a reliable measure and has validity as a dynamic test to predict risk of lower extremity injury, to identify dynamic balance deficits in patients with a variety of lower extremity conditions, and to be responsive to training programs in both healthy people and people with injuries to the lower extremity. Clinicians and researchers should be confident in employing the SEBT as a lower extremity functional test.

Key Words: clinical balance, functional tests, dynamic balance tests, dynamic postural-control tasks

Key Points

- The Star Excursion Balance Test should be considered a highly representative noninstrumented dynamic balance test for physically active people.
- The Star Excursion Balance Test is a reliable measure and a valid dynamic test to predict risk of lower extremity injury, to identify dynamic balance deficits in patients with lower extremity conditions, and to be responsive to training programs in healthy participants and those with lower extremity conditions.

Clinicians often use postural-control assessments to evaluate risk of injury, initial deficits resulting from injury, and level of improvement after intervention for an injury. Postural-control and balance can be grouped into static and dynamic categories.[1–6] Static postural-control tasks require the individual to establish a stable base of support and maintain this position while minimizing segment and body movement during the assessment. These assessments can be conducted with instrumented equipment, such as a force platform, or valid, reliable clinical scales, such as the Balance Error Scoring System[1–3,5,7–20] or Berg Balance Scale.[1,21] Whereas static measures of postural-control provide useful clinical information, the underlying task of standing as still as possible might not translate necessarily to movement tasks during physical activity.

Conversely, dynamic postural-control involves some level of expected movement around a base of support. This might involve tasks, such as jumping or hopping to a new location and immediately attempting to remain as motionless as possible or attempting to create purposeful segment movements (reaching) without compromising the established base of support. Although these dynamic measures of postural stability do not exactly replicate

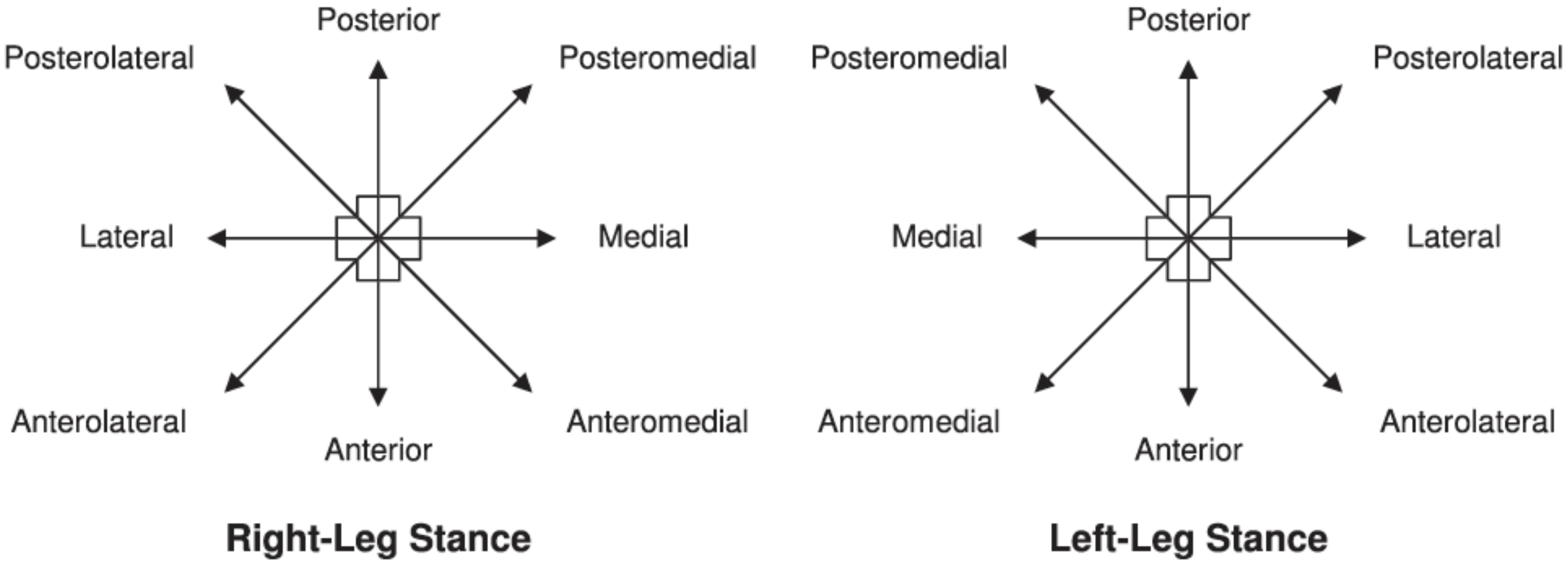


Figure 1. Reaching directions for the Star Excursion Balance Test.

Table 7. Performance Recommendations

Recommendation	Rationale
Shoes off	Individuals attend testing in a variety of footwear so it is difficult to standardize
4 Practice trials[27]	Learning effect
Video instruction	Likely to increase efficiency of testing protocol and standardizes instruction. This might be most important when multiple assessors are performing mass screenings.
Control testing order[a]	Improves consistency in administration of test
Keep starting position of the stance foot in a uniform and reproducible position to which the reach foot can be referenced. Different methods are used for aligning the stance foot. A recent method is to have the stance foot aligned at the most distal aspect of the toes for forward directions (anterior, anteromedial, and anterolateral) and the most posterior aspect of the heel for the backward directions (posterior, posteromedial, and posterolateral).	In the original test, the foot is centered in the grid. In recent usage, the toes or heel are aligned at the end of one of the grid lines. This might help to minimize differences in foot length, potentially influencing reach distances. The most important thing is that the same foot position is used for all assessments when comparing sides, before and after intervention, or when testing multiple patients.
Minimal stance foot movement is allowed[a]	Reduce error from determining if heel/forefoot is lifted slightly from the surface
Trunk movement allowed under control[a]	Difficult to standardize amount of movement allowed
Reach distances (centimeters with 1 decimal place) normalized to limb length of the stance limb[24]	Normalization standardizes measurement to each individual.
Hands placed on hips during trial[b]	Helps to standardize movements outside the trunk and lower limbs

[a] References 1–5, 7–9, 11–15, 17–19, 23–27, 29, 31, 33–37, 42, 45–47, and 51–53.

[b] References 1–3, 5, 7–9, 12–14, 23, 24, 27, 31, 33–37, 42, 46, 51, and 53.

Start position

Anterior reach direction

Posterior-medial reach direction

Posterior-lateral reach direction

Table 1. Ability of the Star Excursion Balance Test to Differentiate Pathologic Conditions: Ankle Instability[a]

Authors	Main Comparison	N	Normalized to Leg Length?	Result	*P* Value	Effect Size (95% CI)
Akbari et al,[47] 2006	Unknown direction for injured and uninjured limbs	30	No	Injured limb = 84.97 ± 10.26 cm Uninjured limb = 86.8 ± 9.34 cm	.03	0.19 (−0.32, 0.69)
Gribble et al,[2] 2004	Anterior direction for CAI-IS and CAI-US	15	Yes	CAI-IS = 78.4% ± 6.2% CAI-US = 81.8% ± 6.6%	.03	0.53 (−0.21, 1.24)
	Medial direction for CAI-IS and CAI-US	15	Yes	CAI-IS = 87.5% ± 5.8% CAI-US = 90.0% ± 7.0%	.02	0.39 (−0.34, 1.10)
	Posterior direction for CAI-IS and CAI-US	15	Yes	CAI-IS = 89.0% ± 9.3% CAI-US = 90.9% ± 9.3%	.01	0.20 (−0.52, 0.92)
Hale et al,[7] 2007[a]	Posteromedial direction for IS and US	29	Yes	IS = 80.0% ± 12.5% US = 83.5% ± 11.5%	.047	0.29 (−0.23, 0.80)
	Posterolateral direction for IS and US	29	Yes	IS = 73.5% ± 10.5% US = 77.5% ± 10.5%	.007	0.38 (−0.14, 0.90)
	Lateral direction for IS and US	29	Yes	IS = 65.5% ± 10.0% US = 70.0% ± 10.5%	.03	0.44 (−0.09, 0.95)
Hertel et al,[29] 2006	Anteromedial direction for CAI-IS and CAI-US and for CAI-IS and CMS	CAI = 48 Control = 39	Yes	CAI-IS = 80.0% ± 10.0% CAI-US = 82.0% ± 9.0% CMS = 84.0% ± 10.0%	.005	Within groups = 0.21 (−0.22, 0.63) Between groups = 0.40 (−0.03, 0.82)
	Medial direction for CAI-IS and CAI-US and for CAI-IS and CMS	CAI = 48 Control = 39	Yes	CAI-IS = 85.0% ± 10.0% CAI-US = 88.0% ± 9.0% CMS = 89.0% ± 9.0%	<.001	Within groups = 0.32 (−0.09, 0.72) Between groups = 0.42 (−0.01, 0.84)
	Posteromedial direction for CAI-IS and CAI-US and for CAI-IS and CMS	CAI = 48 Control = 39	Yes	CAI-IS = 85.0% ± 13.0% CAI-US = 89.0% ± 13.0% CMS = 90.0% ± 13.0%	.03	Within groups = 0.31 (−0.10, 0.71) Between groups = 0.38 (−0.05, 0.81)
Nakagawa and Hoffman,[37] 2004	Total for CAI and control (distance height)	CAI = 19 Control = 19	Yes	CAI = 1.71 ± 0.18[b] Control = 1.80 ± 0.15[b]	.01	0.55 (−0.12, 1.18)
Olmsted and Hertel,[4] 2004	Total for CAI-IS and CAI-US and for CAI-IS and CMS	CAI = 20 Control = 20	No	CAI-IS = 78.6 ± 10.66 cm CAI-US = 81.2 ± 10.91 cm CMS = 82.8 ± 11.54 cm	.05	Within groups = 0.24 (−0.39, 0.86) Between groups = 0.38 (−0.26, 1.00)
Sefton et al,[12] 2009	Anteromedial direction for CAI-IS and CMS	CAI = 22 Control = 21	Yes	CAI-IS = 88.67% ± 6.73% CMS = 88.90% ± 6.10%	.91	0.04 (−0.56, 0.63)
	Medial direction for CAI-IS and CAI-US	22	Yes	CAI-IS = 89.11% ± 6.78% CAI-US = 91.10% ± 7.08%	.35	0.29 (−0.32, 0.88)
	Posteromedial direction for CAI-IS and CAI-US	22	Yes	CAI-IS = 90.49% ± 7.35% CAI-US = 95.12% ± 8.24%	.14	0.59 (−0.02, 1.20)
Martinez-Ramirez et al,[11] 2010	Anterior direction for CAI and control	CAI = 13 Control = 12	Yes	CAI = 70.6% ± 6.55% Control = 66.4% ± 4.45%	>.05 (not specified)	0.74 (−0.09,1.53)
	Posteromedial direction for CAI and control	CAI = 13 Control = 12	Yes	CAI = 89.05% ± 7.45% Control = 88.05% ± 7.05%	>.05 (not specified)	0.13 (−0.66, 0.91)
	Posterolateral direction for CAI and control	CAI = 13 Control = 12	Yes	CAI = 82.8% ± 9.3% Control = 79.85% ± 8.95%	>.05 (not specified)	0.32 (−0.48,1.10)

Abbreviations: CAI, chronic ankle instability; CAI-IS, chronic ankle instability of the injured side; CAI-US, chronic ankle instability of the uninjured side; CMS, control matched side; IS, injured side; US, uninjured side.

[a] Level of evidence for all entries is 3b, except for that of Hale et al,[7] 2007, which is 2b. Phillips B, Ball C, Sackett D, et al. *The Oxford Centre for Evidence-Based Medicine: Levels of Evidence (March 2009)* [updated by Howick J in March 2009]. Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=1025. Accessed November 29, 2011.

[b] Nakagawa and Hoffman[37] did not provide units of measure.

Physical Therapy in Sport 11 (2010) 128–132

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original research

Between-session reliability of the star excursion balance test

Allan G. Munro*, Lee C. Herrington

School of Health, Sport and Rehabilitation Sciences, University of Salford, Salford M6 6PU, United Kingdom

ARTICLE INFO

Article history:
Received 28 April 2010
Received in revised form
5 July 2010
Accepted 7 July 2010

Keywords:
ACL
CAI
Injury rehabilitation
Outcome measures

ABSTRACT

Objective: To assess the learning effect, test–retest reliability and measurement error associated with the SEBT.
Design: Repeated-measures study.
Setting: Controlled university laboratory environment.
Participants: Twenty-two healthy recreational athletes (11 male age 22.3 ± 3.7 years, 11 female age 22.8 ± 3.1 years).
Main Outcome Measures: Repeated-measures ANOVA assessed learning affects. Intraclass correlations coefficients, standard error of measurement and smallest detectable difference values were calculated to assess reliability and measurement error.
Results: Results showed that excursion distances stabilised after four trials, therefore trials five to seven were analysed for reliability. Test–retest reliability for all reach directions was high, with intraclass correlation coefficients ranging from 0.84 to 0.92. 95% confidence intervals, standard error of measurement and smallest detectable difference ranged from 77.84 to 94.00, 2.21–2.94% and 6.13–8.15%, respectively.
Conclusion: These statistics will allow clinicians to evaluate whether changes in SEBT scores are due to change in an individual's performance or random error. The findings of this study show that the SEBT is a reliable measure of lower limb function in healthy recreational athletes. Changes in normalised scores of at least 6–8% are needed to feel confident that a real change in SEBT performance has occurred.

1. Introduction

Dynamic postural control is described as the ability to maintain a stable base of support whilst completing a prescribed movement (Winter, Patla, & Frank, 1990) and underpins the performance of movement skills in the athletic population. The Star Excursion Balance Test (SEBT) has been reported to assess dynamic balance and challenge athletes sufficiently (Hertel, Miller, & Denegar, 2000; Kinzey & Armstrong, 1998). The SEBT has been widely used in research and clinical practice to examine numerous topics, such as chronic ankle instability (CAI) (Gribble, Hertel, Denegar, & Buckley, 2004; Hertel, Braham, Hale, & Olmsted-Kramer, 2006; Olmsted, Carcia, Hertel, & Shultz, 2002), anterior cruciate ligament (ACL) injury (Herrington, Hatcher, Hatcher, & McNicholas, 2009), injury prediction (Plisky, Rauh, Kaminski, & Underwood, 2006) and the effect of patellar taping (Aminaka & Gribble, 2008). The SEBT offers a simple, low-cost alternative to more sophisticated laboratory assessments for use in clinical settings.

The SEBT involves participants carrying out a number of reaching tasks with one limb whilst maintaining balance on the other (Hertel et al., 2000). The SEBT is a closed-kinetic chain exercise which mimics the single-leg squat exercise and therefore the stance leg requires strength, proprioception, neuromuscular control and adequate range of motion at the hip, knee and ankle joints (Olmsted et al., 2002).

One problem which has been associated with the SEBT is the time-consuming protocol. This protocol involves participants performing 6 practice trials in each direction before undertaking a further 3 measured trials and is based on the results of Hertel et al. (Hertel et al., 2000). Hertel and colleagues suggested this number of practice trials were necessary as they found significant learning effects occurred across trials 1 to 6 during testing, with scores stabilising and longest excursion distance occurring from trials 7 onwards. This was further reflected in higher reliability scores for trials 7 to 12 compared to trials 1 through 6. However, the authors administered the 12 trials in 4 blocks on 2 separate days, which may have affected performance between trials. Participants were also allowed to use their arms freely, which does not reflect the

---

* Corresponding author. Directorate of Sport, Exercise and Physiotherapy, Allerton Building, Frederick Road Campus, University of Salford, Lancashire M6 6PU, United Kingdom. Tel.: +44 161 2956611.
E-mail address: A.G.Munro@pgr.salford.ac.uk (A.G. Munro).

1466-853X/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ptsp.2010.07.002

Table 2
Mean, 95% confidence intervals, standard error of measurement, smallest detectable difference and intraclass correlation coefficient values for normalised trials 5–7 of all reach directions.

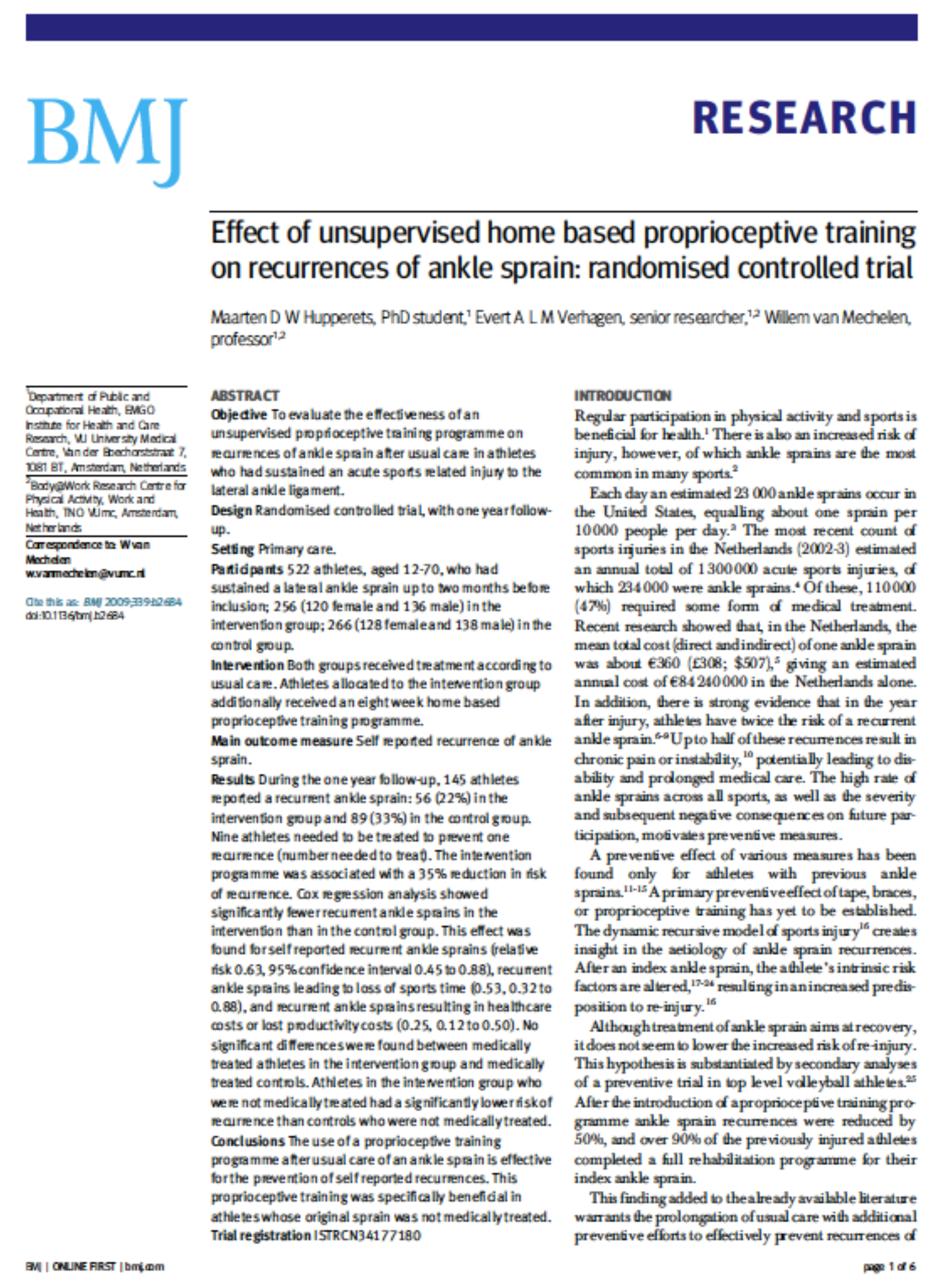
Direction	Mean	95% CI		SEM	SDD	ICC
Anterior	92.73	92.12	93.34	2.48	6.87	0.84
Anterior–medial	93.43	92.87	94.00	2.21	6.13	0.85
Anterior–lateral	78.60	77.84	79.37	2.78	7.71	0.87
Medial	92.01	91.30	92.71	2.67	7.40	0.86
Lateral	80.43	79.52	81.34	2.77	7.68	0.91
Posterior	87.33	86.36	88.31	2.79	7.73	0.92
Posterior–medial	89.25	88.47	90.02	2.94	8.15	0.86
Posterior–lateral	83.69	82.78	84.61	2.62	7.11	0.92

Note: all values except ICC are normalised excursion distance (excursion distance/leg length × 100).


UCD
DUBLIN
HIGH
RMANCE


UCD
DUBLIN
HIGH
RMANCE


UCD
DUBLIN
HIGH
RMANCE



BMJ

RESEARCH

Effect of unsupervised home based proprioceptive training on recurrences of ankle sprain: randomised controlled trial

Maarten D W Hupperets, PhD student,[1] Evert A L M Verhagen, senior researcher,[1,2] Willem van Mechelen, professor[1,2]

[1]Department of Public and Occupational Health, EMGO Institute for Health and Care Research, VU University Medical Centre, Van der Boechorststraat 7, 1081 BT, Amsterdam, Netherlands

[2]Body@Work Research Centre for Physical Activity, Work and Health, TNO VUmc, Amsterdam, Netherlands

Correspondence to: W van Mechelen
w.vanmechelen@vumc.nl

Cite this as: *BMJ* 2009;339:b2684
doi:10.1136/bmj.b2684

ABSTRACT

Objective To evaluate the effectiveness of an unsupervised proprioceptive training programme on recurrences of ankle sprain after usual care in athletes who had sustained an acute sports related injury to the lateral ankle ligament.

Design Randomised controlled trial, with one year follow-up.

Setting Primary care.

Participants 522 athletes, aged 12-70, who had sustained a lateral ankle sprain up to two months before inclusion; 256 (120 female and 136 male) in the intervention group; 266 (128 female and 138 male) in the control group.

Intervention Both groups received treatment according to usual care. Athletes allocated to the intervention group additionally received an eight week home based proprioceptive training programme.

Main outcome measure Self reported recurrence of ankle sprain.

Results During the one year follow-up, 145 athletes reported a recurrent ankle sprain: 56 (22%) in the intervention group and 89 (33%) in the control group. Nine athletes needed to be treated to prevent one recurrence (number needed to treat). The intervention programme was associated with a 35% reduction in risk of recurrence. Cox regression analysis showed significantly fewer recurrent ankle sprains in the intervention than in the control group. This effect was found for self reported recurrent ankle sprains (relative risk 0.63, 95% confidence interval 0.45 to 0.88), recurrent ankle sprains leading to loss of sports time (0.53, 0.32 to 0.88), and recurrent ankle sprains resulting in healthcare costs or lost productivity costs (0.25, 0.12 to 0.50). No significant differences were found between medically treated athletes in the intervention group and medically treated controls. Athletes in the intervention group who were not medically treated had a significantly lower risk of recurrence than controls who were not medically treated.

Conclusions The use of a proprioceptive training programme after usual care of an ankle sprain is effective for the prevention of self reported recurrences. This proprioceptive training was specifically beneficial in athletes whose original sprain was not medically treated.

Trial registration ISTRCN34177180

INTRODUCTION

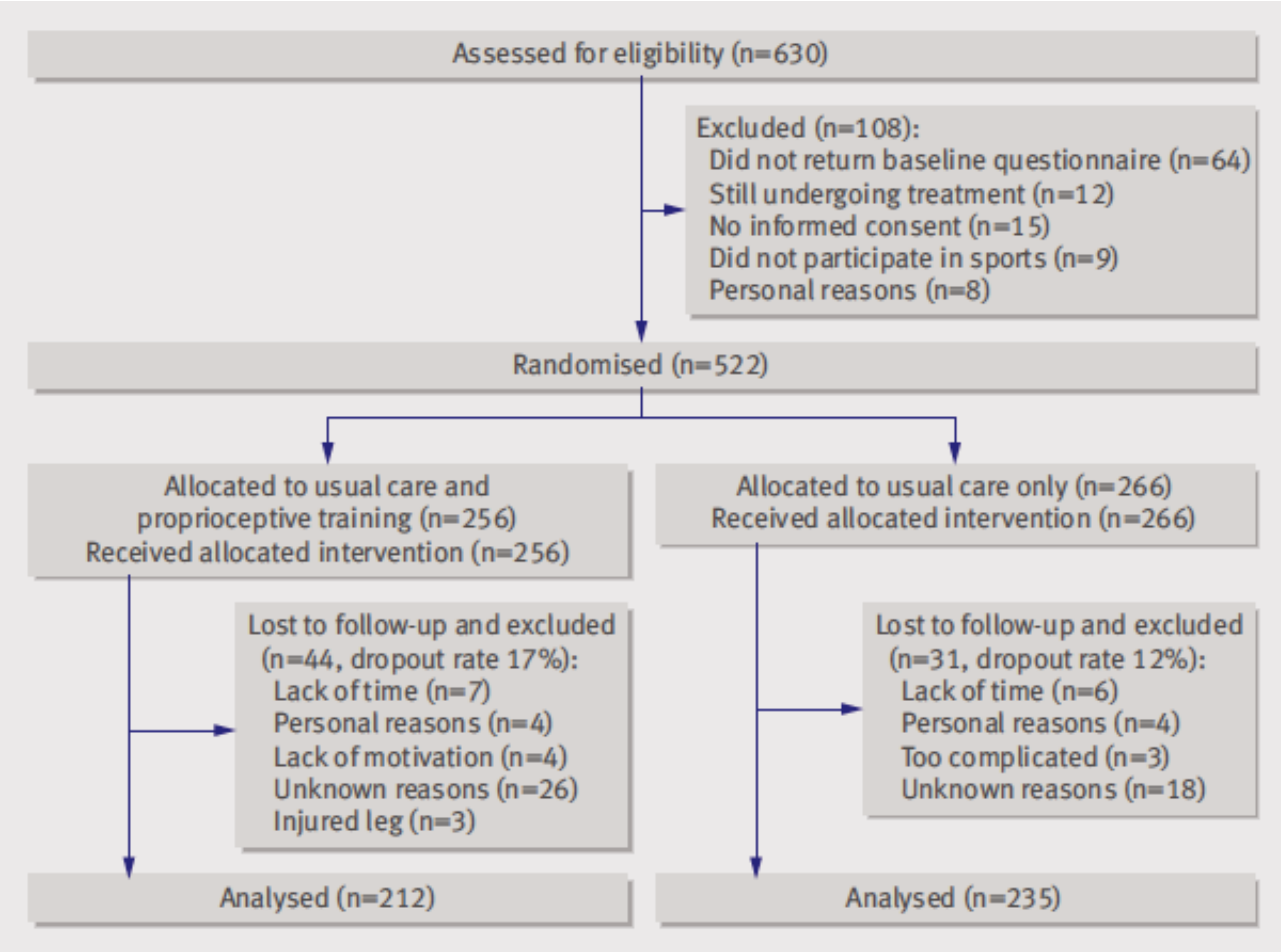
Regular participation in physical activity and sports is beneficial for health.[1] There is also an increased risk of injury, however, of which ankle sprains are the most common in many sports.[2]

Each day an estimated 23 000 ankle sprains occur in the United States, equalling about one sprain per 10 000 people per day.[3] The most recent count of sports injuries in the Netherlands (2002-3) estimated an annual total of 1 300 000 acute sports injuries, of which 234 000 were ankle sprains.[4] Of these, 110 000 (47%) required some form of medical treatment. Recent research showed that, in the Netherlands, the mean total cost (direct and indirect) of one ankle sprain was about €360 (£308; $507),[5] giving an estimated annual cost of €84 240 000 in the Netherlands alone. In addition, there is strong evidence that in the year after injury, athletes have twice the risk of a recurrent ankle sprain.[6-9] Up to half of these recurrences result in chronic pain or instability,[10] potentially leading to disability and prolonged medical care. The high rate of ankle sprains across all sports, as well as the severity and subsequent negative consequences on future participation, motivates preventive measures.

A preventive effect of various measures has been found only for athletes with previous ankle sprains.[11-15] A primary preventive effect of tape, braces, or proprioceptive training has yet to be established. The dynamic recursive model of sports injury[16] creates insight in the aetiology of ankle sprain recurrences. After an index ankle sprain, the athlete's intrinsic risk factors are altered,[17-24] resulting in an increased predisposition to re-injury.[16]

Although treatment of ankle sprain aims at recovery, it does not seem to lower the increased risk of re-injury. This hypothesis is substantiated by secondary analyses of a preventive trial in top level volleyball athletes.[25] After the introduction of a proprioceptive training programme ankle sprain recurrences were reduced by 50%, and over 90% of the previously injured athletes completed a full rehabilitation programme for their index ankle sprain.

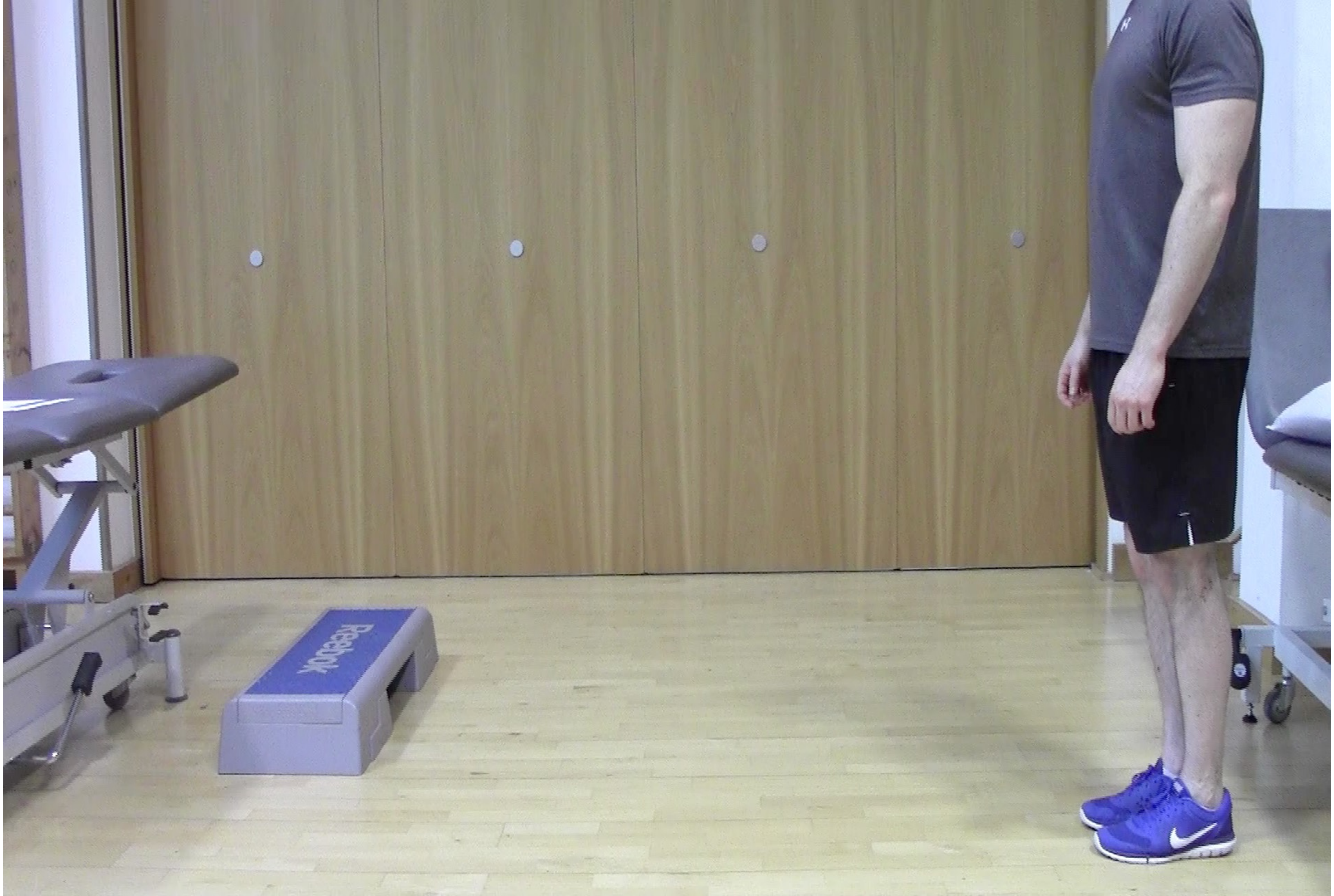
This finding added to the already available literature warrants the prolongation of usual care with additional preventive efforts to effectively prevent recurrences of


Assessed for eligibility (n=630)
Excluded (n=108):
Did not return baseline questionnaire (n=64)
Still undergoing treatment (n=12)
No informed consent (n=15)
Did not participate in sports (n=9)
Personal reasons (n=8)
Randomised (n=522)
Allocated to usual care and proprioceptive training (n=256)
Received allocated intervention (n=256)
Allocated to usual care only (n=266)
Received allocated intervention (n=266)
Lost to follow-up and excluded (n=44, dropout rate 17%):
Lack of time (n=7)
Personal reasons (n=4)
Lack of motivation (n=4)
Unknown reasons (n=26)
Injured leg (n=3)
Lost to follow-up and excluded (n=31, dropout rate 12%):
Lack of time (n=6)
Personal reasons (n=4)
Too complicated (n=3)
Unknown reasons (n=18)
Analysed (n=212)
Analysed (n=235)


Reebok


Reebok


Reebok


Reebok

	Control	**Intervention**
Participants (n)	256	266
Recurrent Injuries (n)	89	56
Group Risk	35%	21%
Relative Risk	[redacted]	[redacted]
Absolute Risk Reduction	[redacted]	[redacted]
Numbers Needed to Treat	[redacted]	[redacted]

	Control	**Intervention**
Participants (n)	212	235
Recurrent Injuries (n)	89	56
Group Risk	42%	24%
Relative Risk	[redacted]	[redacted]
Absolute Risk Reduction	[redacted]	[redacted]
Numbers Needed to Treat	[redacted]	[redacted]

Balance Training Improves Function and Postural Control in Those with Chronic Ankle Instability

PATRICK O. MCKEON[1], CHRISTOPHER D. INGERSOLL[2], D. CASEY KERRIGAN[2], ETHAN SALIBA[2],
BRADFORD C. BENNETT[2], and JAY HERTEL[2]

[1]University of Kentucky, Lexington, KY; and [2]University of Virginia, Charlottesville, VA

ABSTRACT

MCKEON, P. O., C. D. INGERSOLL, D. C. KERRIGAN, E. SALIBA, B. C. BENNETT, and J. HERTEL. Balance Training Improves Function and Postural Control in Those with Chronic Ankle Instability. *Med. Sci. Sports Exerc.*, Vol. 40, No. 10, pp. 1810–1819, 2008. **Purpose:** The purpose of this randomized controlled trial was to determine the effect of a 4-wk balance training program on static and dynamic postural control and self-reported functional outcomes in those with chronic ankle instability (CAI). **Methods:** Thirty-one young adults with self-reported CAI were randomly assigned to an intervention group (six males and 10 females) or a control group (six males and nine females). The intervention consisted of a 4-wk supervised balance training program that emphasized dynamic stabilization in single-limb stance. Main outcome measures included the following: self-reported disability on the Foot and Ankle Disability Index (FADI) and the FADI Sport scales; summary center of pressure (COP) excursion measures including area of a 95% confidence ellipse, velocity, range, and SD; time-to-boundary (TTB) measures of postural control in single-limb stance including the absolute minimum TTB, mean of TTB minima, and SD of TTB minima in the anteroposterior and mediolateral directions with eyes open and closed; and reach distance in the anterior, posteromedial, and posterolateral directions of the Star Excursion Balance Test (SEBT). **Results:** The balance training group had significant improvements in the FADI and the FADI Sport scores, in the magnitude and the variability of TTB measures with eyes closed, and in reach distances with the posteromedial and the posterolateral directions of the SEBT. Only one of the summary COP-based measures significantly changed after balance training. **Conclusions:** Four weeks of balance training significantly improved self-reported function, static postural control as detected by TTB measures, and dynamic postural control as assessed with the SEBT. TTB measures were more sensitive at detecting improvements in static postural control compared with summary COP-based measures. **Key Words:** ANKLE SPRAIN, DYNAMIC BALANCE, FUNCTIONAL OUTCOMES, REHABILITATION, TIME-TO-BOUNDARY

Ankle sprains are among the most common injuries in the physically active population (4). The most common predisposing factor to experiencing an ankle sprain is a previous history of ankle sprain (1). The subjective feeling of the ankle "giving way" after an initial ankle sprain and repetitive bouts of instability resulting in numerous ankle sprains has been termed chronic ankle instability (CAI) (16). CAI has been linked to many different contributing factors, including deficits in postural control (2,12,17,21,26,27).

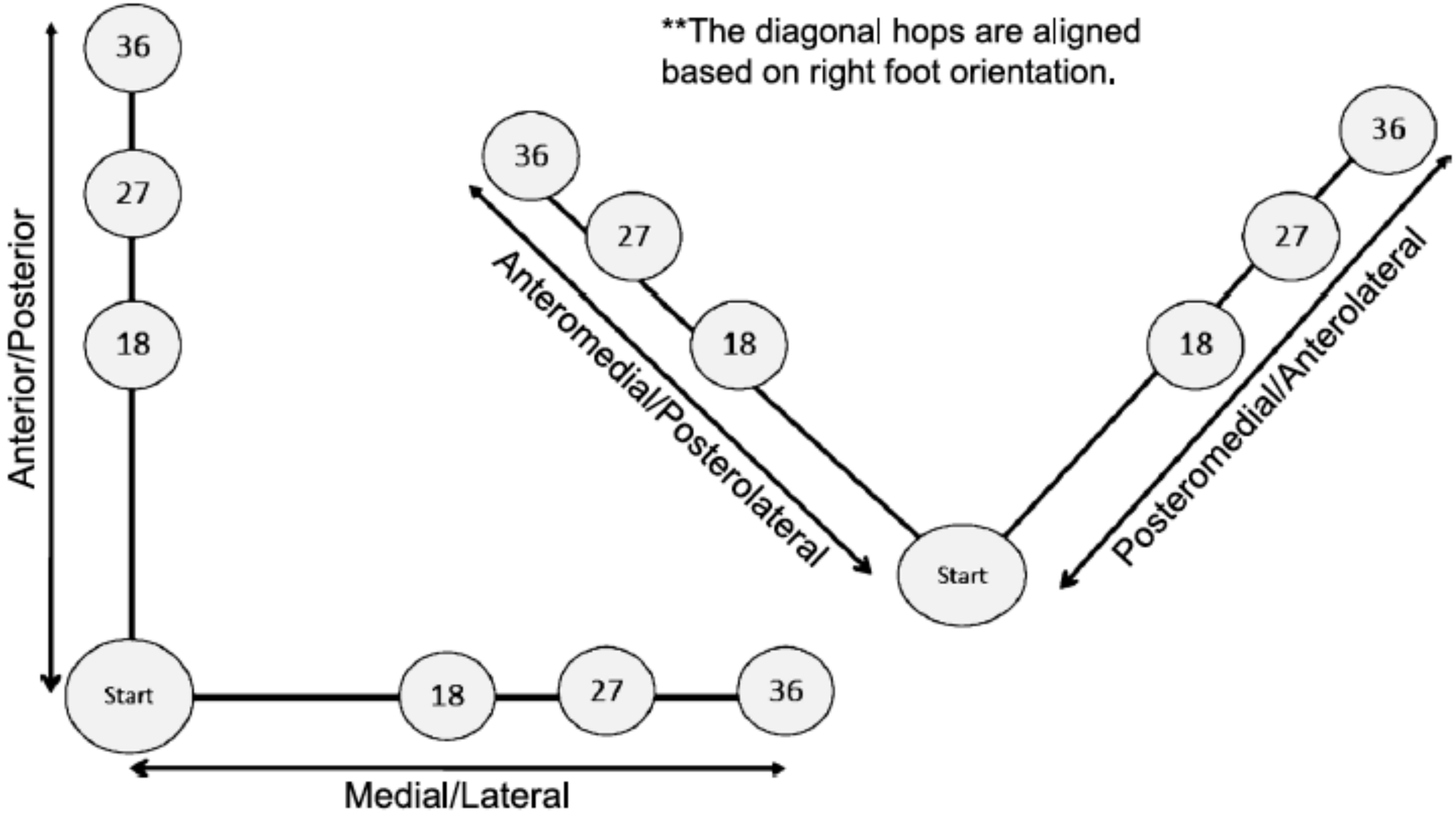
Balance training has been purported to be an effective modality in the rehabilitation and prevention of recurrent sprains in those with CAI; however, there is limited evidence of its effectiveness (3,9,26,28). For example, Eils and Rosenbaum (9) reported a 60% decrease in self-reported episodes of the ankle "giving way" into inversion in individuals with CAI 1 yr after undergoing 6 wk of balance and coordination training, but they did not report values for a control group for comparison. Traditionally, balance training has involved single-limb stance activities on stable and unstable surfaces (9,28). Although self-reported improvements in functional status have been demonstrated in response to balance training (9,26), there is conflicting evidence that postural control improvements occur as a result of balance training in individuals with CAI (3,9,26). The traditional measures used to assess the improvements in postural control may have lacked the sensitivity to detect improvements (21). Moreover, these balance training programs may have not appropriately challenged the sensorimotor system to elicit a detectable change in postural control. A balance training program that emphasizes the dynamic stabilization after perturbations such as predictable and unpredictable changes in direction, landing

---

Address for correspondence: Patrick O. McKeon, Ph.D., ATC, CSCS, Division of Athletic Training, College of Health Sciences, University of Kentucky, Wethington Building, Room 206C, 900 S Limestone, Lexington, KY 40536-0200; Email: Patrick.McKeon@uky.edu.
Submitted for publication September 2007.
Accepted for publication April 2008.

0195-9131/08/4010-1810/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0b013e31817e0f92


**The diagonal hops are aligned based on right foot orientation.
36
27
18
Start
Anterior/Posterior
18
27
36
Medial/Lateral
36
27
18
Anteromedial/Posterolateral
Start
36
27
18
Posteromedial/Anterolateral

Single-Limb Hops to Stabilization
(10 Repetitions per Direction)

Subject performed 10 hops in each direction. Each repetition consisted of a hop from the starting position to the target position (18, 27, or 36 inches). After stabilizing balance in a single-limb stance, participants hopped in the exact opposite direction back to the starting position and stabilized in the single-limb stance.

Four directions of hops: 1) anterior/posterior, 2) medial/lateral, 3) anterolateral/posteromedial, and 4) anteromedial/posterolateral.
Participants were not able to move to the next level in each category until they demonstrated 10 repetitions error-free.

Errors were determined on the basis of the following:
a. Touching down with opposite limb
b. Excessive trunk motion (>30 degree lateral flexion)
c. Removal of hands from hips during hands on hips activities
d. Bracing the non-stance limb against the stance limb
e. Missing the target


UCD
UBLIN
HIGH
FORMANC


CD
BLIN
HIG ERFORMANCE


CD
UBLIN
HIG ERFORMANC

Hop to Stabilization and Reach (Five Repetitions)

Combined with the mentioned exercises, however, after stabilization in the single-limb stance, participants had to reach back to the starting position. Repetitions were counted in the same manner mentioned previously. Participants hopped, stabilized, and reached back to the starting position. Then they hopped back to the starting position and reached to the target position.

Participants were not able to advance to the next level in each direction until they demonstrated five repetitions error-free.

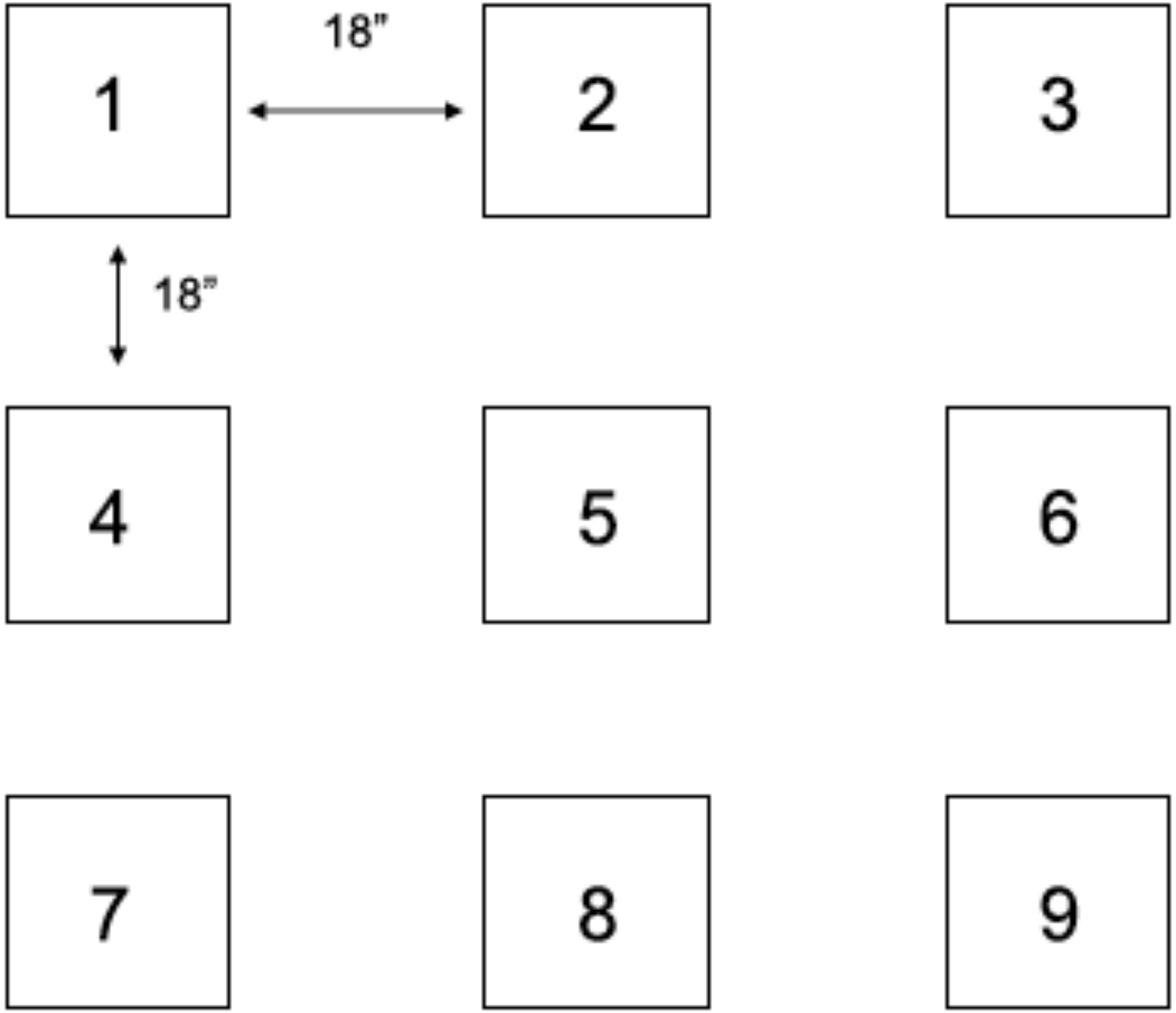
Errors were determined on the basis of the following:
a. All errors associated with hop to stabilization
b. Using the reaching leg for a substantial amount of support during reaching component


HIGH
ERFORMANC


HIGH PERFORMANC
UCD
DUBLIN

All directions for Hop to Stabilization and Hop to Stabilization and Reach had seven levels of difficulty to progress:

Level 1. 18-inch hop. Allowed to use arms to aid in stabilizing balance after landing.
Level 2. 18-inch hop with hands on hips while stabilizing balance after landing.
Level 3. 27-inch hop. Allowed to use arms to aid in stabilizing balance after landing.
Level 4. 27-inch hop with hands on hips while stabilizing balance after landing.
Level 5. 36-inch hop. Allowed to use arms to aid in stabilizing balance after landing.
Level 6. 36-inch hop with hands on hips while stabilizing balance after landing.
7. 36-inch hop from a 6-inch platform.



Un-anticipated Hop to Stabilization

UCD
DUBLIN
HIGH P RFORMANCE

Example random sequence: 9, 7, 1, 6, 4, 5, 3, 8, 2.

Level 1: 5 s per move.
Level 2: 3 s per move.
Level 3: 1 s per move.
Level 4: If subject can progress to completion of all moves within 1 s without error, a foam pad will be placed on one of the numbers during the sequence. The subject will then continue the progression at the same level of intensity. If he or she cannot complete the course error-free, the time constraint will be reduced to the level below.
Level 5: If subject can progress to completion of all moves at Level 3 with the foam pad error-free, a step will be added to an additional number.
Level 6: If a subject progresses error-free, an additional foam pad will be added to one of the numbers, resulting in two foam pads and one step.
Level 7: If a subject progresses error-free, an additional step will be included, resulting in two foam pads and two steps.

Errors were determined on the basis of the following:

a. Subjects touching down with opposite limb
b. Excessive trunk motion (>30 - lateral flexion)
c. Removal of arms from across chest during specified activities
d. Bracing the non-stance limb against the stance limb

Single-limb stance eyes open

Level 1. Arms across chest on hard floor for 60 s
Level 2. Arms across chest for 30 s on foam pad
Level 3. Arms across chest for 60 s on foam pad
Level 4. Arms across chest for 90 s on foam pad

Ball toss on foam
Level 5. 30 s with arms across chest; 20 throws with a 6-lb medicine ball
Level 6. 60 s with arms across chest; 20 throws with a 6-lb medicine ball
Level 7. 90 s with arms across chest; 20 throws with a 6-lb medicine ball

Errors were determined on the basis of the following:
a. Subjects touching down with opposite limb
b. Excessive trunk motion (930- lateral flexion)
c. Removal of arms from across chest during specified activities
d. Bracing the non-stance limb against the stance limb

Single-limb stance eyes closed

Level 1. Arms out on hard floor for 30 s
Level 2. Arms across chest on hard floor for 30 s
Level 3. Arms across chest on hard floor for 60 s
Level 4. Arms out on foam pad for 30 s
Level 5. Arms across chest for 30 s on foam pad
Level 6. Arms across chest for 60 s on foam pad
Level 7. Arms across chest for 90 s on foam pad

Errors were determined on the basis of the following:
a. Subjects touching down with opposite limb
b. Excessive trunk motion (930- lateral flexion)
c. Removal of arms from across chest during specified activities
d. Bracing the non-stance limb against the stance limb

Example of a Typical Session

1. Hop to stabilization
Anterior/posterior—Level 2, 10 repetitions
Medial/lateral—Level 1, 10 repetitions
Anterolateral/posteromedial—Level 2, 10 repetitions
Anteromedial/posterolateral—Level 2, 10 repetitions

2. Unanticipated hop to stabilization—Level 1, Sequence 1

3. Hop to stabilization and reach
Anterior/posterior—Level 2, 5 repetitions
Medial/lateral—Level 1, 5 repetitions
Anterolateral/posteromedial—Level 2, 5 repetitions
Anteromedial/posterolateral—Level 2, 5 repetitions

4. Unanticipated hop to stabilization—Level 1, Sequence 2

5. Single-limb stance eyes open—Level 4, 3 repetitions

6. Single-limb stance eyes closed—Level 2, 3 repetitions

TABLE 1. Pretest and posttest scores on the FADI and the FADI Sport for the balance training and control groups.

	Balance Training Group		Control Group			
	Pretest	Posttest	Pretest	Posttest	Group Effect	Time Effect
FADI, %	85.5 ± 8.4	93.7 ± 7.4*,†	82.9 ± 7.4	81.40 ± 18.1	0.68	0.98
FADI Sport, %	69.9 ± 12.1	85.0 ± 14.4*,†	66.5 ± 9.8	66.3 ± 11.8	1.63	1.25

There was a significant group × time interaction for both instruments. There was no difference between groups at pretest, but there was a significant difference between posttest measures between groups and a significant difference in self-reported function at posttest for the balance training group, $P < 0.05$. Group effect sizes were calculated from posttest scores. Time effect sizes were calculated from the pretest and posttest measures of the balance training group.

* $P < 0.05$ for pretest to posttest comparisons within the balance training group.

†$P < 0.05$ for between-groups comparisons at posttest.

TABLE 6. Pretest and posttest normalized reach distances on the SEBT.

	Balance Training Group		Control Group			
	Pretest	**Posttest**	**Pretest**	**Posttest**	**Group Effect**	**Time Effect**
Anterior reach	0.70 ± 0.10	0.67 ± 0.08	0.68 ± 0.06	0.67 ± 0.05	0	−0.38
PM reach	0.82 ± 0.14	0.91 ± 0.13*,†	0.81 ± 0.08	0.80 ± 0.06	1.83	0.64
PL reach	0.77 ± 0.15	0.87 ± 0.13*,†	0.76 ± 0.08	0.78 ± 0.09	1.0	0.67

There were significant group × time interactions for the PM and PL reaches. The balance training group reached significantly farther than their pretest measures and the posttest measures of the control group, $P < 0.05$. Group effect sizes were calculated from posttest scores. Time effect sizes were calculated from the pretest and posttest measures of the balance training group.

An effect size of zero was calculated when the comparison means were equal.

* $P < 0.05$ for pretest to posttest comparisons within the balance training group.

†$P < 0.05$ for between-groups comparisons at posttest.

Verschueren *et al. Archives of Physiotherapy* (2019) 9:6
https://doi.org/10.1186/s40945-019-0057-4

Archives of Physiotherapy

METHODOLOGY ARTICLE **Open Access**

Bringing context to balance: development of a reactive balance test within the injury prevention and return to sport domain

Jo Verschueren[1], Bruno Tassignon[1], Bert Pluym[1], Jeroen Van Cutsem[1], Evert Verhagen[2] and Romain Meeusen[1*]

Abstract

Background: Balance tests are commonly used in clinical practice with applicability in injury prevention and return to sport decisions. While most sports injuries occur in a changing environment where reacting to a non-planned stimulus is of great importance, these balance tests only evaluate pre-planned movements without taking these dynamics environmental aspects into account. Therefore, the goal of this paper was to develop a clinician-friendly test that respects these contextual interactions and to describe the test protocol of an adapted Y-balance test that includes environmental perception and decision-making.

Methods: Within the theoretical construct of balance and adaptability, balance errors were selected as outcome measures for balance ability and, visuomotor reaction time and accuracy are selected as outcome measures for adaptability. A reactive balance task was developed and described using the Y-balance test for the balance component, while the FitLight training system^{TM} was chosen for the environmental perception and decision-making component of the test.

Results: This paper describes the test protocol of a reactive balance test as an adapted Y-balance test. The LED-lights of the FitLight training systemTM are placed at 80% of the maximal reach distance for each axis along the Y-Balance test kitTM. To induce cognitive load within the visuomotor task, colours were fixed to a corresponding axis, and both the order of the visual stimuli as the interstimulus time were randomised to integrate environmental perception and decision-making.

Conclusion: The reactive balance test is a functional test that allows clinicians to score balance ability and athlete adaptability easily.

Keywords: Balance, Visuomotor reaction time, Adaptability, Stability, Injury prevention, Return to sport

Introduction

Recently, several systematic reviews and clinical commentaries emerged regarding the clinimetric value of clinician-friendly lower extremity functional performance tests, and their associations with injury [1–4]. Although balance is an important part of an athlete's functional ability [5–7], these reviews showed that balance tests are currently underrepresented, accounting for only 1 functional balance test within the functional testing repertoire of 14 tests. Nevertheless, balance tests are commonly used in the assessment of ankle and knee injury prevention and return to sport decisions in clinical practice [8–14]. Glasgow et al. (2013) illustrated that reacting to a non-planned stimulus is of great importance in sports. They stated that the key driver for effective sporting performance and injury prevention is the athlete's ability to adapt his or her responses under a comprehensive variety of conditions [15]. This makes the applicability of the outcomes of pre-planned balance tests to open skilled sports (e.g. tennis, football) low, given that static tests neglect the importance of balance in its inherent relation with being able to react to a changing environment.

---

* Correspondence: Romain.Meeusen@vub.be
[1]Faculty of Physical Education and Physiotherapy, Human Physiology Research Group, Vrije Universiteit Brussel, Brussels, Belgium
Full list of author information is available at the end of the article

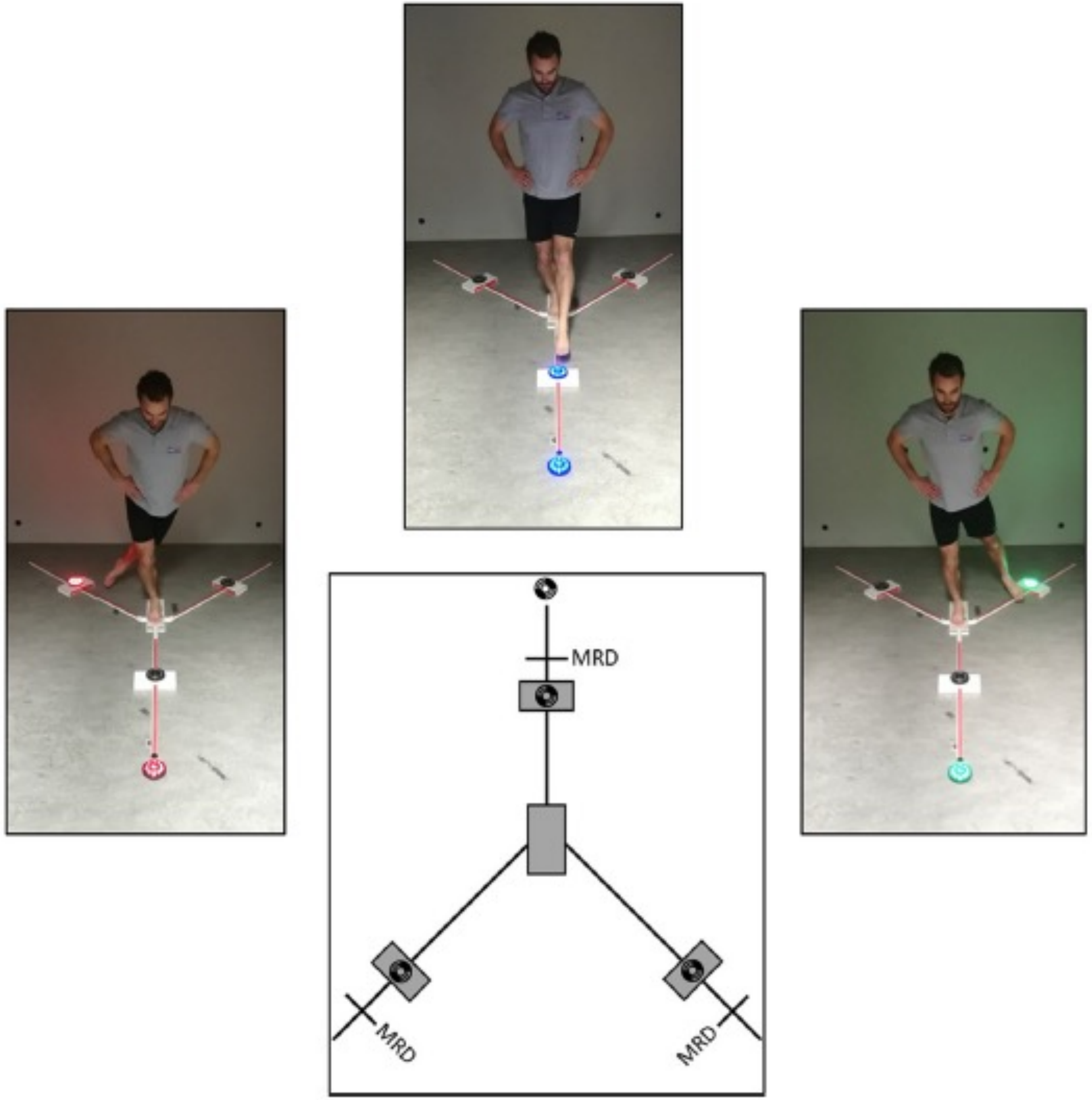


Fig. 1 Reactive balance test. MRD = Maximal Reach Distance; ◉ = Fit-light trainer^{TM} LED-lights. The LED-lights are placed on the axes of the Y-balance kit at 80% of the MRD. Also, each LED-light on every axis has a designated colour (e.g. blue = anterior axis). The LED-light in front of the Y-balance kit randomly shows one of the corresponding colours and indicates in which direction the participant has to reach as fast as possible and without losing balance

Table 2 Recommendations for reactive balance test protocol

Recommendation	Rationale
Randomize order of stimuli	Avoids stimulus anticipation for direction by subject
12 stimuli per axis	As much as possible to improve reliability of visuomotor reaction time without exceeding a two minute test duration
Randomized interstimulus time	Avoid stimulus anticipation for timing by subject
80% reach distance	Balance perturbation, without the intend to impair accuracy
80% reach distance	Balance perturbation, without the intend to cause balance error that discontinues test sequence

Table 1 Reactive balance test outcome measures

Visuomotor Reaction Time = averaged total visuomotor reaction time

Accuracy = (Total number of stimuli – (missed stimuli + multiple attempts needed + decision errors))/100

- *Missed stimulus* = failed to extinguish LED-light
- *Multiple attempts* = reaching from standardized position, but failed to extinguish the LED-light from the first time; second or third attempt needed
- *Decision error* = initiating movement in wrong direction

Balance error = number of balance errors [25]

- *Minor balance error* = looking for balance but able to start from standard position at stimulus onset or looking for balance during reach
- *Major balance error* = not starting from standard position at stimulus onset or during stimulus presentation caused by hand or foot on floor; stepping off the YBT
- *Predefined balance errors* = moving hands off the hips; step, stumble or fall; Abduction or flexion of the hip while looking for balance; lifting the forefoot or heel off the testing surface; placing the free foot on the floor; remaining out of the proper testing position for greater than 2 s

Individual/organismic	• Structural or functional deficits influencing the sensorimotor system • Injury, illness
Task	• Change of activity that shapes sensorimotor system strategies for movement goal execution • Complexity
Environment	• Environmental cues shaping strategies for movement goal execution • Predictability, Uneven terrain

Hoch & McKeon, *Athl Train Sports Healthcare*, 2010