Proprioception & Performance: The role of below-knee compression garments and secondary tasks

A thesis

submitted in partial fulfilment

of the requirements for the degree

of

Master of Sport & Leisure Studies

at

The University of Waikato

by

Shashank Ghai

KO TE TANGATA

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2016

Abstract

Proprioception is an integral component of the voluntary and involuntary motor control processes of the body. Studies have suggested that proprioception plays an important prophylactic role in preventing injuries and can be disrupted by unnecessary conscious attention, imposed during high-stress conditions and/or due to physiological processes of ageing and injury. A systematic in-depth analysis of published literature was therefore conducted to evaluate the current state of literature pertinent to joint stabilizers (e.g. compression, taping, braces), secondary tasks and their effects on proprioception and stability. The first systematic review and meta-analysis revealed beneficial aspects of joint stabilizers, namely compression garments and taping on knee (Hedge's g: 0.48, 95%CI: 0.35- 0.61) and ankle (0.42, 0.18- 0.65) joint proprioception. A second systematic review revealed a 1b level of evidence for the efficacy of secondary task training procedures to enhance postural stability amongst elderly participants. The review also demonstrated that secondary tasks are less efficient in enhancing postural stability among participants with prior history of falls. Following the literature review, gaps in literature were identified and experimental studies were designed to address these gaps. In the first quasi-experimental study, the effects of below-knee compression garments and secondary tasks on knee joint proprioception were studied. Statistical analysis revealed main effects of both compression ($p<0.001$) and secondary task ($p=0.04$). Thereafter, a second quasi-experimental study evaluated the effects of secondary tasks on proprioception (joint repositioning task), peak jump velocity, peak jump height, pre and post exercise. The study revealed a significant ($p<0.05$) enhancement of proprioception accuracy when a secondary task was implemented, pre and post exercise. Likewise, *large* and *small* effect sizes were calculated for proprioception and peak jump velocity, in between trails, pre and post exercise. The research carried out in the thesis is novel as it demonstrates that below-knee compression and secondary tasks can improve proprioception of the knee. Clinical implications are discussed with respect to proprioception in modern sports and rehabilitation settings.

Acknowledgements

I would like to express my gratitude to the many people that have contributed to this thesis:

I would like to express my sincere gratitude to my supervisors Prof. Rich Masters and Dr. Matthew Driller for the continuous support of my Master's study and research. I am immensely grateful for your patience, motivation, and immense knowledge. Your guidance has helped me not only develop as a researcher but as a human being. I could not have imagined having better supervisors and mentors for my Masters study.

I would like to thank Education New Zealand and Government of India, for awarding me the prestigious New Zealand India Sports Scholarship, which has supported me throughout my Master's coursework.

I am obliged and indebted towards all the participants who took part in my research. Last but not the least I would like to thank Ms. Heather Morell, Prof. Robert Isler, Dr. Neha Malhotra, Mr. Mamadou Diouma Bah, Mr. Muhammad Irfan and Ms. Anne Mason for their kind inputs and suggestions in different parts of the thesis.

Finally, I must express my very profound gratitude to my family for providing me with unfailing support and continuous encouragement throughout my Master's coursework and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you very much.

Table of Contents

List of Figures

List of Tables

Publications arising from the thesis

1. Ghai, S., Driller, M., & Ghai, I. Effects of joint stabilizers on proprioception and postural stability: systematic review and meta-analysis. Re-submitted after minor revision to *Physical Therapy in Sport*.
2. Ghai, S., Driller, M., & Masters, R. S. W. The influence of below-knee compression garments on knee joint proprioception. Submitted to *Gait and Posture*.
3. Ghai, S., Masters, R. S. W., & Driller. M. The effects of applying a secondary task on proprioception and jump performance following exercise. Submitted to *Science and Sports*.

Awards

New Zealand India Sports Scholarship, Education New Zealand.

Abbreviations

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analysis

PEDro: Physiotherapy Evidence Database

EMBASE: Excerpta Medical dataBASE

MEDLINE: Medical Literature Analysis and Retrieval System Online

CMA: Comprehensive meta-analysis

SPSS: Statistical Package for Social Science

MeSh: Medical Subject Headings

JS: Joint stabilizers

LOE: Level of evidence

Chapter 1

Proprioception & awareness

Background

Proprioception is defined as an internal neuromuscular feedback system that readily conveys information related to the joint position to higher neural centres (Herrington, Simmonds, & Hatcher, 2005). The term was first coined in 1906 by Sherrington to represent the sense of body position (Sherrington, 1906), and is suggested to be mediated at a multifaceted conscious-unconscious level (Johnson, Babis, Soultanis, & Soucacos, 2007). The conscious domain, on one hand, plays an integral role in executing coordinated motor skills, whereas, the unconscious domain mediates autonomic functioning of involuntary motor skills, namely postural stability and gait (Johnson et al., 2007). Proprioception has also been speculated to possess key performance and prophylactic properties, essential for executing simple and complex coordinated motor activities (Herrington et al., 2005; Michael, Dogramaci, Steel, & Graham, 2014). Studies have suggested that even the slightest of changes within the proprioception accuracy can predispose people towards neuromuscular injuries (McCloskey, 1978b; Michael et al., 2014).

Physiologically, the modulation of proprioception requires a group of receptors, namely, Ruffini endings, Pacini corpuscles, Golgi tendon organs, Muscle spindles, which are present in joints, muscles, fascia and skin. These receptors have been demonstrated to convey high fidelity information for joint positioning (Edin, 2001), and in the stabilization of skeletal structures (Krishnamoorthy, Slijper, & Latash, 2002). Activation of these mechanoreceptors is triggered by mechanical disturbances developed in musculoskeletal structures, which then are transmitted through afferent proprioceptive pathways to higher neural centres, where the actual perception of movement takes place (Augustine, Fitzpatrick, Katz, LaMantia, & McNamara, 2001; Callaghan, McKie, Richardson, & Oldham, 2012). Disruptions within the processing and transmission of proprioceptive inputs can significantly affect movement perception and ultimately the coordinated execution of motor skills. Studies have speculated that these proprioceptive processes can be hindered either due to constraints in the physiological domain as a result of injury (Lee, Lim, Jung, Kim, & Park, 2013), fatigue (Van Tiggelen, Coorevits, & Witvrouw, 2008a), ageing (Prasansuk, Siriyananda, Nakorn, Atipas, & Chongvisal, 2004), or a consequence of higher conscious attention, which when directed internally to control movements disrupts performance.

Lee et al. (2013) suggested that injury or ageing related change in musculoskeletal structures leads to blockage of afferent inputs from the mechanoreceptors located on the articular and musculoskeletal structures of the joint. In order to offset these deficits joint stabilizers (Fu, Liu, & Fang, 2013), exercise, and proprioceptive training (Aman, Elangovan, Yeh, & Konczak, 2014) are commonly employed. Nevertheless, studies have suggested the application of joint stabilizers, such as braces and compression garments, to be more viable measures for providing proprioceptive increments (Michael et al., 2014). These stabilizers have also been reported to provide performance increments during recovery (Michael et al., 2014), fatigue (Van Tiggelen, Coorevits, & Witvrouw, 2008b), and provide support to the weak musculoskeletal structures to prevent re-injury (Fu et al., 2013). The physiological principle behind the functioning of these stabilizers has been suggested to be an enhancement of afferent proprioceptive inputs by stimulating and pressurizing underlying skin and musculoskeletal structures by the joint stabilizer (Janssen & Kamper, 2013; Perlau, Frank, & Fick, 1995). Additionally, the pertained changes post joint stabilizer application have been suggested to involve subtle changes in musculoskeletal activation (Lin, Hung, & Yang, 2011), and cerebral haemodynamics (Callaghan et al., 2012). Furthermore, studies have also suggested that these stabilizers, pertaining to their structural integrity allow imitation of normal joint biomechanics by supporting the injured musculoskeletal structures. In addition, these stabilizers have also been speculated to provide an enhanced perception of stability and confidence (Bernhardt & Anderson, 2005; Callaghan et al., 2012), which also are considered as a major factor for enhancing proprioception.

Secondly, to manage proprioceptive deficits associated with higher conscious involvement as a consequence of movement specific re-investment, secondary tasks interventions are commonly incorporated (Donker, Roerdink, Greven, & Beek, 2007; Masters & Maxwell, 2008; Schaefer, Jagenow, Verrel, & Lindenberger, 2015). A secondary task is a measure for directing a performer's attention away from the primary task that they are carrying out (e.g. backward counting task[1],

[1] Secondary task condition requiring a participant to count backwards from a given number, e.g. 799,798….

mental arithmetic production task[2]). According to the constrained action hypothesis, this attentional change might allow motor systems to function in an automatic manner, unconstrained by interferences caused by conscious control, thereby resulting in more effective performance (Wulf, McNevin, & Shea, 2001). Moreover, secondary tasks are hypothesized to effectively 'soak up' information processing resources that otherwise would be available for focussing on a motor task. Therefore, a conjoint approach was developed within this research for enhancing proprioceptive and performance based measures while using secondary tasks and joint stabilizers.

Research aim & techniques

The aim of this thesis is to develop a comprehensive understanding of the effects of differential information processing constraints on proprioception. This includes critical evaluation of published literature to understand the current state of knowledge, and efficiently develop research methodologies. The research in the thesis focussed on identifying and elucidating key proprioceptive factors in a clinical and practical context.

Within this theme, specifically covered objectives are as follows:

1. Systematic investigation of research-based literature pertinent to joint stabilizers, secondary task interventions and their effects on proprioceptive, performance and stability measures.
2. Description of the underlying physiological mechanisms associated with joint stabilizers for enhancements associated with proprioception.
3. Identification of the differential effects of the abovementioned variables on various population groups (e.g. age, gender, neurological ailments).
4. Development of novel methodological protocols for assessing clinical and dynamic aspects of proprioceptive measures, with the use of joint stabilizers and secondary task interventions.
5. Suggest practical applications from the research that can be incorporated in the activities of daily living.
6. Provide directions for future research work.

---

[2] Secondary task condition requiring a participant to solve mathematical equation 3+2+9-7=?

Thesis structure

To achieve the abovementioned objectives the thesis is comprised of six chapters, including three submitted articles that are under review.

Chapter 2 is a systematic review and meta-analysis of 50 research articles using PRISMA guidelines, analysing the effects of joint stabilizers on postural stability, neurological activity, and proprioception among different age groups.

Chapter 3 systematically reviews the effects of secondary tasks on static and dynamic postural stability in 29 studies. The systematic review complies with PRISMA guidelines and further outlines effects of secondary tasks on various population groups differentiated on the basis of age and neurological ailments.

Chapter 4 includes clinical examination of knee joint proprioception accuracy in 44 healthy participants when applying below-knee compression garments and secondary tasks. The research study revealed novel and practical implications of the abovementioned variables, with the statistical analysis revealing significant main effects for the below-knee compression garments and the secondary task intervention.

Chapter 5 advances the previous research study's findings. This research study deduced practical aspects of proprioception and performance measures, pre and post exercise. Twenty-two recreational runners took part in a research study evaluating the aspects of a secondary task intervention on dynamic proprioception, peak jump height and peak jump velocity while performing a modified squat jump. Statistical analysis revealed significant enhancements in proprioceptive accuracy and peak jump velocity, pre and post exercise.

Chapter 6 synthesizes the results of the thesis. Clinical implications are discussed with respect to proprioception and stability in modern sports and rehabilitation settings.

Chapter 2

Effects of joint stabilizers on proprioception and stability: a systematic review and meta-analysis

Preface

This chapter systematically reviews the current state of research-based literature encompassing the effects of stabilizers on proprioception across various joints of the body, postural stability and motor performance. The effects in this research were studied amongst population groups differentiated on the basis of age, gender and injury status. To the best of our knowledge, no research exists that categorizes the differential effects demonstrated by various joint stabilizers on multiple joint sites and conditions. The systematic review in the following chapter was performed across four academic databases; Scopus, PEDro, SportDiscus, and EMBASE. Further, the inclusion of a meta-analysis of heterogeneous studies and narrative analysis of underlying neurophysiological mechanisms for the effects of joint stabilizers, adds towards the novelty of the analysis. This chapter relates to the following objectives of the thesis:

1. Systematic investigation of research-based literature pertinent to joint stabilizers, secondary task interventions and their effects on proprioceptive, performance and stability measures.
2. Description of the underlying physiological mechanisms associated with joint stabilizers for enhancements associated with proprioception.
3. Identification of the differential effects of the abovementioned variables on various population groups (e.g. age, gender, neurological ailments).

Abstract

Objective: The current review and meta-analysis systematically investigated the effect of joint stabilizers on proprioception, postural stability, and neurological activity.

Methods: Systematic identification of published literature was performed on online databases; Scopus, PEDro, SportDiscus, and EMBASE, followed by a critical PEDro methodological quality appraisal. Data from the studies were extracted and summarised in a tabular format.

Results: Of 2954 records, "50 studies", involving 1443 participants met our inclusion criteria. In the included studies, 60% of studies reported significant enhancements ($p<0.05$), 19% of studies reported enhancements ($p>0.05$) and 21% of studies reported no effects of joint stabilizers on proprioception and/or postural stability. Meta-analysis of pooled studies demonstrated beneficial effects of joint stabilizers on the knee (95%CI: 0.35° to 0.61°) and ankle (at 10°: 0.1° to 0.65°) joint proprioception, and negligible effects on postural stability (-0.28° to 0.19°).

Conclusion: The pooled evidence suggests that application of joint stabilizers enhances joint proprioception and stability by not merely altering the mechanical stability of the underlying musculoskeletal structures but by also causing subtle changes in cerebral hemodynamics and musculoskeletal activation. These findings support clinical implications of joint stabilizers as a prophylactic and rehabilitation measure in modern sports and rehabilitation settings.

Introduction

Proprioception is an integral component of the motor control and coordination process in which body identifies inputs from various mechanoreceptors, nociceptors, and muscle afferents and further integrates the information attained into the motor programming that is required for perception of movement, force and joint position (Baumeister, Reinecke, & Weiss, 2008; Grigg, 1994). It also possesses important prophylactic properties for preventing musculoskeletal and neuromuscular injuries by avoiding excessive joint movements (beyond the physiological and anatomical range of motion) (Jerosch & Prymka, 1996).

Likewise, incorporation of joint stabilizers (brace, bandage, compression garment, taping and corsets) in modern clinical and sports settings as a rehabilitative, prophylactic and performance enhancement measure is primarily attributed to their beneficial capabilities of enhancing proprioception (Bottoni, Herten, Kofler, Hasler, & Nachbauer, 2013; Fu et al., 2013). Several physiological mechanisms have been suggested for this effect (Birmingham et al., 1998; Herrington et al., 2005). Researchers primarily hypothesize that joint stabilizers enhance proprioception by enhancing the cutaneous stimulation and by pressurizing the underlying musculoskeletal structures (Janssen & Kamper, 2013; Perlau et al., 1995). These cutaneous receptors convey high fidelity information for joint positioning (Edin, 2001), and have also been shown to play a major role in postural stabilization (Krishnamoorthy et al., 2002). Moreover, joint stabilizers have also been reported to play a significant role in the rehabilitation of various musculoskeletal injuries, such as osteoarthritis, patellofemoral pain syndrome, and low back pain (Birmingham et al., 2001; Callaghan, Selfe, McHenry, & Oldham, 2008). Lee et al. (2013) suggested that injury to musculoskeletal structures leads to blockage of afferent inputs from the mechanoreceptors located on the articular and musculoskeletal structures of the joint. Furthermore, the enhancement of proprioception accuracy post application of joint stabilizer occurs as a result of increased afferent sensory inputs from the cutaneous mechanoreceptors and the imitation of normal joint biomechanics that the injured musculoskeletal structures are subjected to. Likewise, enhanced perception of stability and confidence has also been reported amongst participants post application of joint stabilizers in several studies (Bernhardt & Anderson, 2005; Callaghan et al., 2012; Lien et al., 2014;

Michael et al., 2014). Callaghan et al. (2012) confirmed this effect and reported an associated decrease in BOLD (Blood oxygen level dependence) response in the anterior cingulate cortex and cerebellum post application of taping. Similarly, modulation of musculoskeletal activation and neurological activity has been reported in some studies post application of joint stabilizers. Lin et al. (2011) in their electromyography (EMG) study reported differential activation levels of the underlying musculoskeletal structures post application of scapular taping. Likewise, Callaghan et al. (2012) in their functional magnetic resonance imaging (fMRI) analysis asserted that the application of joint stabilizer (tape) causes subtle changes in brain centres associated with sensation, coordination, decision making, planning of complex coordination tasks and coordination of unconscious tasks. Similarly, enhancement of cerebral hemodynamics has been reported in the primary sensorimotor cortex, cerebellum and ventral tegmental area of the brainstem, signifying enhanced regional brain perfusion in areas related to motor control and coordination (Thijs, Vingerhoets, Pattyn, Rombaut, & Witvrouw, 2010).

In addition to the abovementioned factors, one of the most critical and least researched components of different methods of joint stabilizers are its structure, material, and fitting. Several studies have discussed the importance of comfortable fitting, application of joint stabilizers for enhancing proprioception and performance (Bernhardt & Anderson, 2005; Fu et al., 2013; Lien et al., 2014; Michael et al., 2014). For instance, Bernhardt and Anderson (2005) suggested that increased resistance offered by elastic stabilizers (compression garments) when lengthened, results in a progressive resistive force that limits the joint movement to an optimal physiological range of motion. This function may be crucial for injury prevention. Likewise, studies have also suggested that lack of comfort and poor fit can adversely affect performance as it might lead to differential activation of the underlying musculature and/or might not provide optimal support to weak musculoskeletal structures. According to Fu et al. (2013), an ideal joint stabilizer should provide optimized compression, comfort, fit, and skin contact. Incorporation of these factors is crucial not only for optimal sports performance but also for efficient injury prevention and rehabilitative approaches.

The present literature aims to identify the beneficial capabilities of JS for enhancing proprioception, stability at various joints amongst athletes, sedentary individuals of both sexes and across all age groups. In the current review, the authors have also attempted to generate a comprehensive understanding of the underlying mechanisms and function of various joint stabilizers amongst different population groups.

Methods

This review was conducted according to the guidelines outlined in Preferred Reporting Items for Systematic Reviews and Meta-analysis: The PRISMA statement (Moher, Liberati, Tetzlaff, & Altman, 2009).

Data sources and search strategy

The databases Scopus, PEDro, SportDiscus, and EMBASE were searched from inception until June 2015. The search strategy was limited to four databases because of the limited accessibility levied by the university's database. Key words for the search strategy were included using medical subject headings (MeSH). A combination of keywords related to various joints, proprioception, proprioceptive tests, postural/balance stability, joint stabilizers, age groups, gender, athletes, injury, disability, and rehabilitation injury were used. An example of search strategy for the EMBASE database has been provided in the supplementary file (Appendices 8).

The inclusion criteria for the studies was (i) Performed studies were either randomized controlled trials (RCTs), cluster RCTs or controlled clinical trials (CCTs); (ii) Measurement of proprioception accuracy was performed using one or more of the following reliable procedures (Threshold for detection of passive motion, joint position sense, force perturbation, active joint repositioning test, active movement extent discrimination apparatus, tracking test, biodex-system test, wilcox quad logger test, and proprioceptive feed-back magnitude); (iii) Measurement of postural stability was done using reliable methods (Centre of pressure, centre of mass, centre of gravity sway, star excursion balance test, modified star excursion balance test, active movement extent discrimination apparatus); (iv) Studies evaluating joint kinematics post application of joint stabilizers; (v) Studies evaluating agility post application of joint stabilizers

(Hopping tests, boomerang test, T-test) (vi) Studies qualified PEDro methodological quality scale (≥4 score); (vii) Experiments conducted on human participants; (viii) Published in a peer-reviewed academic journal; (ix) Articles published in English and German language. Moreover, tests of peroneal reaction time were not considered to be appropriate tests for proprioceptive and studies incorporating unreliable procedures were excluded from the study. Bibliographic sections of all the articles were retrieved for further evaluations. Citation search for all the included articles was performed using Web of Science.

All the studies identified during the search were independently screened (Figure 1.0) for eligibility by a single researcher under the "supervision of the second and the third author and every effort was undertaken to avoid subjective bias" (Centre for Reviews and Dissemination, 2009). Preliminary analysis for selection was performed by analysing titles and abstracts and wherever necessary, the entire text of the article was studied. In case further clarification for the published data was required, the researcher made attempts to contact the respective authors. Furthermore, classification of studies based on their experimental design (Higgins & Green, 2008), and country of origin was also made (Appendix 9).

Quality & risk of bias assessment

The quality of the studies was assessed using the PEDro methodological quality scale (de Morton, 2009). The scale consists of 11 items addressing external validity, internal validity and interpretability. The PEDro scale can detect potential bias with fair to good reliability (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003), and is a valid measure of methodological quality of trials (de Morton, 2009). A blinded rating of the methodological quality of the studies was carried out by the primary reviewer. Ambiguous issues were discussed between reviewers and consensus was reached. For the included studies, a scoring of 9-10, 6-8 and 4-5 was considered to be to of "excellent", "good" and "fair" quality (Teasell, 2008), respectively. Likewise, a modified PEDro level of evidence synthesis guideline was utilized to analyse the strength of the findings for each outcome (Sackett, Straus, Richardson, Rosenberg, & Haynes, 2000). A level of evidence was suggested to be of level: 1a (strong) if more than one RCT (≥6), 1b if one RCT (≥6), and 2 if one RCT (<6), or CCT with similar methodological approaches were consistent with the results

(Teasell, 2008). In case of differential results amongst paired group of studies, the result of study(s) with higher PEDro score were given more consideration (Teasell et al., 2005b). Inadequate randomization, non-blinding of assessors, no intention to treat analysis and no measurement of compliance were considered as major threats to biasing (Ramsey, Winder, & McVeigh, 2014).

Data Analysis

A narrative synthesis of the findings structured around the type of intervention, population characteristics; methodological quality (Table 1, Appendix 9) and the type of outcome are provided. Likewise, summaries of intervention effects for each study were provided in a tabular form (Table 1, Appendix 9). To adhere according to journals guidelines and due to space constraints studies scoring below (PEDro <7) were included in Appendix 9. A meta-analysis was conducted in between pooled studies using CMA (Comprehensive meta-analysis V 3.0, USA) (Borenstein, Hedges, Higgins, & Rothstein, 2005). Heterogeneity between the studies was assessed using I^2 and Tau^2 statistics. The data was systematically distributed and for each available variable pooled, dichotomous data was analysed and forest plots with 95% confidence intervals are reported. The effect sizes were adjusted and reported as Hedge's g (Schinka, Velicer, & Weiner, 2003). Thresholds for interpretation of effect sizes were as follows; a standard mean effect size of 0 means no change, negative effect size means a negative change, mean effect size of < 0.01 considered a *small* effect, 0.01- 0.10 a *medium* effect and >0.10 a *large* effect (Cohen, 1988). Moreover, interpretation of heterogeneity via I^2 statistics was as; 0-40%: might *not be significant*, 30-60%: represents *moderate heterogeneity*, 50-90%: represents *substantial heterogeneity*, 75-100%: represents *considerable heterogeneity* (Higgins & Green, 2008). Meta-analysis reports including heterogeneity among studies were evaluated to determine the reason of heterogeneity, and the included studies were then pooled separately and analysed again. The alpha level was set at 95%.

Results

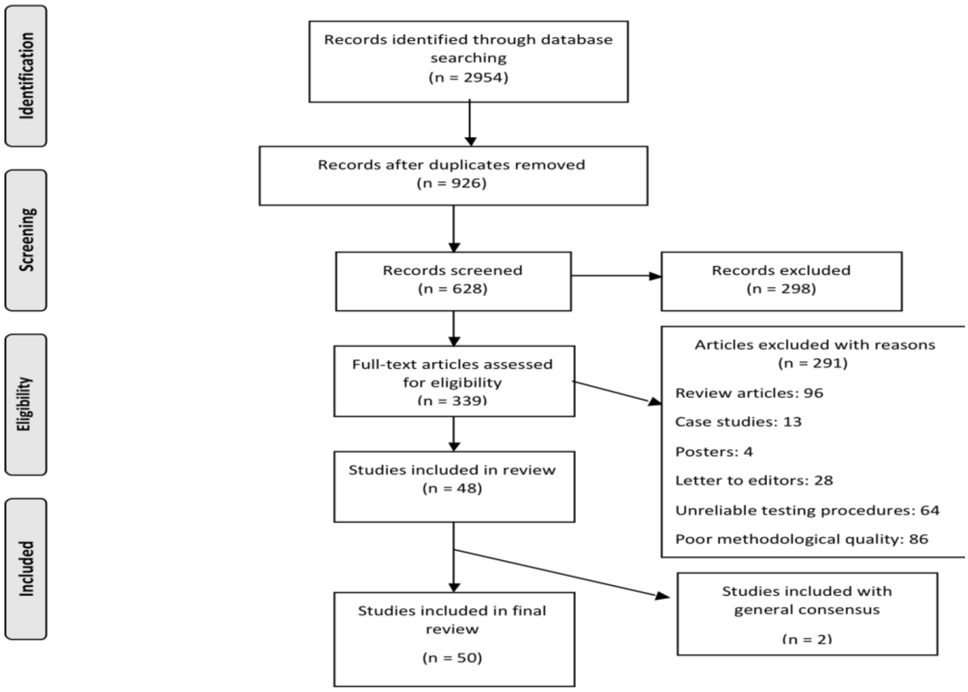

Figure 1 Flow diagram illustrating studies for inclusion in the review study (PRISMA flow diagram)

Characteristics of included studies

Data from the included studies have been summarized in (Tables 1 and Appendix 9). In the 50 included studies 6 were RCTs, 42 were CCTs and 2 were observational neuroimaging studies. The studies were conducted in Europe (18), USA (13), Australia (5), Canada (4), Iran (4), South Africa (2), South Korea (2), Hong Kong (1) and Taiwan (1). The sub-classification for representation of various joint stabilizers methods on different parameters was made over nine categories; postural stability (4), kinematic analysis (1), brain activity (2), shoulder joint (3), elbow joint (1), spine (3), hip joint (2), knee joint (21) and ankle joint (14). Furthermore, the review yielded studies on compression garments/sleeves (12), taping (12), braces (13), elastic bandages (3), and corset (1). Four studies included a comparison between compression garments and braces while two studies compared the beneficiary effects between bracing and taping. Our initial search yielded a total of 2954 studies, which on implementing our inclusion/exclusion criteria, were reduced to 50.

Quality

The individual scores attained by the studies have been reported in their respective (Table 1 and Appendices 9). The average PEDro score of the fifty included studies was 6.1 out of 11. Thereby, indicating "good" overall quality of the included studies. The incidence of publication bias was reduced by including high-quality studies with research protocol limited to gold standard RCTs, cluster RCTs and CCTs (Ryan et al., 2009). Moreover, a test of publication bias could not be incorporated in the meta-analysis because less than 10 studies were incorporated in all of the pooled analysis (Higgins & Green, 2008).

Participants

The majority of the studies were carried out in mixed sex populations (35), with a further 7 studies incorporating only females and 9 studies included only male participants. The included studies provided data on 1443 participants (n=719 female/627 male). Sex distribution information was not provided in three studies (Hadadi, Mousavi, Fardipour, Vameghi, & Mazaheri, 2014; Lee et al., 2013; Newcomer, Laskowski, Yu, Johnson, & An, 2001), and one study was a continuation of a previous study exploring the outcomes of proprioception in different groups (Van Tiggelen et al., 2008a).

Meta-Analysis

The evaluation of research studies via meta-analysis requires strict inclusion criteria to efficiently limit the heterogeneity (Bolier et al., 2013). However, among the pooled group of studies post strict inclusion criteria, some amount of unexplained heterogeneity was still observed. Deeks, Higgins, and Altmann (2013) suggested incorporation of a random-effect meta-analysis under such conditions. The researchers added that a random-effect meta-analysis involves an assumption that the estimated effects in various studies are un-identical but follow some distribution. Therefore, studies analysing similar variables were pooled and a random effect meta-analysis was conducted across four categories (postural stability, spine, knee joint and ankle joint). The statistical approach could not be incorporated across the other two categories (brain activity, shoulder joint) due to following reasons:

Brain activity: Studies involved observation and evaluation of brain activity post application of joint stabilizers.

Kinematic analysis: Only single study included.

Shoulder joint: Three studies under this category evaluated the effects of joint stabilizers on proprioception and EMG. Different proprioceptive tests and joint stabilizers were utilized across the studies. For instance, Lin et al. (2011) evaluated the effects of scapular taping on shoulder proprioception using proprioceptive-feedback magnitude, Ulkar, Kunduracioglu, Cetin, and Güner (2004) and Chu, Kane, Arnold, and Gansneder (2002) utilized the effects of neoprene bracing on shoulder proprioception, but while using passive, and active proprioceptive tests, respectively. Active and passive proprioceptive tests have been reported to assess proprioceptive accuracy on different physiological pathways (Kaminski & Perrin, 1996; Lephart, Pincivero, Giraido, & Fu, 1997; McCloskey, 1978b). Therefore, a statistical evaluation of the studies was not considered appropriate.

Outcomes

The results suggest clear evidence for a positive impact of joint stabilizers for enhancing proprioception and postural stability. Thirty studies demonstrated significant enhancement of proprioception accuracy post-application of a joint stabilizer, eight studies demonstrated non-significant enhancement of proprioception accuracy and ten studies demonstrated no effect following the application of a joint stabilizer. No study reported detrimental/negative effects in proprioception and/or postural stability post-application of joint stabilizers.

Table 1 Studies showing effects of joint stabilizers on postural stability, brain activity, joint kinematics and proprioception

Study	Assessed	Sample description, age: (M ±SD years)	PEDro score (LOE)	Joint stabilizer	Methodology	Findings
Postural stability						
Michael, et al. (2014)	Postural stability	12 F (24 ±7) healthy participants (CO)	9 (1a)	Compression garment	Postural stability analysed with single leg balance task for 60 s: EO, EC; CoP, CoM sway	Significantly enhanced postural stability with use of WFCG garments as compared to the control group. EC significantly enhanced, EO no significant enhancement
Hadadi, et al. (2014)	Dynamic postural stability	6 F, 10 M (22±2) participants with FAI, 10M, 6F (22±2) healthy participants	6 (2)	Brace (SO, SRO)	Postural stability analysed with SEBT task	Significant enhancement of dynamic postural balance with orthosis. Participants wearing SO performed better as compared to SRO
Nakajima and Baldridge (2013)	Vertical jump and dynamic postural control.	24 F, 28 M (22 ±2) healthy participants (CO)	8 (1b)	Tape (KT)	Postural stability analysed with SEBT task	Enhanced dynamic postural stability with taping. Females had better dynamic postural control as compared to males

Hettle, et al. (2013)	Dynamic postural stability	10 F, 6 M (22±1) participants with CAI (CO)	6 (1b)	Tape	Postural stability analysed with SEBT task	No enhancement of dynamic postural stability post-application of tape
Faraji, et al. (2012)	Postural stability	9 F, 11 M (20±4) Basketball players with CAI (CO)	6 (2)	Brace (SO, SRO)	Postural stability analysed with biodex balance system	Significant enhancement of dynamic and semi-dynamic postural stability
Bicici, et al. (2012)	Postural stability	15 M (18-22 y) Basketball players CAI (CO)	6 (2)	Tape (KT)	Postural stability analysed with SEBT task	No significant difference in postural stability post application of KT
Ambegaonkar, et al. (2011)	Dynamic postural stability	6 F, 4 M (25±2) Healthy participants (CO)	6 (2)	Tape, brace (LUB, SRB)	Postural stability analysed with modified bass test	Enhanced dynamic balance post-application of tape and SRB
Munoz, et al. (2010)	Postural stability	7 F, 4 M (44±8) participants with low back pain and lumbar discopathy (CO)	6 (2)	Brace (LLB)	Postural stability analysed with EO, EC; CoP sway	Significant enhancement of postural stability post application of LLB

Cameron, et al. (2008)	Swinging leg movement discrimination scores (proprioception) using AMEDA	20 M (18 – 22) participants with low MDA; 20 M (19 – 25) participants with high MDA all football players	7 (1a)	Compression garment	Postural stability analysed with AMEDA task	Significant enhancement proprioception accuracy in “low” MDA participants, no enhancement in “high” MDA participants with compression neoprene shorts
Sawkins, et al. (2007)	Postural stability and hopping test	19 F, 11 M (21±3) participants with ankle instability (CO)	8 (1b)	Tape	Postural stability analysed with MSEBT task	No difference in hopping and balance test, but perception for stability, confidence and reassurance increased
Brain activity						
Callaghan, et al. (2012)	Cerebral hemodynamics	8 M (29±6) healthy participants (CO)	5 (5)	Tape	fMRI (BOLD) tested while 2 extension repetitive movements (simple and proprioceptive)	pT modulates brain activity in primary sensorimotor cortex and cerebellum
Thijs, et al. (2010)	Cerebral hemodynamics	13 F (19±1) healthy participants, right-side dominant CO)	5 (5)	Compression garment and brace	fMRI conducted (flexion-extension 0-90°, knee joint)	Application of B, S modulates brain activity in frontal lobe, paracentral lobule, parietal lobe and superior parietal lobule
Kinematic analysis						

Vogt, et al. (2000)	Assess the effects of lumbar corset (LC) on kinematics of pelvis.	4 F, 8 M (32 ±11) healthy participants (CO)	6 (2)	Brace (LC)	3D kinematic data analysis tested, with & without lumbar corset.	Significant enhancement of pelvic stability post application of lumbar corset in frontal and sagittal plane
Shoulder joint						
Lin, et al. (2011)	EMG activity UT, LT, SA, AD and shoulder joint proprioception.	2 F, 10 M (23±4) healthy participants (CO)	6 (2)	Tape (ST)	EMG and proprioception analysed with PFM	Significant enhancement in PFM post-application of taping. Enhanced activity in SA, lower activity in UT
Ulkar, et al. (2004)	Shoulder joint proprioception	13 F, 13 M (21±3) healthy sedentary volunteers (CO)	5 (2)	Compression garment (NC)	Proprioception analysed with PAR at 45° internal rotations and 75° (0.5°/sec) external rotation	Significantly enhanced shoulder joint proprioception with compression neoprene sleeve in both IR and ER
Chu, et al. (2002)	Shoulder joint	10 F, 10 M (21±2) participants with stable; 8F, 12 M	5 (2)	Brace (NS)	Proprioception analysed with AJRS task	Significant enhancement of shoulder proprioception in unstable group participants during full external rotation. No significant

	proprioception.	(21±3) athletes with unstable shoulder				enhancement of proprioception noted in stable group
Spine						
Cholewicki, et al. (2006)	Trunk proprioception	3 F, 11 M (26±8) healthy participants (CO)	6 (2)	Brace (LSO)	Proprioception analysed with PAR task for 3 weeks (day 0, 7, and 21)	LSO affected proprioception, but no beneficial effects were seen post-application of LSO on lumbar proprioception
Newcomer, et al. (2001)	Trunk proprioception	20 (40 y) participants with low back pain; 20 (40 y) healthy participants	6 (2)	Brace (LS)	Proprioception analysed with re-positioning task (F, Ex, RB, LB, standing immobilized)	Significant enhancement of trunk proprioception in Ct and LBP group post-application of stabilizer
McNair and Heine (1996)	Trunk proprioception	20 F, 20 M (26±6) healthy participants (CO)	6 (2)	Brace (NLB)	Proprioception analysed with active re-positioning task	Enhanced trunk proprioception post-application of brace. More enhancements in participants with poor prior proprioception
Hip joint						
Lien, et al. (2014)	Accuracy of novel kicking task (drop-punt-kicks) i.e. active	15 M (18±1) elite football players (CO)	9 (1b)	Compression garment	Proprioception analysed with re-positioning task of kicking accuracy with hip flexion and ankle plantar flexion angles	No enhancement in kicking accuracy, post-application of CG. “Less skilled participants” improved their accuracy. Significant correlation was reported

	re-positioning					with kicking accuracy of dominant leg in WFCG and comfort
Bernhardt and Anderson (2005)	Performance and hip joint proprioception	3 F, 10 M (25 y) healthy participants (CO)	7 (2)	Compression garment	Proprioception analysed with re-positioning task and postural stability analysed with stork test	No effect on performance, 93.3% of participants felt compression garments to be supportive
Knee joint						
Cho, et al. (2015)	Range of motion and knee joint proprioception	33 F, 13 M (57±4) participants with osteoarthritis (CO)	9 (1b)	Tape	Proprioception and AROM analysed	Significantly enhanced knee proprioception post-application of taping with proper tension
Bottoni, et al. (2014)	Knee joint proprioception after uphill and downhill walking	24 F (23±2) healthy participants (CO)	6 (2)	Compression garment and brace	Proprioception analysed with JPS task post 30 min uphill and 30 min downhill walking	Significantly enhanced knee joint proprioception in subjects with poor proprioception after uphill and downhill walking with compression sleeve and brace
Karimzadehfini, et al. (2014)	Knee joint proprioception	22 F (24±5) participants with lateral displacement of patella (CO)	6 (2)	Brace	Proprioception analysed with PAR task	Significantly enhanced proprioception accuracy with brace as compared to exercise program

Bottoni, et al. (2013)	Knee joint proprioception.	20 M (26±1) athletes (CO)	6 (2)	Brace and compression garment	Proprioception analysed with TDPM task at 30° and 60°, both in flexion and extension	No enhancement in knee proprioception accuracy with knee brace or compression garment
Collins, et al. (2011)	Knee joint proprioception during PWB and NWB.	26 F, 12 M (59±10) participants with osteoarthritis (CO)	5 (2)	Compression garment (NC)	Proprioception analysed with JPS task during PWB and NWB	Significant enhancement of knee joint proprioception during PWB. Enhancement of knee joint proprioception during NWB
Collins, et al. (2009)	Knee joint proprioception during PWB and NWB.	12 F, 12 M (24±3) healthy participants (CO)	5 (2)	Compression garment (NC)	Proprioception analysed with JPS task during PWB and NWB	Enhanced knee joint proprioception with neoprene compression sleeve in PWB and NWB conditions
Mokhtarinia, et al. (2008)	Knee joint proprioception.	25 M (23±3), participants with PFPS (CO)	5 (1b)	Tape (pT)	Proprioception analysed with AAR, PAR and TDPM tasks	Significant enhancement of proprioception during AAR, enhancement of proprioception during PAR and TDPM
Callaghan, et al. (2008)	Knee joint proprioception	14 F, 18 M (31±11) participants with PFPS	6 (1b)	Tape (pT)	Proprioception analysed with AAR and PAR tasks at target angle 60° and 20°	Significantly enhanced proprioception acuity for subjects with “poor” prior proprioception status

Van Tiggelen, et al. (2008)	Knee joint proprioception post isokinetic fatigue protocol	5 F, 26 M (23±3) participants with poor proprioception; 10 F, 23 M (22±3) participants with good proprioception	7 (2)	Compression garment (NC)	Proprioception analysed with AJRT task at baseline and post-fatigue	Significantly enhanced knee joint proprioception in subjects with “poor proprioception” performing repositioning task even after fatigue
Van Tiggelen, et al. (2008)	Knee joint proprioception post isokinetic fatigue protocol	15 F, 49 M (24±4) healthy participants (CO)	7 (2)	Compression garment (NC)	Proprioception analysed with AJRT task at baseline and post-fatigue	Significantly enhanced knee joint proprioception at baseline and after isokinetic fatigue protocol with neoprene compression sleeve
Herrington, et al. (2005)	Knee joint proprioception	12 F, 8 M (27±7) healthy participants (CO)	7 (2)	Compression garment (NC)	Proprioception analysed with tracking, perception and re-production tasks	Significantly enhanced knee joint proprioception acuity was observed with the neoprene compression sleeve
Kruger, et al. (2004)	Knee joint proprioception and stability	30 M (22-30) rugby players (CO)	6 (2)	Brace (PKB)	Proprioception analysed with 2 min Wilknox Quad time logger task	Significantly enhanced knee proprioception with brace application

Barrett (2003)	Knee joint proprioception and stability	15 F (15±1) adolescent female athletes (CO)	5 (2)	Compression garment (NC)	Proprioception analysed with AJRT, movement sensation tasks and balance test	Enhanced knee joint proprioception in adolescent female athletes with application of neoprene compression sleeve, at specific angles
Hassan, et al. (2002)	Knee joint proprioception and postural stability	49 F, 19 M (67, 36-87) participants with osteoarthritis (CO)	7 (2)	Bandage	Proprioception analysed with PAR task and postural stability	No significant effect of elastic bandage on proprioception, loose bandage significantly enhanced static postural sway
Callaghan, et al. (2002)	Knee joint proprioception	27 F, 25 M (23±4. y) healthy participants (CO)	6 (1b)	Tape (PT)	Proprioception analysed with AAR, PAR and TDPM tasks	Enhanced proprioception accuracy post-application of taping. Significantly enhanced proprioception in participants with inherent poor proprioceptive capabilities
Wong, et al. (2001)	Knee joint proprioception.	26 F (17-27) dancers (CO)	5 (2)	Bandage	Proprioception analysed with PAR task	Significantly enhanced proprioception accuracy post-application of knee bandaging
Birmingham, et al. (2001)	Knee joint proprioception and postural stability	6 F, 14 M (59±9 y) participants with osteoarthritis (CO)	6 (2)	Brace (FKB)	Proprioception analysed with re-positioning task and postural stability analysed on stable, unstable surface	Significantly enhanced proprioception and enhanced postural control with bracing.

Birmingham, et al. (2000)	Knee joint proprioception with axial loading	39 F, 20 M (23±2) healthy participants (CO)	5 (2)	Compression garment (NC)	Proprioception analysed with active, passive knee re-positioning task in sitting (NAX), supine (AX, 15% body weight)	Significantly enhanced knee proprioception during A.NAX and enhanced proprioception during P.NAX and A.AX conditions post-application of sleeve
Beynnon, et al. (1999)	Knee joint proprioception	7 F, 13 M (26-53) participants with ACL deficits (CO)	6 (2)	Compression garment (NC) and brace (FB)	Proprioception analysed with TDPM task	Enhanced TDPM post-application of compression garment
Birmingham, et al. (1998)	Knee joint proprioception	18 F, 18 M (24±2) healthy participants (CO)	5 (2)	Compression garment (NC)	Proprioception analysed with JPS task in sitting (OKC), supine (CKC)	Significantly enhanced proprioception accuracy with sleeve application, sitting OKC test better as compared to supine CKC
Jerosch and Prymka (1995)	Knee joint proprioception	10 F, 20 M (33 y) healthy participants (CO)	6 (2)	Bandage	Proprioception analysed with re-positioning task in supine position	Significantly enhanced knee joint proprioception post-application of bandage
Ankle joint						
Ellapen, et al. (2014)	Ankle joint proprioception	22 F participants with ankle injuries (14±1), 78 F healthy	7 (2)	Brace	Proprioception analysed with biodex system (bilateral dynamics limit of stability)	No enhancement of ankle proprioception noted post-application of ankle brace in injured

		participants (14±1) all hockey players				athletes, significant enhancement in non-injured athletes
Lee, et al. (2013)	Ankle joint proprioception and postural stability	41 M (21±3) athletes with CAI (CO)	6 (2)	Brace	Proprioception analysed with JPS task and postural stability analysed with static, dynamic, functional balance	Enhanced proprioception and balancing post 3 weeks application of orthosis
Iris, et al. (2010)	Ankle joint proprioception	28 F, 12 M (23±4) healthy participants (CO)	6 (2)	Tape	Proprioception analysed with JPS task	Significantly enhanced ankle proprioception during DF with taping
Son, et al. (2010)	Ankle joint proprioceptive thresholds and unipedal stance stability	3 F, 8 M (72±7) participants with peripheral neuropathy (CO)	4 (2)	Brace (MLSB)	Proprioception analysed with PT and UT tasks	No enhancement in PT and US, post-application of MLSB
Spanos, et al. (2008)	Ankle joint proprioception	4 F, 16 M (20 – 35) participants with injury (CO)	6 (2)	Tape (BWHL)	Proprioception analysed with AAR task	Significantly enhanced ankle proprioception post-application of tape

Halseth, et al. (2004)	Ankle joint proprioception	15 F, 15 M (18-30) healthy participants (CO)	6 (2)	Tape (KT)	Proprioception analysed with JPS task in IN and plantar flexion 20^{o}	No significant enhancement of joint position sense reported during plantar flexion with KT
Mumford (2003)	Ankle joint proprioception	16 F, 4 M (23±2) participants with unilateral chronic inversion injury (CO)	5 (2)	Tape	Proprioception analysed with AJRT task for IN and EV	Enhanced proprioception accuracy at rest post-application of taping, but no enhancement after activity
Simoneau, et al. (1997)	Ankle joint proprioception	20 M (20±1) healthy participants (CO)	6 (2)	Tape (ATs)	Proprioception analysed with JPP and JMPT tasks in CWB, NWB	Significantly enhanced joint proprioception under NWB, enhanced proprioception under CWB

EO: Eyes open, EC: Eyes closed, HT: Hopping test, KAT: Kinematic analysis test, AP: Anterior-posterior, ML: Medial-lateral, AT: Athletic tape, KT: Kinesio-tex tape, LLB: Lumbar lordosis brace, AMEDA: Active movement extent discrimination apparatus, EMG: Electromyography, PFM: Proprioceptive feed-back magnitude, UT: Upper trapezius, LT: Lower trapezius, AD: Anterior deltoid, SA: Serratus anterior, PAR: Passive angle reproduction, TDPM: Threshold for detection of passive motion, fMRI: Functional magnetic resonance imaging, BOLD: Blood oxygen level dependent, ST: Scapular taping, CoP: Centre of pressure LBP: Low back pain, F: Flexion, Ex: Extension, RB: Right bend, LB: Left bend, LSO: Lumbosacral orthosis, MDA: movement discrimination ability, WFCG: Well-fitted compression garment, LFCG: Loose fitted compression garment, AROM: Active range of motion, AAR: Active angle reproduction, PAR: Passive angle reproduction, E: Electrical stimulation, NLB: Neoprene lumbar brace, OA: Osteoarthritis, ACL: Anterior cruciate ligament, OKC: Open kinetic chain, CKC: Close kinetic chain, SEBT: Star excursion balance test, MSEBT: Modified star excursion balance test, SO: Soft orthosis, SRO: Semi-rigid orthosis, PKB: prophylactic knee brace, JPS: Joint position sense, FAI: Functional ankle instability, MLSB: Mediolateral support brace, LUB: Lace-up brace, SRB: Semi-rigid brace, BWHL: Basket-weave heel lock taping, AJRT: Active joint repositioning test, IN: Inversion, EV:

Eversion, ST: Standard taping technique, GTEE: Gibney taping eversion error, JPP: Joint position perception, JMPT: Joint movement perception threshold, CWB: Complete weight bearing, NWB: Non-weight bearing, ATs: Athletic taping strips, LC: lumbar corset, NC: neoprene compression sleeve, CO: crossover, PFPS: patellofemoral pain syndrome, OKC: open kinetic chain, CKC: closed kinetic chain, NS: neoprene shoulder stabilizer, US: unipedal stance, PT: proprioceptive threshold, AX: axial loading, NAX: non-axial loading, PWB: partial weight bearing, NWB: non-weight bearing, pT: patellar taping, AJRS: active joint re-positioning task, A: active, P: passive, LOE: Level of evidence, significant: $p < 0.05$, non-significant: $p > 0.05$

Postural Stability

Ten studies evaluating the effect of joint stabilizers on postural stability amongst healthy participants, participants affected by ankle instability and lumbar discopathy, were included in this review. Significant enhancements were reported in one excellent, and four good quality studies. No significant enhancements were reported in two good quality studies. Negligible enhancements were reported in two good and one fair quality studies. A 1a PEDro level of evidence, supported by two RCT's, suggested compression garments to significantly enhance postural stability among healthy participants. Likewise, a 2 PEDro level of evidence, supported by three CCT's, suggested an enhancement in postural stability post brace application. Further, a 1b PEDro level of evidence, supported by 1 RCT and four CCT's, suggested no significant effects of taping for enhancing postural stability amongst participants affected by ankle instability. The included studies overall scored an average of 6.7 indicating the quality of the studies to be good.

Brain activity

Two observational neuroimaging studies evaluating the effects of joint stabilizers on brain activity amongst healthy participants were included in this review. One study utilized taping, whereas the other study used compression garment and brace while analysing brain activity. A 5 PEDro level of evidence was computed for the included studies. The included studies overall scored an average of 5 indicating the quality of the studies to be fair.

Kinematic analysis

One study evaluated the effects of joint stabilizers on pelvic kinematics. Significant enhancement was reported in one good quality study. A 2 PEDro level of evidence, suggested significant enhancement of pelvic stability post lumbar corset application. The included study overall scored a PEDro score of 6 indicating the quality of the study to be good.

Shoulder joint

Three studies evaluated the effects of joint stabilizers on shoulder joint proprioception amongst healthy participants and participants with unstable shoulders were included in this review. Significant enhancements were reported in one good and two fair quality studies. A 2 PEDro level of evidence, suggested an enhancement in shoulder joint proprioception post brace, compression sleeve and scapular taping application, respectively. The included studies overall scored an average of 5.3 indicating the quality of the studies to be fair.

Spine

Three studies evaluated the effects of joint stabilizers on trunk proprioception amongst healthy participants and participants with low back pain were included in this review. Significant enhancements were reported in one good and two fair quality studies. A 2 PEDro level of evidence, supported by two CCT's, suggested an enhancement in trunk proprioception post brace application amongst healthy participants and participants affected by low back pain. Likewise, a 2 PEDro level of evidence, supported by one CCT, suggested no beneficial effects post brace application with a 3 week follow-up duration. The included studies overall scored an average of 6 indicating the quality of the studies to be good.

Hip joint

Two studies evaluated the effects of joint stabilizers on hip proprioception amongst healthy participants and football players were included in this review. No enhancements were reported in one excellent and one good quality study. A 1b PEDro level of evidence, supported by one RCT, suggested no enhancement in hip proprioception (kicking accuracy) post compression garment application amongst football players. Likewise, a 2 PEDro level of evidence, supported by one CCT, suggested negligible effects on proprioception and postural stability post compression garment application. The included studies overall scored an average of 8 indicating the quality of the studies to be good.

Knee joint

Twenty-one studies evaluated the effects of joint stabilizers on knee proprioception amongst healthy participants, participants with osteoarthritis, patellar disorders, and ACL deficits, were included in this review. Significant enhancements were reported in one excellent, ten good and five fair quality studies. No significant enhancements were reported in two good and 2 fair quality studies. Negligible enhancements were reported in two good quality studies. A 1b PEDro level of evidence, supported by one RCT, suggested tape to significantly enhance knee proprioception among participants affected by osteoarthritis. A 2 PEDro level of evidence, supported by

CCTs evaluating: ten (compression garment), two (bandage), three (tape) and four (brace), suggested significant enhancements in knee proprioception, amongst healthy participants, participants with patellofemoral pain syndrome, ACL deficits and osteoarthritis, respectively. Likewise, a 2 PEDro level of evidence, supported by one CCT, suggested negligible enhancements in knee proprioception post bandage application among participants affected by osteoarthritis.

Ankle joint

Eight studies evaluating the effect of joint stabilizers on ankle proprioception amongst healthy participants, and participants affected from ankle instabilities were included in this review. Significant enhancements were reported in three good quality studies. No significant enhancements were reported in one good and one fair quality study. Negligible enhancements were reported in two good, and one fair quality studies. A 2 PEDro level of evidence, supported by two CCT's, suggested taping to significantly enhance ankle proprioception among healthy participants. Likewise, a 2 PEDro level of evidence, supported by two CCT's (ankle instability), and one CCT (peripheral neuropathy), suggested negligible enhancements in ankle proprioception post brace application. Further, a 1b PEDro level of evidence, supported by 1 RCT and four CCT's, suggested no significant effects of taping for enhancing postural stability amongst participants affected by ankle instability. The included studies overall scored an average of 6.7 indicating the quality of the studies to be good.

Meta-analysis

Meta-analysis report

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Hettle et al. 2013	-0.146	0.239	0.057	-0.614	0.322	-0.613	0.540
Bicici et al. 2012	0.003	0.244	0.060	-0.475	0.482	0.014	0.989
Sawkins et al. 2007	-0.011	0.178	0.032	-0.359	0.338	-0.061	0.952
A	-0.043	0.123	0.015	-0.285	0.198	-0.351	0.725

	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chdewicki et al. 2006	0.000	0.252	0.063	-0.493	0.493	0.000	1.000
McNair et al. 1999	0.274	0.158	0.025	-0.036	0.584	1.733	0.083
B	0.196	0.134	0.018	-0.066	0.459	1.467	0.142

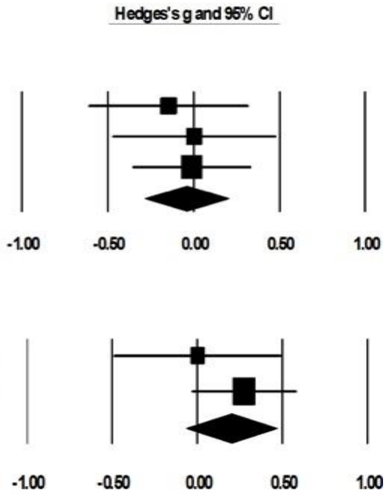

Figure 2 Forest plot illustrating individual studies evaluating the effects of joint stabilizers (A) taping on postural stability among participants with ankle instability (B) brace on trunk proprioception. Adjusted effect sizes; Hedge's g (boxes) and 95% C.I (whiskers) are presented, demonstrating repositioning errors for individual studies. The (Diamond) represents pooled effect sizes and 95% CI. A negative mean difference indicates a favourable outcome for control groups; a positive mean difference indicates a favourable outcome for experimental groups.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Collins et al. 2009	0.218	0.200	0.040	-0.173	0.610	1.093	0.275
Van Tiggelen et al. 2008	0.513	0.132	0.017	0.255	0.771	3.900	0.000
Herrington et al. 2005	0.514	0.230	0.053	0.065	0.964	2.241	0.025
Barrett 2003	0.537	0.263	0.069	0.022	1.053	2.042	0.041
Birmingham et al. 2000	0.445	0.135	0.018	0.181	0.710	3.302	0.001
Birmingham et al. 1998	0.716	0.184	0.034	0.356	1.076	3.898	0.000
Jerosch et al. 1996	0.460	0.187	0.035	0.092	0.827	2.453	0.014
A	0.486	0.066	0.004	0.357	0.615	7.359	0.000

	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Callaghan et al. 2008	-0.045	0.173	0.030	-0.383	0.298	-0.262	0.793
Moktarinia et al. 2008	-0.170	0.195	0.038	-0.553	0.212	-0.873	0.382
B	-0.100	0.129	0.017	-0.354	0.153	-0.775	0.438

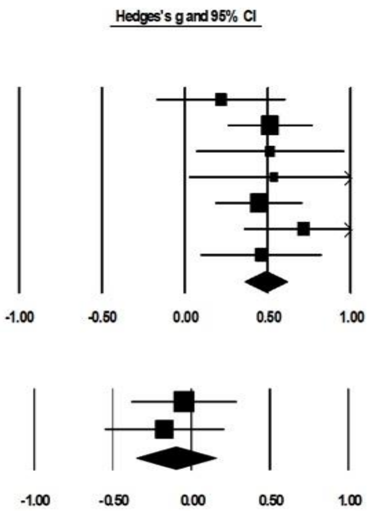

Figure 3 Forest plot illustrating individual studies evaluating the effects of joint stabilizers (A) compression garment on knee joint (B) taping on knee proprioception among participants affected from patellofemoral pain syndrome. Adjusted effect sizes; Hedge's g (boxes) and 95% C.I (whiskers) are presented, demonstrating repositioning errors for individual studies. The (Diamond) represents pooled effect sizes and 95% CI. A negative mean difference indicates a

favourable outcome for control groups, a positive mean difference indicates a favourable outcome for experimental groups.

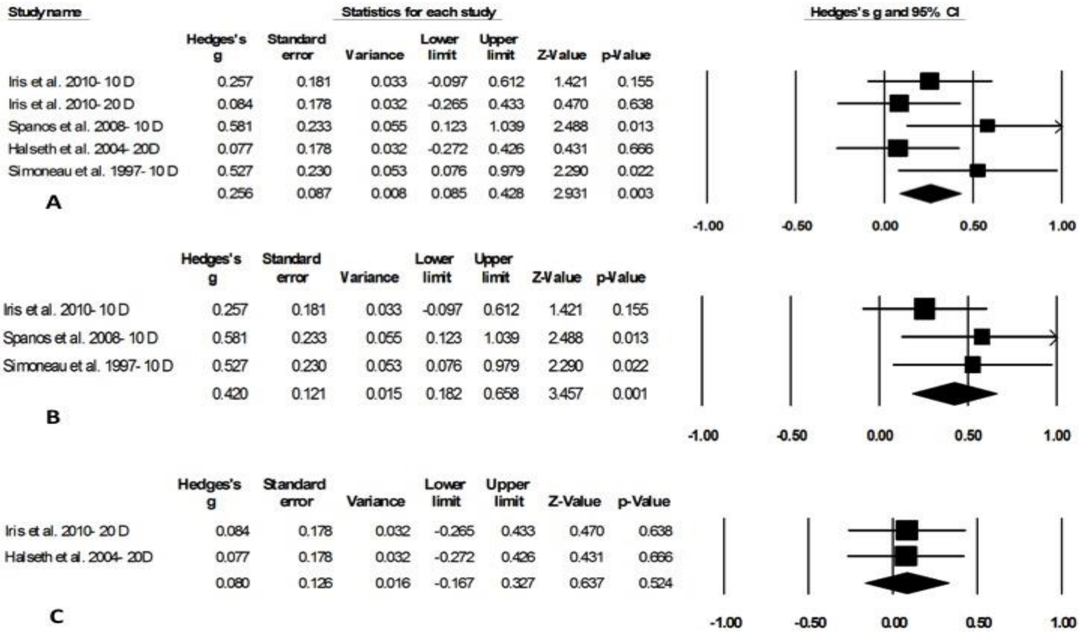

Figure 4 Forest plot illustrating individual studies evaluating the effects of joint stabilizer (taping) on ankle proprioception on participants affected from ankle instability (plantar flexion at 10° and 20°). Adjusted effect sizes; Hedge's g (boxes) and 95% C.I (whiskers) are presented, demonstrating repositioning errors for individual studies. The (Diamond) represents pooled effect sizes and 95% CI. A negative mean difference indicates a favourable outcome for control groups; a positive mean difference indicates a favourable outcome for experimental groups. 10D: target angle 10°, 20D: target angle 20°.

Postural stability

Three studies evaluating (Figure 2 A) the effects of ankle taping on postural stability were included in the analysis (Bicici, Karatas, & Baltaci, 2012; Hettle, Linton, Baker, & Donoghue, 2013; Sawkins, Refshauge, Kilbreath, & Raymond, 2007). The included studies evaluated the postural stability by incorporating functional dynamic reach using SEBT and MSEBT. The data incorporated in the analysis was from posterior medial direction (Robinson & Gribble, 2008). Upon analysis a *small* effect size was observed (Hedge's g: -0.04) and 95% CI (-0.28 to 0.19) was reported marginally in the negative domain, demonstrating a negligible effect of taping on functional amongst people affected by ankle joint instability. Heterogeneity tests reported negligible heterogeneity (I^2: 0%, p: 0.88, T^2: 0).

Spine

Two studies evaluating (Figure 2 B) the effects of lumbar and lumbosacral brace on trunk proprioception among healthy participants were included in the analysis (Cholewicki, Shah, & McGill, 2006; McNair, Stanley, & Strauss, 1996). Both the studies evaluated the proprioception accuracy using active proprioceptive tests. Statistical analysis revealed a *large* effect size of (Hedge's g: 0.19) and 95% CI (-0.06 to 0.45). However, cummulative analysis revealed beneficial significant effect of joint stabilizers on trunk proprioception among healthy participants. Heterogeneity tests revealed negligible heterogeneity (I^2: 0%, p: 0.35, T^2: 0).

Knee

Two separate analysis were included in this category evaluating the effects of joint stabilizers on proprioception (active tests), and patellofemoral pain syndrome (PFPS). Seven studies evaluating (Figure 3 A) the effects of compression sleeves on knee joint proprioception among healthy participants were included in the analysis (Barrett, 2003; Birmingham, Inglis, Kramer, & Vandervoort, 2000; Birmingham et al., 1998; Collins, Blackburn, Olcott, Dirschl, & Weinhold, 2009; Herrington et al., 2005; Jerosch & Prymka, 1995; Van Tiggelen et al., 2008b). All the studies evaluated the proprioception accuracy using active proprioceptive tests in a non-weight bearing condition. Upon analysis, a *large* effect size was observed (g: 0.48) and 95% CI (0.35 to 0.61) was reported in the positive domain, demonstrating a beneficial effect of compression sleeve application on knee joint proprioception amongst healthy participants. Heterogeneity tests revealed negligible heterogeneity (I^2: 0%, p: 0.73, T^2: 0).

In the second analysis, two studies evaluating (Figure 3 B) the effects of taping on knee joint proprioception among participants affected by patellofemoral pain syndrome were included (Callaghan et al., 2008; Mokhtarinia, Ebrahimi-Takamjani, Salavati, Goharpay, & Khosravi, 2008). Both the studies evaluated the proprioception accuracy using active proprioceptive tests in a non-weight bearing condition. Upon analysis, a *small* effect size of (g: -0.1) and 95% CI (-0.35 to 0.15) were observed in the negative domain. Heterogeneity tests revealed a negligible heterogeneity (I^2: 0%, p: 0.63, T^2: 0). Two separate analysis were also conducted evaluating the effects of joint stabilizers on proprioception where studies utilized passive proprioceptive tests, (Birmingham et al., 2000; Callaghan, Selfe, Bagley, & Oldham, 2002; Herrington et al., 2005; Wong, To, & Lam, 2001), and studies elucidating the effects of joint stabilizers on osteoarthritis (Birmingham et al., 2001; Cho, Kim, Kim, & Yoon, 2015; Collins et al., 2011; Hassan, Mockett, & Doherty, 2002). However, the studies varied considerably in terms of methods incorporated in evaluating the proprioception variables and the joint stabilizer. Significant heterogeneity was observed in both the analysis; passive proprioceptive tests (I^2: 84.5%, $p < 0.001$, T^2: 0.15) and osteoarthritis (I^2: 84.2%, p: 0.02, T^2: 0.23). Therefore, an inclusion of the statistical analysis was not considered appropriate.

Ankle

Four studies evaluating (Figure 4 A) the effects of taping on ankle proprioception among participants affected by ankle instability injuries were included in the initial statistical analysis (Halseth, McChesney, DeBeliso, Vaughn, & Lien, 2004; Iris et al., 2010; Simoneau, Degner, Kramper, & Kittleson, 1997; Spanos, Brunswic, & Billis, 2008). All the studies evaluated the proprioception accuracy using active proprioceptive tests in a non-weight bearing condition. Initial analysis included studies evaluating proprioception accuracy at different target angles (10° and 20°). Upon analysis a *large* effect size of (g: 0.25) and 95% CI (0.08 to 0.42) were observed in the positive domain, demonstrating a beneficial effect of taping application on ankle joint proprioception amongst people affected by ankle joint instability. Heterogeneity tests revealed minor heterogeneity among the studies (I^2: 24.14%, p: 0.26, T^2: 0.012). Further, the studies were again analysed separately studies based on their repositioning angles. Three studies were pooled separately for target angle of (Figure 4 B) 10° (Iris et al., 2010; Simoneau et al., 1997; Spanos et al., 2008), and two studies were separately pooled for target angle of (Figure 4 C) 20° (Halseth et al., 2004; Iris et al., 2010). The analysis for target angle of (10°) revealed a *large* effect size (g: 0.42) and 95% CI (0.18 to 0.65), with heterogeneity evaluated at (I^2: 0%, p: 0.47, T^2: 0) and for (20°) a *medium* effect size of (g: 0.08) and 95% CI (-0.16 to 0.32), with heterogeneity (I^2: 0%, p: 0.97, T^2: 0) were evaluated. Therefore, suggesting a beneficial impact of ankle taping on proprioceptive accuracy at a target angle of 10° as compared to 20°.

Discussion

This systematic review and meta-analysis aimed to further our understanding of the effects pertained by different joint stabilizers on postural stability, and joint proprioception among different population groups. The present literature, meta-analysis and PEDro level of evidence shows that joint stabilziers have demonstrated beneficial capabilities for enhancing proprioception and stability. The prominent role of proprioception in maintaining postural stability and motor control has been emphasized in several studies (Grigg, 1994; Herrington et al., 2005; Michael et al., 2014; Munoz, Salmochi, Faouen, & Rougier, 2010; Vaugoyeau, Viel, Amblard, Azulay, & Assaiante, 2008). Proprioception has been suggested to serves as a major prophylactic measure to avoid musculoskeletal injuries (Jerosch & Prymka, 1996). In order to offset any decline in proprioceptive accuracy joint stabilizers are commonly incorporated in modern sport (Fu et al., 2013), and rehabilitation (Callaghan et al., 2002; Callaghan et al., 2008), settings. The current review identified multiple mechanisms by which joint stabilizers enhance proprioceptive feedback. Firstly, Herrington et al. (2005), Birmingham et al. (2000) and Van Tiggelen et al. (2008b) suggested amplification of the afferent inputs by the cutaneous tactile receptors, and mechanoreceptors present on the musculoskeletal structures underneath the joint stabilizers to be the primary mechanism for enhancing proprioception. Secondly, Thijs et al. (2010) and Callaghan et al. (2012) asserted amplified BOLD activity within brain centres related to proprioception, sensation, and coordination to be additional factors for amplifying proprioceptive feedback. Thirdly, changes in musculoskeletal activation pattern post joint stabilizer application in the EMG analysis were also speculated to be important factors for modulation of proprioceptive factors. Lin et al. (2011) for instance, reported an increased activity of serratus anterior and decreased activity of upper trapezius and anterior deltoid, post scapular taping application. The researchers associated this differential activation pattern with the rehabilitation of scapulo-thoracic syndrome (Lin et al., 2011). Additionally, altered vastus medialis obliqus activity and threshold recruitment have been reported in studies (Gilleard, McConnell, & Parsons, 1998; Mokhtarinia et al., 2008), which further were reported to enhance knee joint proprioception. Lastly, the passive supporting, stabilizing properties of the joint stabilizers towards relatively weak musculoskeletal structures has been suggested to stimulate normal kinematic (Vogt, Pfeifer, Portscher, & Banzer, 2000), and biomechanical positions (Lee et al., 2013), which further allows improved proprioceptive feedback. Munoz et al. (2010) and Vogt et al. (2000) for instance, related these supportive properties as key factors in their study for restoring the lumbar spine curvature and reducing the range of pelvic oscillations, which further resulted in improved proprioceptive accuracy, pelvic stability amongst healthy participants and participants affected by low back pain, respectively. In agreement with the abovementioned mechanisms, two meta-analysis studies included in this review revealed beneficial effects of compression garments (g: 0.48) 95% CI (0.35 to 0.61), taping (g: 0.42) 95% CI (0.18 to 0.65) on knee and ankle joint respectively

Retrospectively, these joint stabilizers in addition to their prophylactic, performance enhancing nature have been suggested to also play a preventative role during motor performance. Bernhardt and Anderson (2003) for instance, asserted their non-significant results while measuring proprioception, agility and balance towards protective resistance offered by the compression garments on the musculoskeletal structures to restrict the range of motion and generate fatigue, further leading to poor proprioception. However, upon the further interpretation of results from different studies, the authors identified these preventative properties to go either ways i.e. provide beneficial or detrimental effects depending upon the grade of musculoskeletal injury, and the tests for measuring stability/proprioception. To begin with, Hadadi et al. (2014) and Faraji, Daneshmandi, Atri, Onvani, and Namjoo (2012) observed significantly enhanced reaching capabilities in participants affected by functional ankle injuries performing SEBT. The researchers reported an enhanced reach capability while using soft orthosis as compared to semi-rigid orthosis and asserted their benefits towards limited constraints provided by soft orthosis on the musculoskeletal structures as compared to the semi-rigid orthosis. This was also shown in the meta-analysis evaluating postural stability, where a cumulative effect size of (Hedge’s g: -0.04) and 95% CI (-0.28 to 0.19) was observed, signifying adverse effects of joint stabilizers with higher mechanical restraints for functional performance. On the contrary, Ellapen et al. (2014) inferring from their results speculated inadequate mechanical restraint provided by taping, towards weak musculoskeletal structures (anterior and posterior talofibular and calcaneofibular ligaments), to limit neural firing and subsequent evertor activation of ankle proprioceptors, thereby adversely impacting the proprioception. Therefore, suggesting an inverse relationship in between increased mechanical restraints of the joint stabilizers towards dynamic stability tests and vice versa for the proprioceptive/ stability tests for weak musculoskeletal structures.

Moreover, recent research has contemplated certain psychological benefits that can be imparted post joint stabilizers application. For instance, enhanced perception of stability and confidence post application of Joint Stabilizers has been reported in several studies (Bernhardt & Anderson, 2005; Callaghan et al., 2008; Lien et al., 2014; Michael et al., 2014). Callaghan et al. (2012) re-affirmed these results within their fMRI analysis and linked decreased BOLD response in the anterior cingulate cortex and cerebellum during application of taping to be associated with the diminished perception of task difficulty. This increase in perception of stability and confidence can have widespread implications as it has been suggested to play key roles during sports performance (Feltz, 1988), and rehabilitation (Armatas, Chondrou, Yiannakos, Galazoulas, & Velkopoulos, 2007). This review also included studies analysing critical aspects of structure, material, fitting of joint stabilizers and their implications for enhancing performance and rehabilitation. According to Fu et al. (2013), joint stabilizers should provide optimized compression, fit, and skin contact, which is an essential component for assisting throughout sports performance and rehabilitation. This was supported by two excellent quality (9 PEDro) randomized controlled trials. Firstly, Michael et al. (2014) reported enhanced single leg stance with closed eyes, when participants wore well-fitted compression garments. Secondly, Lien et al. (2014) while analysing the drop punt kick accuracy amongst elite football players speculated a strong correlation between the fitting, comfort, and enhanced accuracy. Researchers from both the studies implied that participants felt more confident with comfortable and well-fitted compression garments. Moreover, Lien et al. (2014) further speculating from their results suggested the low skill group i.e. the group with poor inherent proprioceptive feedback performed better post joint stabilizers application as compared to their counterparts (high skill group). Adding to that, Cameron, Adams, and Maher (2008) asserted such differences encountered among participants with different proprioceptive capabilities to an “overload mechanism”. The mechanism implies that excessive cutaneous feedback amongst highly skilled individuals with “good” inherent proprioceptive capabilities (receiving optimal afferent input), for instance, sports personnel, may result in the decrement of proprioception. On the contrary, low skilled individuals with “poor” inherent proprioceptive capabilities (lacking sufficient afferent input), such as injured participants, are benefited by this mechanism of enhanced proprioceptive inputs via enhanced cutaneous stimulation. The findings obtained from the meta-analysis conducted on studies analysing spine where a cumulative effect size of (0.19) and 95% CI (-0.06 to 0.45), and knee joint proprioception among participants affected by patellofemoral pain syndrome (-0.1) and 95% CI (-0.35 to 0.15), can be asserted towards the “overload mechanism” suggested by (Cameron et al., 2008). Likewise, overload mechanism has been attributed by Chu et al. (2002), Callaghan et al. (2002), Bernhardt and Anderson (2005), Bottoni, Heinrich, Kofler, Hasler, and Nachbauer (2014), and Bottoni et al. (2013) while reporting no significant enhancements amongst healthy participants, sports personnel and Cho et al. (2015), Birmingham et al. (2001), and Callaghan et al. (2008) while reporting significant enhancements amongst injured participants, in proprioception accuracy post joint stabilizers application.

The review also briefly analysed the functioning of common proprioceptive testing procedures that are conducted in an active or passive manner. Cholewicki et al. (2006) hypothesized that active proprioceptive tests are associated with higher extent of fusimotor drive and muscle receptor involvement in the sensory input during active repositioning trials. Additionally, studies have also reported active repositioning trials to be a more functional assessment of afferent pathways as a result of general attenuation and selective gating of kinaesthetic awareness during active voluntary movements (Kaminski & Perrin, 1996; Lephart et al., 1997). The researchers also related the role of muscle spindles during conscious perception of limb movement to be higher as they detect changes in muscle length during voluntary contractions (McCloskey, 1978a), as compared to the passive trials (Kaminski & Perrin, 1996; Lephart et al., 1997). Thereby, suggesting active proprioceptive tests to be a more functional assessment of proprioception as compared to the passive tests. The differences in proprioceptive perceptions within different tests might explain the non-significant enhancements observed within studies using passive proprioceptive tests (Cholewicki et al., 2006; Hassan et al., 2002). Consequently, some studies also reported no significant enhancements while analysing elderly participants (Hassan et al., 2002), and participants with neurological disorders (Son, Ashton-Miller, & Richardson, 2010). We believe, the enhancement procured post joint stabilizers application despite being “trivial” can be of great importance. Proprioception has been inversely related with age (Skinner, Barrack, & COOK, 1984). Moreover, the participants in the study were affected by peripheral neuropathy (Son et al., 2010), and osteoarthritis (Hassan et al., 2002), which further predisposes towards poorer proprioception (Birmingham et al., 2001). Attaining even slightest of benefits in the similar conditions can be of remarkable value. This present review also pertained some limitations. A major limitation of the current review was the selection of limited academic databases (Scopus, PEDro, SportDiscus, and EMBASE) within the search strategy due to limited database accessibility levied by the academic institution.

In summary, our literature search was conducted on four online academic search databases Scopus, PEDro, SportDiscus, and EMBASE. We encountered 2954 articles in our initial search, however, the implementation of our inclusion criteria reduced the number of studies to 50 (PRISMA flowchart). Thereafter, a modified PEDro level of evidence and meta-analysis was conducted within homogenous paired studies. A 1a PEDro level of evidence suggested beneficial effects of compression garments for enhancing postural stability. Moreover, a 1b PEDro level of evidence suggested beneficial effects of taping for enhancing postural stability and knee joint proprioception. In conclusion, the systematic review revealed beneficial effects of joint stabilizers for enhancing have demonstrated their beneficial abilities across the population groups for enhancing performance, rehabilitation, and reducing the risks of injuries during short/longer term durations. The findings inform clinical implications for the preventive and rehabilitative use of joint stabilizers in modern sports and rehabilitation settings.

Future directions

A significant paucity of literature persists for evaluating the effects of joint stabilizers at musculoskeletal sites with a higher predisposition to injuries, such as wrist, elbow, and shoulder joint. We recommend that future research studies elucidate the stabilizing effects of joint stabilizers on these joints. Moreover, to the best of our knowledge only two articles have evaluated the effects of joint stabilizers on brain activity, therefore, we strongly encourage future researchers to carry out similar research studies so as to evaluate the underpinning physiological mechanisms for proprioceptive enhancements behind joint stabilizers.

Chapter 3

Posture & awareness: A systematic review and level of evidence analysis

Preface

The primary objective of this chapter was to review the current state of literature pertinent to secondary tasks and their effects on proprioception. An emphasis was placed on elucidating factors that are highly associated with proprioceptive functioning, namely static and dynamic postural stability. This chapter included a systematic review across five academic databases; Scopus, PEDro, MEDLINE, EMBASE and SportDiscus. The effects of tasks on postural stability were studied in population groups differentiated on the basis of age and neurological ailments. A critical appraisal of the included studies from a PEDro methodological scale and Cochrane risk of bias assessment tool was included. Thereafter, a conclusive synthesis of the included studies on the basis of modified PEDro level of evidence scale was developed. The review also included viable secondary task training methods and posture first strategies applicable across different population groups. The chapter also discusses mechanisms that effectively compensate the limited central capacity-sharing model and reduce conscious attention build-up while maintaining postural stability. The objectives were to:

1. Systematically investigate research-based literature pertinent to secondary task interventions and their effects on proprioceptive, performance and stability measures.
2. Describe the underlying physiological mechanisms associated with secondary task interventions for enhancements pertained with motor skill execution.
3. Identify the differential effects of secondary task interventions on different population groups, differentiated on the basis of age, gender and neurological ailments.

Abstract

Objective: A systematic review was performed to examine the influence of secondary tasks and training application on static and dynamic postural stability.

Literature survey: Systematic identification of published literature was performed adhering to PRISMA guidelines, from inception until August 2015, on online databases; Scopus, PEDro, MEDLINE, EMBASE and SportDiscus.

Methodology: Experimental studies analysing the effects of secondary task on postural stability were extracted and critically appraised using PEDro scale and Cochrane risk of bias tool. 1284 studies met the inclusion criteria and were further analysed for inclusion. The studies were then summarized according to modified PEDro level of evidence scale.

Synthesis: Twenty-nine studies including two randomized controlled trials and 27 quasi-experimental studies with a total of 1052 participants, was included in the synthesis. According to PEDro level of evidence scale a level 1b of evidence suggested beneficial effects of secondary task training on postural stability among elderly. Moreover, a 2 PEDro level of evidence suggested no significant effects of secondary task on postural stability amongst participants affected by neurological disorders, such as Parkinson's disease, and multiple sclerosis. Likewise, a level 2 PEDro evidence suggested enhanced decrements in postural stability post-secondary task inclusion among elderly participants with history of falls as compared to healthy young and elderly participants.

Conclusion: Incorporation of a secondary task paradigm causes more enhancements in postural stability among young compared to old people and fall prone population groups. Recent research evidence suggests incorporation of "posture first" and "secondary task training" maneuvers to prioritize lower conscious attention to a primary task. Clinical implications are discussed with respect to secondary task application in modern sports and rehabilitation settings.

Introduction

Postural stability is an integral component of the motor control and coordination process of the body, which is required for preserving steadiness during static and dynamic activities (Wikstrom, Tillman, Smith, & Borsa, 2005). These involuntary "postural-control" components, for instance, proprioception are dependent on complex sensorimotor actions, which in turn are based upon automated and reflexive spinal programs under separate supraspinal centres in the brainstem, cerebellum, and cortex (Fujita, Kasubuchi, Wakata, Hiyamizu, & Morioka, 2016). Several studies have suggested that any increase in conscious attention to postural control increases the likelihood of disrupting coordination and stability, possibly as a consequence of movement specific reinvestment (Masters, 1992; Masters & Maxwell, 2008), and consequently increases the possibilities of postural instability and injuries. The theory of reinvestment suggests that directing attention internally to control movements that are normally automatic can disrupt their performance. The theory further adds that ageing (Schaefer, Schellenbach, Lindenberger, & Woollacott, 2015), neurological ailment and injuries (Masters & Maxwell, 2008) are common conditions that promote movement specific reinvestment. Seidler et al. (2010) reaffirmed these suggestions and associated physiological changes with ageing, injury to loss in gray/white matter within the central nervous system, further resulting in differential-reorganized cortical activation. Additionally, this differential cortical activation within the higher neural centres has been speculated to be an important reason for changes in task prioritization and conscious attention, while carrying out tasks (Talelli, Ewas, Waddingham, Rothwell, & Ward, 2008).

To overcome this higher conscious attention, distracting secondary tasks have been commonly employed in several studies (Donker, Roerdink, Greven, & Beek, 2007; Masters & Maxwell, 2008; Schaefer, Jagenow, Verrel, & Lindenberger, 2015). A secondary task is a measure for directing a performers attention towards an external source of attention (e.g. backward counting task, random letter generation), other than the primary task. According to the constrained action hypothesis, this attentional change might allow motor systems to function in an automatic manner, unconstrained by interferences caused by conscious control, thereby resulting in more effective performance (Wulf, McNevin, & Shea, 2001). Moreover, secondary tasks might effectively 'soak up' information processing resources that otherwise would be available for focussing on a motor task, for instance gait or postural control. Subsequently, practical applications for enhancing the automation of postural control has been demonstrated in several studies evaluating complex motor skills (Beilock & Carr, 2001), stability (Resch, May, Tomporowski, & Ferrara, 2011), and gait (Schaefer, Jagenow, et al., 2015). Interestingly, recent studies have also suggested beneficial effects of secondary task training methods over conventional secondary task application. Hiyamizu, Morioka, Shomoto, and Shimada (2012) and Choi, Kim, Han, and Kim (2015) for instance, demonstrated beneficial aspects of secondary task training to contribute towards smoothening of various cognitive abilities that are essential for preventing falls.

We, therefore, conducted a systematic review analysing the effects of secondary tasks and secondary task training on postural stability among various population groups. The review is the first to simultaneously examine the effects of secondary task training and secondary tasks on static and dynamic postural stability.

Methods

This review was conducted according to the guidelines outlined in Preferred Reporting Items for Systematic Reviews and Meta-analysis: The PRISMA statement (Moher et al., 2009).

Data sources and search strategy

The databases Scopus, PEDro, SportDiscus, EMBASE and MEDLINE were searched from inception until September 2015. The included databases were limited to Scopus, PEDro, SportDiscus, EMBASE and MEDLINE due to access regulations from the university. The selection of the search keywords was done according to existing knowledge of the authors, and additionally, medical subject headings (MeSH) was also searched for relevant search keywords. The following keywords were used: postural stability OR balance stability OR static stability OR dynamic stability OR posturography OR centre of pressure sway OR CoP OR centre of mass sway OR CoM OR centre of gravity sway OR CoG AND cognitive task OR secondary task OR motor task OR dual task OR secondary task OR triple task OR multitasking OR working memory task OR individuals prone to fall AND young adults OR old adults OR elderly AND neurological conditions OR Parkinson’s disease OR parkinsonism OR stroke OR multiple sclerosis OR ataxia

OR cerebellar dystrophy AND rehabilitation OR training OR prevention of injury were used. The inclusion criteria for the studies were (i) Performed studies were either randomized controlled trials (RCTs), cluster RCTs, quasi-experimental studies; (ii) Measurement of postural stability used highly valid and reliable methods (static & dynamic posturographic analysis, star excursion balance test, modified star excursion balance test, active movement extent discrimination apparatus); (iii) Secondary tasks performed during the research were reliable & valid; (iv) Studies scored (≥4) on PEDro methodological quality scale; (v) Experiments were conducted on human participants; (vi) Published in a peer-reviewed academic journal; (vii) Articles published in English and/or German language. Studies evaluating the abovementioned parameters on participants below the age of 18 years were not included, as the development of postural control centres has been reported to take place during this developmental phase (Steindl & Ulmer, 2004). Studies where a secondary task was used to evaluate postural stability whilst sitting were excluded. Moreover, studies which evaluated postural stability using video graphic and kinematic analysis were also excluded. All the studies identified during the search were independently screened (Figure 1.0) for eligibility by a primary researcher under the supervision of the second author and every effort was undertaken to avoid subjective bias (Centre for Reviews and Dissemination, 2009). Preliminary analysis for selection was performed by analysing titles and abstracts and, wherever necessary, the entire text of the article was studied. In cases where further clarification of the published data was required, the researcher made attempts to contact the respective authors. Bibliographic sections of all the articles were retrieved for further evaluations. Citation search for all the included articles was performed using Web of Science.

Data extraction

Upon selection for review, the following data were extracted from each article; author, date of publication, selection criteria, sample size, sample description (gender, age, health status), intervention, outcome measures, results and conclusions. The data were then summarized and tabulated. Furthermore, classification of studies was made based on their experimental application (Higgins & Green, 2008), and the population groups assessed.

Quality & risk of bias assessment

The quality of the studies was assessed using the PEDro methodological quality scale (de Morton, 2009). The scale consists of 11 items addressing external validity, internal validity and interpretability. The PEDro scale can detect potential bias with fair to good reliability (Maher et al., 2003), and is a valid measure of methodological quality of trials (de Morton, 2009). A blinded rating of the methodological quality of the studies was carried out by the primary reviewer. Ambiguous issues were discussed between reviewers and consensus was reached. For the included quasi experimental studies, a scoring of 9-10, 6-8 and 4-5 was considered to be to of "excellent", "good" and "fair" quality (Teasell, 2008), respectively. Likewise, level of evidence was suggested to be of level 1a (strong) if more than one RCT (≥6) with similar methodological approaches were consistent with the results (Teasell, 2008). Likewise, a modified evidence synthesis guideline was utilized to analyse the strength of the findings for each outcome (Sackett, 2000). In case of differential results amongst paired group of studies, the result of study(s) with higher PEDro score were given more consideration (Teasell et al., 2005a). Moreover, assessment of risk of biasing for RCTs was made using Cochrane's risk of bias tool (Bero et al., 1998), modified by (Dorrestijn, Stevens, Winters, van der Meer, & Diercks, 2009). Inadequate randomization, non-blinding of assessors, no intention to treat analysis and no measurement of compliance were considered as major threats to biasing (Ramsey et al., 2014).

Data Analysis

Inclusion of a meta-analysis although theoretically possible was not considered appropriate for the study. The included research studies were extremely heterogeneous as they varied greatly in research designs, parameters, testing procedures, settings, sample size and participants. Inclusion of a heterogeneity test, such as I^2, Tau^2 was not possible because of differential, methods, variables and population groups evaluated. Therefore, a formal statistical analysis was not considered appropriate (Weightman & Williamson, 2005). As per recommendations by the Centre for Reviews and Dissemination (Higgins & Green, 2008), narrative synthesis of the findings structured around the type of intervention, population characteristics, methodological quality and the type of outcome were tabulated and described.

Results

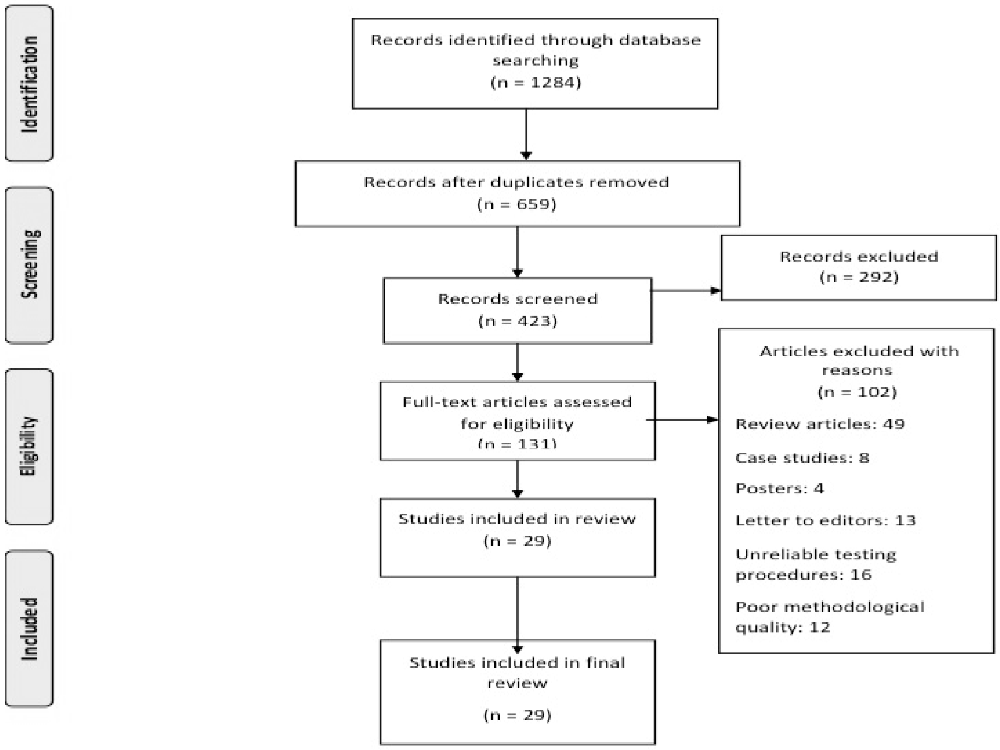

Figure 5 Flow diagram illustrating studies for inclusion in the review study (PRISMA flow diagram)

Characteristics of included studies

Our initial search yielded a total of 1284 studies, which on implementing our inclusion/exclusion criteria, were reduced to twenty-nine (Figure 5). Data from the included studies have been summarized in Tables (2-5). Of the twenty-nine studies, two were RCTs and twenty-seven were quasi-experimental studies. Twenty one studies evaluated the effects of secondary tasks on postural stability amongst healthy young and/or old participants, with/without history of fall. Six studies evaluated similar effects amongst participants suffering from neurological ailments, such as degenerative cerebellar disorder (Jacobi et al., 2015), Parkinson’s disease (Holmes, Jenkins, Johnson, Adams, & Spaulding, 2010; Marchese, Bove, & Abbruzzese, 2003), and multiple sclerosis (Boes et al., 2012; Negahban et al., 2011; Prosperini et al., 2015). Two studies evaluated the effects of secondary task training on postural stability amongst healthy old adults (Hiyamizu et al., 2012), and participants affected by sub-acute stroke (Choi et al., 2015).

Participants

In the included studies, twenty-four studies incorporated mixed gender populations. Three studies incorporated only female participants (Swan, Otani, & Loubert, 2007; Swan, Otani, Loubert, Sheffert, & Dunbar, 2004), and one study incorporated only male participants (Vuillerme, Isableu, & Nougier, 2006). One study didn't specify the gender of the included participants (Melzer, Benjuya, & Kaplanski, 2001). The included studies provided data on 1052 participants (n=614 females/438 males). Descriptive statistics relating to the age (mean ± standard deviation) of the participants were tabulated across the studies. Three studies provided the median age of participants (Hunter & Hoffman, 2001; Teasdale, Bard, LaRue, & Fleury, 1993; Teasdale & Simoneau, 2001), and five studies mentioned the age range of participants (Donker et al., 2007; Pellecchia, 2003; Ramenzoni, Riley, Shockley, & Chiu, 2007; Swan et al., 2007; Swan et al., 2004).

Interventions for stability assessment

All the included studies except (Resch et al., 2011), assessed the effects of secondary task interventions on postural stability by measuring centre of pressure, mass and gravity sway. Resch et al. (2011) assessed postural stability using sensory organization test a test to measure static and dynamic aspects of postural stability. Additionally, two studies evaluated the postural stability while analysing sway analysis post-secondary task training (Choi et al., 2015; Hiyamizu et al., 2012).

Secondary task

The primary aim of the systematic review was to evaluate the effects of secondary tasks on postural stability. Secondary tasks that were included in the studies have been specified in Table 2-5.

Risk of bias within studies

In order to efficiently reduce the risks of bias, the included studies had to score ≥4 on PEDro scale to be included in the review. Moreover, the limitation of research protocols to be included in the review was limited to gold standard RCT's, cluster RCTs and quasi-experimental studies. The individual scores attained by the studies using the PEDro scale have been reported (Table 2-5, Appendices 10), and Cochrane risk of bias assessment and scoring reported (Appendices 11). The average PEDro score for the twenty nine included studies was computed to be 5.8 out of 11, indicating fair quality of the overall studies (Teasell, 2008). One study scored 9 (Hiyamizu et al., 2012), one study scored 8 (Choi et al., 2015), eight studies scored 7 (Brown, Shumway-Cook, & Woollacott, 1999; Marsh & Geel, 2000; Negahban et al., 2011; Ramenzoni et al., 2007; Resch et al., 2011; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997; Swan et al., 2007; Swan et al., 2004), six studies scored 6 (Boes et al., 2012; Donker et al., 2007; Haggerty, Jiang, Galecki, & Sienko, 2012; Teasdale et al., 1993; Teasdale & Simoneau, 2001; Vuillerme et al., 2006), nine studies scored 5 (Brauer, Woollacott, & Shumway-Cook, 2002; Brauer, Woollacott, & Shumway-Cook, 2001; Dault, Geurts, Mulder, & Duysens, 2001; Huxhold, Li, Schmiedek, & Lindenberger, 2006; Jacobi et al., 2015; Marchese et al., 2003; Pellecchia, 2003; Prosperini et al., 2015; Shumway-Cook & Woollacott, 2000), and four studies scored 4 (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; Holmes et al., 2010; Hunter & Hoffman, 2001; Melzer et al., 2001). Likewise, two RCT's were appraised using the Cochrane risk of bias tool; one study obtained a score of 6 (Hiyamizu et al., 2012), indicating a low risk of bias and one study scored 5 (Choi et al., 2015), indicating limited biasing.

Risk of bias across studies

Common methodological shortfalls were inadequate concealment, non-blinding of participants, non-blinding of assessors, and randomized allocation. Ten studies reported randomized allocation of experimental groups (Brown et al., 1999; Choi et al., 2015; Hiyamizu et al., 2012; Marsh & Geel, 2000; Negahban et al., 2011; Ramenzoni et al., 2007; Resch et al., 2011; Shumway-Cook et al., 1997; Swan et al., 2007; Swan et al., 2004). Further, only two studies reported blinding of subjects (Choi et al., 2015; Hiyamizu et al., 2012), and only one study reported blinding of assessors and concealed allocation (Hiyamizu et al., 2012). Additionally, the authors were unable to interpret concealed allocation of participants in three studies (Negahban et al., 2011; Ramenzoni et al., 2007; Swan et al., 2007).

Three studies evaluated the effects of secondary tasks on posture stability as an additional measure, involving assessments of stability with calf stimulation

(Andersson et al., 2002), electromyography evaluations (Melzer et al., 2001), and biofeedback evaluations (Haggerty et al., 2012). Overall risk of bias for quality assessment within studies has been illustrated in Figure 6.

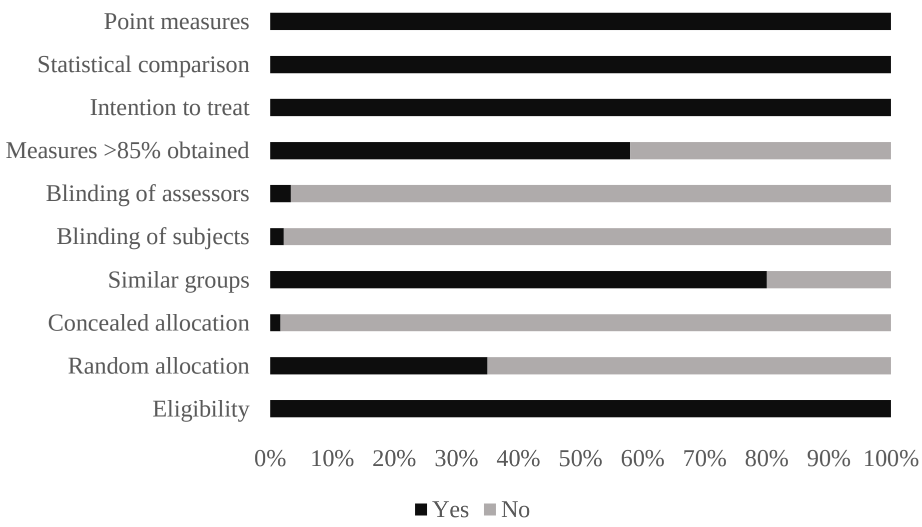

Figure 6 Risk of bias across studies

Secondary task training

Two RCTs (Table 2) evaluated the effects of secondary task training on postural stability amongst healthy old participants (Hiyamizu et al., 2012) and participants affected by sub-acute stroke (Choi et al., 2015). Choi et al. (2015) incorporated a training duration of 4 weeks, and Hiyamizu et al. (2012) incorporated a training duration of 3 months. One study reported significant enhancement in postural stability post training (Choi et al., 2015), whereas the other study evaluating healthy and old participants revealed no significant difference in postural stability amongst participants (Hiyamizu et al., 2012). RCTs according to the PEDro methodological scale computed an average score of 8.5, indicating the average quality of the studies to be good. Cochrane risk of bias assessment of the two included RCT’s revealed a score of 6 (Hiyamizu et al., 2012), and 5 (Choi et al., 2015), indicating high quality with limited biasing amongst the studies.

Table 2 Studies showing effects of secondary task training on postural stability

Study	Research aim	Sample description	PEDro score	Research design	Conclusion
Choi et al. (2015)	Assess the effects of ST training on postural stability amongst participants suffering from SAC.	SAS: 8F, 12 M (59±12)	8	Postural stability assessed post ST training for 4 weeks.	Significant enhancement in postural stability post ST training.
Hiyamizu et al. (2012)	Assess the effects of ST training on postural stability amongst healthy old participants.	Old: STr- 10F, 7M (72±5) ST: 16F, 3M (71±4)	9	Postural stability assessed post ST training 3 months (ST) with/without ST, EO/EC.	No significant difference in postural sway after ST training. ST performance significantly enhanced post ST training.

SAS: Sub-acute stroke, ST: Secondary task, STr: Secondary task training, EO: Eyes open, EC: Eyes closed, M: Male, F: Female, Significant: $p < 0.05$, Non-significant: $p > 0.05$.

Neurological impairments

Six studies (Table 3) evaluating the effects of secondary task performance on postural stability amongst participants affected by neurological disorders such as, cerebellar disorder (Jacobi et al., 2015), Parkinson's disease (Holmes et al., 2010; Marchese et al., 2003), and multiple sclerosis (Boes et al., 2012; Negahban et al., 2011; Prosperini et al., 2015), were included in the review. Significant enhancements in postural stability were reported in one good and one fair quality study, conducted amongst participants affected by multiple sclerosis (Negahban et al., 2011) and Parkinson's disease (Holmes et al., 2010), respectively. Additionally, three good quality studies reported significant reduction in postural stability amongst individuals affected by Parkinson's disease, multiple sclerosis (Boes et al., 2012; Prosperini et al., 2015), and degenerative cerebellar disorder (Jacobi et al., 2015). One good quality study reported reduction in postural stability (not significant) amongst participants affected by Parkinson's disease (Marchese et al., 2003). Five studies evaluated the comparative effects between healthy participants and participants affected by neurological disorders (Holmes et al., 2010; Jacobi et al., 2015; Marchese et al., 2003; Prosperini et al., 2015), but one study evaluated the comparison between participants affected by mild and moderate multiple sclerosis (Boes et al., 2012). Additionally, two studies evaluated the inclusion of stable and unstable surfaces for maintaining postural stability whilst performing a secondary task (Jacobi et al., 2015; Negahban et al., 2011). According to the PEDro methodological scale, the studies overall scored an average of 5.3, indicating the quality of the studies to be fair.

Table 3 Studies showing effects of secondary task on postural stability among participants affected from neurological disorders

Study	Research aim	Sample description	PEDro score	Research design	Conclusion
Jacobi et al. (2015)	Assess the effects of ST on postural stability amongst healthy & participants suffering from DCD.	Healthy: 10F, 10M (58±11) DCD: 10F, 10M (58±11)	5	Static & dynamic postural stability while EO/EC with platform stable/ unstable & with/without ST (VWMT).	Significantly reduced postural stability in participants with DCD as compared to healthy participants.
Prosperini et al. (2015)	Assess the effects of ST on postural stability amongst healthy & participants suffering from MS.	Healthy: 30F, 16M (39±9) MS: 60F, 32M (39±10)	5	Postural stability assessed with/without EO/EC, ST (SWCT).	Significantly reduced postural stability in participants with MS as compared to healthy participants.

Boes et al. (2012)	Assess the effects of ST on postural stability amongst participants suffering from MS.	MS: Mild- 17F, 2M (46±13) Moderate: 24F, 3M (58±7)	6	Postural stability assessed with/without ST (WLG).	Significantly reduced postural stability in participants classified in moderate MS as compared to mild MS group.
Negahban et al. (2011)	Assess the effects of ST on postural stability amongst healthy & participants suffering from MS.	Healthy: 15F, 8M (31±7) MS: 15F, 8M (32±7)	7	Postural stability assessed on rigid/foam surface, while EO/EC & with/without ST (SBC).	Significantly enhanced postural stability in MS & healthy participants whilst ST performance.
Holmes et al. (2010)	Assess the effects of ST on postural stability amongst healthy & participants suffering from PD.	Healthy: 4F, 8M (62±8) PD: 4F, 8M (64±9)	4	Postural stability assessed with/without ST (NR, MgT).	Significantly enhanced postural stability observed in participants affected from PD as compared to healthy controls with/without secondary tasks, MgT.
Marchese et al. (2003)	Assess the effects of ST on postural stability	Healthy: 7F, 13M (60±7)	5	Postural stability assessed with/ without	Reduced postural stability observed in participants affected

	amongst healthy & participants suffering from PD.	PD: 8F, 16M (66±7)	EO/EC, ST (CaT), MT (ToT)	from PD as compared to healthy controls with/without secondary & motor tasks during eyes closed/open. With PD Fa performing significantly poorer.

ST: Secondary task, EO: Eyes open, EC: Eyes closed, VWMT: Verbal working memory task, MS: Multiple sclerosis, SWCT: Stroop word colour task, PD: Parkinson's disease, MgT: Monologue generation task, NR: Numeral recitation, CaT: Calculation task, ToT: Thumb opposition task, Fa: History of fall, Nfa: No history of falls, MT: Motor task, SBC: Silent backwards counting, M: Male, F: Female, Significant: $p < 0.05$, Non-significant: $p > 0.05$.

Participants

Young

Nine studies (Table 4) evaluated the effects of secondary task performance on postural stability amongst young participants. Three good quality studies reported significant enhancements in postural stability (Donker et al., 2007; Resch et al., 2011; Swan et al., 2007), whereas two good quality study reported significant reduction in postural stability (Ramenzoni et al., 2007; Vuillerme et al., 2006). Further, four fair quality studies (Andersson et al., 2002; Dault et al., 2001; Hunter & Hoffman, 2001; Pellecchia, 2003), reported significant decrements in postural stabilization. The experimental studies according to the PEDro methodological scale scored an average of 5.6, indicating average quality of the studies to be fair.

Table 4 Studies showing effects of secondary task on postural stability among young participants

Study	Research aim	Sample description	PEDro score	Research design	Conclusion
Resch et al. (2011)	Assess the effects of ST on postural stability amongst healthy young participants.	Young: 10F, 10M (20±1)	7	Postural sway assessed by using SOT with/without ST (AuST)	Significantly enhanced postural control.
Ramenzoni et al. (2007)	Assess the effects of ST on postural stability amongst healthy young participants.	Healthy: 10F, 13M (28-25)	7	Postural stability assessed with/without ST (verbal & visual) during encoding & rehearsal with combination of verbal & visual interference.	Significantly reduced postural stability during encoding of verbal & visual task as compared to rehearsal period.
Donker et al. (2007)	Assess the effects of ST on postural stability amongst healthy young participants.	Healthy: 20F, 10M (19-30)	6	Postural stability assessed while EO/EC & with/without ST (UNB).	Significant enhancement of postural stability when ST performed with eyes closed.

Swan et al. (2007)	Assess the effects of ST on postural stability amongst healthy female young participants.	Healthy: 98F (18-27 y)	7	Postural stability assessed with varied difficulty in ST (BST, NMT) & balance task.	Significant enhancement in postural stability with enhanced ST difficulty. No effect of difficulty enhancement in balance task.
Vuillerme et al. (2006)	Assess the effects of ST on postural stability amongst healthy young participants.	Young: 9M (23±1)	6	Postural stability assessed with/without EO/EC, ST (AuST).	Significant reduced postural stability during eyes open, closed ST as compared to eyes closed.
Pellecchia (2003)	Assess the effects of ST on postural stability amongst healthy young participants.	Young: 10F, 10M (18-30)	5	Postural stability assessed with/without CT (DRT, 2BC, CBT).	Significantly reduced postural stability with ST (Single task<DRT<2BC<CBT).

Andersson et al. (2002)	Assess the effects of ST, calf stimulation & self-balance focus on postural stability amongst healthy participants.	Healthy: 17F, 13M (27±8) 10F, 10M (30±8)	4	Postural stability assessed with/without ST (SBC).	Significantly reduced postural stability during ST performance.
Dault et al. (2001)	Assess the effects of ST on postural stability amongst healthy young participants.	Healthy: 12F, 12M (20-40)	5	Static & dynamic postural stability assessed with/without ST (SWCT).	Significantly reduced postural stability when dynamic stability assessed whilst ST performance. No significant difference in postural sway during static ST performance.
Hunter and Hoffman (2001)	Assess the effects of ST on postural stability amongst healthy young participants.	Young: 15F, 15M (24)	4	Postural stability assessed with modulation of eye movement & modality of presentation of visual & auditory ST.	Significantly reduced postural stability within eye movement condition.

ST: Secondary task, SOT: Sensory organization test, EO: Eyes open, EC: Eyes closed, AuST: Auditory switch task, SWCT: Stroop word colour task, UNB: Uttering name backward, BST: Brooks spatial task, BNST: Brooks non-spatial task, NMT: Nonsense memory task, AuST:

Auditory switch task, PRT: Probe reaction time task, DRT: Digit reversal task, 2BC: 2-bit classification task, CBT: Count backward by 3 task, SBC: Silent backwards counting, M: Male, F: Female, Significant: $p < 0.05$, Non-significant: $p > 0.05$.

Old

Twelve studies (Table 5) evaluated the effects of secondary task performance on postural stability amongst old and young participants. Ten included studies evaluated the comparative factors in between young-old participants (Brauer et al., 2002; Brown et al., 1999; Huxhold et al., 2006; Marsh & Geel, 2000; Melzer et al., 2001; Shumway-Cook & Woollacott, 2000; Shumway-Cook et al., 1997; Swan et al., 2004; Teasdale et al., 1993; Teasdale & Simoneau, 2001), and two studies evaluated the effects upon old participants only (Brauer et al., 2001; Haggerty et al., 2012). Further, four studies evaluated the comparative factors between individuals with and without history of falls (Brauer et al., 2002; Brauer et al., 2001; Shumway-Cook & Woollacott, 2000; Shumway-Cook et al., 1997). Significant enhancements in postural stability were reported in three studies, whereas six studies reported significant reduction in postural stability, and two studies reported reduction (not significant) in postural stability. Two good quality studies reported significant enhancements in postural stability amongst both young and old participants (Haggerty et al., 2012; Swan et al., 2004), four good quality studies reported significant reduction in postural stability (Marsh & Geel, 2000; Shumway-Cook et al., 1997; Teasdale et al., 1993; Teasdale & Simoneau, 2001), four fair quality studies reported significant decrements (Brauer et al., 2001; Huxhold et al., 2006; Melzer et al., 2001; Shumway-Cook & Woollacott, 2000). Likewise, two studies including one good (Brown et al., 1999), and one fair quality study (Brauer et al., 2002), reported significant and non-significant reductions in postural stability among old participants as compared to young participants, respectively. Poor recovery in postural stability was reported while assessing dynamic postural stability amongst old participants with history of falls as compared to old and young healthy participants (Brauer et al., 2002). The quasi-experimental studies according to the PEDro methodological scale computed an average score of 5.5, indicating the average quality of the studies to be fair.

Table 5 Studies showing effects of secondary task on postural stability among old participants

Study	Research aim	Sample description	PEDro score	Research design	Conclusion
Haggerty et al. (2012)	Assess the effects of ST on postural stability amongst healthy old participants.	Old: 4F, 6M (74±4)	6	Postural stability assessed with/without ST (verbal or push button), with/without VTf & both.	Significant enhancement of postural stability when ST performed with VTf as compared to ST alone.
Huxhold et al. (2006)	Assess the effects of ST on postural stability amongst healthy young & old participants.	Young: 10F, 10M (24±2) Old: 9F,10M (69±3)	5	Postural stability assessed under single (DCRT, 2BDWM, 2BSWM) & dual (WDC) ST.	Significantly enhanced postural stability in both age groups with simple ST (WDC).
Swan et al. (2004)	Assess the effects of ST on postural stability amongst	Young: 18F (19-25)	7	Postural stability assessed under with/ without ST (BST, BNST) & EO/EC.	Significantly enhanced postural stability under BST & BNST for both age groups.

	healthy young & old participants.	Old: 15F (60-74)			
Brauer et al. (2002)	Assess the effects of ST on postural stability amongst healthy young & old participants with & without history of fall.	Young: 5F, 10M (22±5) Old: NFa- 4F, 11M (72±6) Fa- 6F, 7M (79±6)	5	Postural stability assessed with sudden movement at the balance platform, with/ without ST (VCTT).	Reduced postural stability in old participants (Fa) & young participants during ST as compared to old (NFa). Also poor recovery by Fa with ST & limited effect of ST on NFa and young participants.
Melzer et al. (2001)	Assess the effects of ST on postural stability amongst healthy young & old participants.	Young: 20 (26±3) Old: 20 (77±2)	4	Postural stability assessed with/without narrow/wide BoS ST* (MdST) & EMG.	Significantly reduced postural stability amongst old participants during ST performance & narrow BoS. Enhancement in stability during ST performance in young participants.

Teasdale and Simoneau (2001)	Assess the effects of ST on postural stability amongst healthy young & old participants.	Young: 5F, 3M (24±0) Old: 2F,6M (68±0)	6	Postural stability assessed with/without ST (PRT).	Significantly reduced postural stability as compared to young participants.
Brauer et al. (2001)	Assess the effects of CT on postural stability amongst healthy young & old participants with & without history of fall.	Old: NFa- 5F, 9M (72±6) Fa- 6F, 7M (79±6)	5	Postural stability assessed with sudden movement at the balance platform, with/ without ST (VCTT).	Significantly reduced postural stability in old participants (Fa) during ST as compared to old (NFa). Also poor recovery by Fa with ST & no effect of ST on NFa.
Shumway-Cook and Woollacott (2000)	Assess the effects of ST on postural stability amongst healthy young & old participants with & without history of fall.	Young: 3F, 15M (34±8) Old: NFa- 4F, 14M (74±6)	5	Postural stability assessed with balance disturbances, with/without, EO/EC, somatosensory input & ST (CRTAT).	Significantly reduced postural stability amongst old participants Fa as compared to young and old Nfa participants during ST.

		Fa- 3F, 15M (85±6)			
Marsh and Geel (2000)	Assess the effects of ST on postural stability amongst healthy young & old participants.	Young: 14F (25±2) Old: 16F (71±3)	7	Postural stability assessed, with EO/EC, with/without ST (VCTT).	Significantly reduced postural stability amongst old participants as compared to young participants.
Brown et al. (1999)	Assess the effects of ST on postural stability amongst healthy young & old participants.	Young: 5F, 10M (25±5) Old: 3F,7M (78±4)	7	Postural stability assessed with balance disturbances, with/without ST (BDRT)	Reduced postural stability amongst old as compared to young participants during balance disturbances.
Shumway-Cook et al. (1997)	Assess the effects of ST on postural stability amongst healthy young & old	Young: 10F, 10M (31±6) Old: NFa- 11F, 9M (74±6)	7	Postural stability assessed with without ST (SC, VP) performed under flat & compliant surfaces.	Significantly reduced postural stability old participants (Fa) during secondary tasks on both surfaces as compared to young participants. No significant

	participants with & without history of fall.	Fa- 13F, 7M (78±8)			effect on young and old (NFa) on flat surface under simple ST.
Teasdale et al. (1993)	Assess the effects of ST amongst healthy young & old participants.	Young: 8M (24±0) Old: 3F, 6M (71±0)	6	Postural stability assessed during ST (ARTT).	Significantly reduced postural stability amongst old participants as compared to young participants during ST performance.

Fa: With history of fall, NFa: No history of fall, M: Male, F: Female, EO: Eyes open, EC: Eyes closed, ST: Secondary task, VTf: Vibro-tactile feedback, DCRT: Digit choice reaction time task, 2BDWM: 2-back digit working memory task, 2BSWM: 2-back spatial working memory task, WDC: Watching digit conditions, VCTT: Vocal reaction time task, BDRT: Backward digit recall task, CRTAT: Choice reaction time auditory task, PRT: Probe reaction time task, DRT: Digit reversal task, 2BC: 2-bit classification task, CBT: Count backward by 3 task, SBC: Silent backwards counting, ST: Stroop test, MdST: Modified stroop test, EMG: Electromyography, BoS: Base of support, ArT: Arithmetic task, WLG: Word list generation task, SAS: Sub-acute stroke, ARTT: Auditory reaction time task, UNB: Uttering name backward, BST: Brooks spatial task, BNST: Brooks non-spatial task, NMT: Nonsense memory task, Exp: Experimental group, Cnt: Control group, SC: Sentence completion, VP: Visual perception, Significant: $p< 0.05$, Non-significant: $p> 0.05$.

Review

Summary of strength of evidence (Level of evidence)

Randomised controlled trials

We incorporated two RCTs, which were of excellent (Hiyamizu et al., 2012), and good (Choi et al., 2015) quality (Appendices 10). The review categorized the studies evaluating population groups differentiated on the basis of evaluated neurological disorders and age. The level of evidence pertaining towards the effect of secondary task training on participants has been descripted in Table 6.

Table 6 PEDro level of evidence for the effects of secondary task training on postural stability (randomized controlled trials)

PEDro level of evidence	Effect of secondary task training on postural stability	Positive effects & quality of study	Negative effect & quality of study	No effect & quality of study	Final outcome
1b	Elderly	-	-	Excellent: Hiyamizu et al. (2012)	No effect
1b	Sub-acute stroke	Good: Choi et al. (2015)	-	-	Positive effect

Quasi-experimental studies

Twenty-seven quasi-experimental studies were incorporated in our systematic review. The classification for the supporting level of evidence was computed using a modified PEDro level of evidence scale (de Morton, 2009; Eng et al., 2007; Sackett, 2000).

Six quasi-experimental studies evaluated the effects of secondary tasks on postural stability amongst participants affected by neurological disorders (Boes et al., 2012; Holmes et al., 2010; Jacobi et al., 2015; Marchese et al., 2003; Negahban et al., 2011; Prosperini et al., 2015). Nine quasi-experimental studies evaluated the effects of a secondary task on postural stability amongst young population groups (Andersson et al., 2002; Dault et al., 2001; Donker et al., 2007; Hunter & Hoffman, 2001; Pellecchia, 2003; Ramenzoni et al., 2007; Resch et al., 2011; Swan et al., 2007; Vuillerme et al., 2006). Twelve quasi-experimental studies evaluating the effects of secondary task performance on old participants were included in the review (Brauer et al., 2002; Brauer et al., 2001; Huxhold et al., 2006; Melzer et al., 2001; Shumway-Cook & Woollacott, 2000; Shumway-Cook et al., 1997; Swan et al., 2004; Teasdale et al., 1993; Teasdale & Simoneau, 2001). Table 7 illustrates the level of evidence analysis within different categories based on the study of different neurological disorders, age groups and comparisons in between young, elderly and fall prone participants.

Table 7 PEDro level of evidence for the effects of secondary task on postural stability (Quasi experimental studies)

PEDro level of evidence	Effect of secondary task on postural stability	Positive effects & quality of study	Negative effect & quality of study	No effect & quality of study	Final outcome
2	Parkinson's disease	-	Good: Marchese et al. (2003) Fair: Holmes et al. (2010)	-	Negative effect
2	Degenerative cerebellar disorder	-	Good: Jacobi et al. (2015)	-	Negative effect
2	Multiple sclerosis	Good: Negahban et al. (2011)	Good: Boes et al. (2012); Prosperini et al. (2015)	-	Negative effect
2	Young	Good: Donker et al. (2007); Resch et al.	Good: Ramenzoni et al. (2007; Vuillerme et al. (2006)	-	Negative effect

		(2011); Swan et al. (2007)	Fair: Andersson et al. (200(2; Dault et al. (2001); Hunter & Hoffman (2001); Pellecchia (2003)		
2	Elderly	Good: Haggerty et al. (2012)	-	-	Positive effect
2	Elderly vs. young	Good: Swan et al. (2004) Fair: Huxhold et al. (2006)	Good: Brown et al. (1999); Marsh & Geel (2000); Teasdale et al. (1993); N Teasdale & Simoneau (2001) Fair: Brauer et al. (2002); Brauer et al. (2001; Melzer et al. (2001; Shumway-Cook & Woollacott (2000)	-	Negative effect on elderly
2	Fall prone vs. non-fallers	-	Good: Shumway-Cook et al. (1997) Fair: Brauer et al. (2002; S. G. Brauer et al. (2001); Shumway-Cook & Woollacott (2000)	-	Negative effect on fall prone

Discussion

This systematic review aimed to further our understanding of the effects of secondary task training on static and dynamic postural stability among different population groups. Postural control is used to achieve, maintain and restore a state of balance during a specific posture or activity (Mori, Stuart, Wiesendanger, & Pierce, 2004). It is an integral involuntary component of the central nervous system, required for supporting coordinated activities during daily living. Studies have suggested that any conscious attention directed towards these automatic tasks can adversely affect performance (Schaefer & Lindenberger, 2013), possibly as a consequence of movement specific reinvestment (Masters, 1992; Masters & Maxwell, 2008). The theory of reinvestment suggests that conscious attention to movements can disrupt their automaticity if the performer tries to consciously control the movements in order to ensure their efficiency (Masters, 1992; Masters & Maxwell, 2008). Secondary tasks are commonly employed under similar circumstances to offset such conscious attention, as they eat up information processing resources necessary for conscious control (see also constrained action hypothesis (Wulf et al., 2001)).

This present systematic revealed that secondary tasks have beneficial effects upon postural stability: marginally amongst young participants (Marsh & Geel, 2000; Resch et al., 2011), rarely amongst elderly participants (Brauer et al., 2002; Swan et al., 2004) and participants with persisting neurological balance related deficits (Negahban et al., 2011). Synthesis of evidence suggested detrimental effects of secondary task performance on postural stability among healthy young and old participants affected by Parkinson's disease, degenerative cerebellar disorder, and multiple sclerosis. Jacobi et al. (2015) and Prosperini et al. (2015), for instance, evaluated the effects of verbal working memory task and Stroop word-colour task on participants affected by degenerative cerebellar disorder and multiple sclerosis respectively. Both the studies reported a significant reduction in postural stability with increased secondary task complexity. Interestingly, Negahban et al. (2011) administered silent backward counting to participants affected by multiple sclerosis and reported enhancements in postural stabilization. The researchers associated the enhancements with the easiness of the task in comparison to aloud backward counting tasks, which have been reported to result in significant decrements within postural stability (Marchese et al., 2003).

These findings imply that complexity of a secondary task is directly proportional to the resources utilized within the central capacity domain, and participants with a higher predisposition to fall are adversely impacted under such conditions. Similarly, poor postural stability whilst performing a secondary task was higher among elderly participants compared to younger participants, and even higher in elderly participants with prior history of falls. Brauer et al. (2001), Brauer et al. (2002), and Shumway-Cook et al. (1997) reported postural stability and its recovery to be poorer amongst fall prone participants, when a verbal reaction to auditory tone task and sentence completion with visual perception tasks were executed while maintaining standing, respectively. Ruthruff, Pashler, and Hazeltine (2003) proposed similar conditions to cause interference in central capacity-sharing while concomitantly executing a secondary task. Further, Talelli et al. (2008) added that superimposing a secondary task over already weak reorganized cortical structures (i.e., recovery post fall, injury or ailment) may impart more stress on the neural structures ultimately affecting a participant's performance and stability.

Nevertheless, to reduce unnecessary conscious attention to a task, recent research has suggested incorporation of "posture-first" and "secondary task training" strategies during rehabilitation. While evaluating studies elucidating secondary task training one study observed a level 1b standard of evidence for enhancements in postural stability amongst participant's suffering from sub-acute stroke, post-secondary task training. However, in the second study Hiyamizu et al. (2012) administered secondary task training (Stroop task) within the rehabilitation protocols for elderly participants. The researchers reported no detrimental effects within the sway length, but, significant enhancements in Stroop performance. The researchers implied that enhancements within the secondary task performance might contribute towards smoothening of cognitive activities while standing, which inturn might contribute towards preventing falls. Lim, Amado, Sheehan, and Van Emmerik (2015) added that incorporated secondary tasks if associated with activities of daily living, can have widespread application, especially during vocational training. Similarly, teaching fall prone population groups to prioritize balance over concurrent cognitive tasks within complex fall-prone environments (Bloem, Grimbergen, van Dijk, & Munneke, 2006), for instance, escalators and stairs.

In summary, this systematic review was conducted across five online academic search databases Scopus, PEDro, EMBASE, MEDLINE and SportDiscus. A total of 1284 articles were incorporated in our initial search, which later on implementing our inclusion criteria were reduced to 29 (Figure 5.0). The synthesis of studies according to PEDro level of evidence (Table 6 and 7) suggested beneficial effects of secondary task training for enhancing postural stability and cognitive performance. Moreover, the review also suggested detrimental effects of complex secondary tasks amongst population groups with a higher predisposition to fall (i.e. neurological disorders, elderly).

Limitations

Several limitations persisted in the systematic review, which needs to be considered when interpreting the results. The average quality of the included studies according to PEDro methodological quality scale was found to be 5.8, indicating a fair quality of the studies. Moreover, a high risk of bias prevailed because of the limited number of randomized controlled trials. Also, the restriction of search strategy limited to English, German language, exclusion of conference proceedings and observational studies might have resulted in omission of relevant research.

Additionally, the difficulty of a secondary task has been suggested to impart effects on postural stability performance (Swan et al., 2007). A wide array of secondary tasks in different studies might have produced variability in the results. As the study didn’t impose restrictions on the type of included secondary task, higher chances of biasing and differential outcomes can be expected. Likewise, the systematic difference between the population group base statistics related to age, weight, gender and disease severity led to difficulty in comparing studies. Furthermore, many of the above mentioned studies incorporated a small sample size which generates a high possibility of a type II error (Freiman, Chalmers, Smith Jr, & Kuebler, 1978). Additionally, the conclusions derived in the review based on incorporation of secondary task and posture first training in rehabilitation protocol is based upon limited research.

Future directions

Analysing the current state of literature we believe future research studies should focus upon the amalgamation of these different secondary task approaches, such as utilizing secondary tasks related to activities of daily living in a rehabilitation protocol, while simultaneously focussing upon posture first principles. Moreover, a comparatively less researched aspect warranting immediate elucidation remains understanding the influence of differentially complex secondary tasks. We believe the concurrent evaluation of associated brain related centres by using functional imaging techniques, such as functional magnetic resonance imaging, functional electroencephalography, and magnetoencephalography will provide additional insights.

Chapter 4

The influence of below-knee compression garments on knee-joint proprioception

Preface

The previous chapters have provided a background to the existing state of knowledge within the physiological and psychological domains of proprioception and stability. After identifying lack of persisting literature analysing effects of differential information processing constraints on proprioception, an experimental study was designed to address these research gaps. The current chapter utilizes a counterbalanced application of below-knee compression garments and secondary task interventions among forty-four healthy participants to analyse their effects on knee joint proprioception. Participants were asked to perform a battery of four active re-positioning trials with the target angle at 60° and 90° for dominant and non-dominant legs respectively. The research study precisely elucidated proprioception accuracy from a clinical aspect. The present research is the first to elucidate the effects of cognitive constraints on proprioception and to apply to compression garments below the knee joint. This chapter relates to the following objectives of the thesis.

1. Systematic investigation of research-based literature pertinent to joint stabilizers, secondary task interventions and their effects on proprioceptive, performance and stability measures.
2. Development of novel methodological protocols for assessing clinical and dynamic aspects of proprioceptive measures, with the use of joint stabilizers and secondary task interventions.
3. Suggest practical applications from the research that can be incorporated in the activities of daily living.
4. Provide directions for future research work.

Abstract

Objective: The purpose of the study was to assess the influence of below-knee compression garments on proprioception accuracy under information processing constraints designed to cause high or low conscious attention to the task.

Methods: In a counterbalanced, single-blinded, crossover trial, 44 healthy participants (26 male/18 female) with a mean age of 22.7 ± 6.9 years performed an active joint repositioning task using their non-dominant and their dominant leg, with and without below-knee compression and with and without conducting a secondary task.

Results: Analysis of variance revealed no significant interactions ($p > .05$) or main effects of group ($F_{1, 43} = 0.505$, $p = 0.481$, $\eta_p^2 = 0.12$). However, a significant main effect was evident for both compression ($F_{1, 43} = 84.23$, $p < 0.001$, $\eta_p^2 = 0.665$) and secondary task ($F_{1, 43} = 4.391$, $p = 0.04$, $\eta_p^2 = 0.093$).

Conclusions: The study is the first to evaluate the effects of a below-knee compression garment on knee proprioception under differential information processing constraints. We conclude that proprioception accuracy of the knee joint is significantly enhanced post application of below-knee compression garments and when a secondary task is conducted concurrently with active joint repositioning. The findings suggest that below-knee compression garments may improve proprioception of the knee, regardless of leg dominance, and that secondary tasks that direct attention away from proprioceptive judgments may also improve proprioception, regardless of the presence of compression. Clinical implications are discussed with respect to proprioception in modern sports and rehabilitation settings.

Introduction

Studies suggest that compression garments may be beneficial in modern sports (Davies, Thompson, & Cooper, 2009; Driller & Halson, 2013; Fu et al., 2013) and rehabilitation settings (Herrington et al., 2005; Michael et al., 2014; Van Tiggelen et al., 2008b). These studies have shown that compression garments enhance performance (Fu et al., 2013), aid recovery (Davies et al., 2009; Driller & Halson, 2013), and prevent injuries (Fu et al., 2013; Van Tiggelen et al., 2008b). The physiological mechanisms underlying such benefits are likely to be multi-factorial. The garments promote stable muscle alignment (Davies et al., 2009), increase skin stretch (Collins & Prochazka, 1996), enhance cutaneous afferent inputs (Birmingham et al., 1998; Herrington et al., 2005; Van Tiggelen et al., 2008b) and encourage nerve fiber recruitment in muscles (Miyamoto, Hirata, Mitsukawa, Yanai, & Kawakami, 2011), thereby improving proprioceptive feedback and joint position awareness (Herrington et al., 2005; Van Tiggelen et al., 2008b).

Typically, knee compression garments cover the knee joint completely, extending approximately four cm above and below the patella. However, recently below-knee compression garments have become popular in active sports (Armstrong, Till, Maloney, & Harris, 2015), with speculation that such garments differ in providing support/stabilization than their predecessors (i.e. complete knee compression garments). However, to the best of our knowledge, no research has examined the effects of below-knee compression garments on knee-joint proprioception. Therefore, we assessed active joint repositioning accuracy in participants with and without below-knee compression.

Active joint repositioning performed in a clinical environment is likely to be subject to high levels of conscious awareness (Han, Waddington, Adams, Anson, & Liu, 2015), given that participants are instructed to be as accurate as possible. It has been argued that high conscious awareness adversely impacts proprioception (Yasuda, Sato, Iimura, & Iwata, 2014), possibly as a consequence of movement specific reinvestment (Masters, 1992). The theory of reinvestment suggests that directing attention internally to control movements that are normally automatic can disrupt their performance (Masters, 1992; Masters & Maxwell, 2008). We therefore asked participants to complete the active joint repositioning task with and without a secondary task. Secondary tasks are often used to 'soak up' information processing resources that otherwise would be available for the primary task, thus limiting conscious attention to the repositioning task (Beilock & Carr, 2001; Masters, 1992) .

The present study is the first to investigate the effects of below-knee compression garments on knee joint proprioception under conditions of high and low conscious attention. We hypothesized that wearing a below-knee compression garment would benefit knee joint proprioception accuracy and that accuracy would be better when accompanied by a secondary task.

Methods

Participants

Forty-four recreational athletes (26 male/18 female; mean ± SD: age (y) 22.7 ± 6.9, height (cm) 174 ± 9, weight (kg) 72.2 ± 13) volunteered to participate in the study. All participants self-reported as healthy with no history of significant hip, knee or back injury. Written informed consent was obtained from each participant, and ethical approval was obtained from the Human Research Ethics Committee of the Institution.

Experimental Design

Participants were randomly allocated in equal numbers to wear the compression garment on the dominant leg (CompDom group), or to wear the compression garment on the non-dominant leg (CompNon-Dom group). In each group, and for both the dominant and the non-dominant leg, participants carried out the active (knee-joint) repositioning task while conducting or not conducting a concurrent secondary task (SecTask or No-secTask, respectively). The secondary task (random word generation) was designed to direct conscious attention away from the repositioning task and its presence or absence was counterbalanced within leg in each group (Davidoff, 2000).

The target angle for the repositioning task was 30° and 60° for the dominant and non-dominant leg, respectively (Callaghan et al., 2008), to reduce learning effects.

Compression Garment

A standard below-knee unisex compression sleeve (BSX Insight®, USA) was worn by the participants. The compression garment extended from the superior aspect of the tibial tuberosity to the proximal two-thirds of the tibial shaft. The garment was allocated to each participant according to the manufacturer's size guidelines. While not measured in the current study, interface pressure measurements of these garments have been recorded in our laboratory, with average pressures ranging from 10-15mmHg (unpublished observations).

Procedure

Participants were seated with their feet on the floor (knee-joint angle 90°). The chair backrest was adjusted to an 85° incline and the pelvis was stabilized (Van Tiggelen et al., 2008b). Participants were blindfolded to eliminate visual cues. The researcher passively moved the dominant or non-dominant leg to a previously identified target position (30° or 60°) in an open kinetic chain (Van Tiggelen et al., 2008b) for 10 seconds to allow the participant to memorize the position (Callaghan et al., 2008). The leg was then returned to the initial position (90°) and following a 5 seconds interval the participant attempted to reposition the leg at the same joint angle. The participant was required to hold the leg at the perceived target angle for 4 seconds and then return it to the starting position. Repositioning error (RE) was assessed in each trial using a universal 360° manual goniometer (RBMS®, USA) to measure the knee-joint angle with ± 0.2° precision. Repositioning error was calculated as the difference from target angle in magnitude but not direction (Ju, Wang, & Cheng, 2010). Good reliability and validity of both the repositioning procedure and the manual goniometer have previously been reported (Ju et al., 2010; Olsson et al., 2004).

Statistical Analysis

Statistical analyses were performed using Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL). We examined Repositioning Error (the dependent measure), by conducting a Group (CompDom/CompNon-Dom) x Secondary task (present/absent) x Compression (present/absent) RM-ANOVA with repeated measures on the last two factors. Effect sizes of the independent variables were expressed using partial eta squared (η_p^2), with effect sizes < 0.01 considered to be small, effect sizes between 0.01 and 0.10 considered to be medium and effect sizes >0.10 considered to be large (Peat & Barton, 2008). An alpha level of 0.05 was adopted.

Results

Descriptive statistics are summarized in (Table 8). Statistical analysis revealed no significant interactions (*p's* > .05) or main effect of group ($F_{1, 43} = 0.505$, $p = 0.481$, $\eta_p^2 = 0.12$). However, a significant main effect was evident for both compression ($F_{1, 43} = 84.23$, $p < 0.001$, $\eta_p^2 = 0.665$) and secondary task ($F_{1, 43} = 4.391$, $p = 0.04$, $\eta_p^2 = 0.093$). For clarity, Figure 7 illustrates these effects separately for the dominant and non-dominant legs.

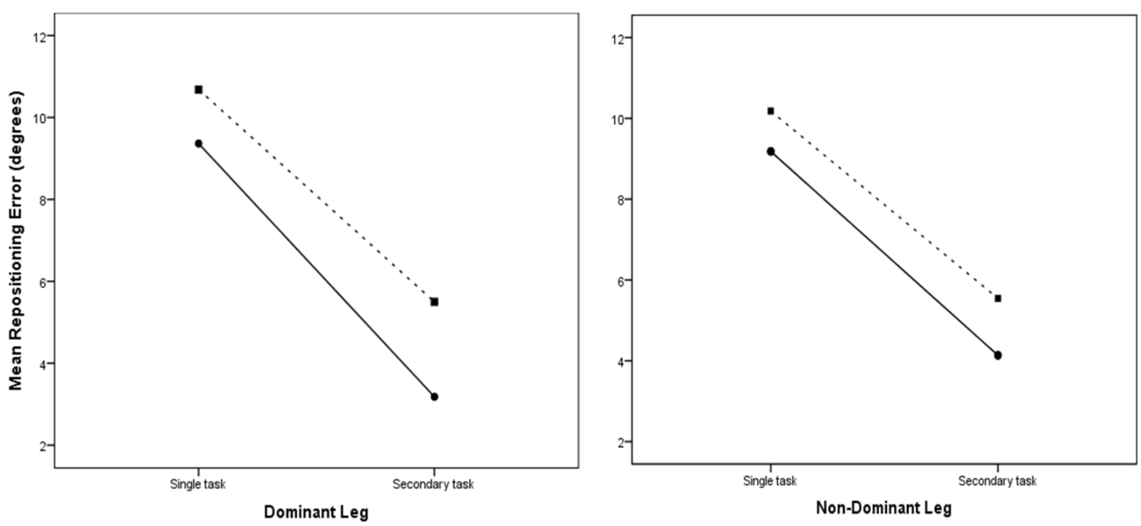

Figure 7 Mean and SE of repositioning error (°) for the dominant and non-dominant leg with and without a concurrent secondary task and with and without the presence of a compression garment. (Dotted line represents without compression garment. Darkened line represents with compression garment).

Table 8 Mean (SD), standard error and 95% confidence intervals (CI) for repositioning error (°) in the different treatment conditions for dominant (Dom, 30°) and non-dominant (Non-Dom, 60°)

	M ± SD		95% C.I	
Repositioning Task	Dom	Non-Dom	Dom	Non-Dom
Compression/sec task	3.3 ± 3	4.1 ± 3.1	2.4- 4.1	3.1- 5
No-compression/sec task	5.5 ± 3.3	5.5 ± 4.4	4.5- 6.4	4.2- 6.8
Compression/no sec task	9.3 ± 5.2	9.1 ± 4.6	7.7- 10.8	7.7- 10.4
No-compression/no sec task	10.6 ± 4.6	10.1 ± 4.6	9.2- 11.9	8.7- 11.4

Discussion

This study aimed to further our understanding of the effects of below-knee compression on proprioception under conditions of high and low conscious attention. In agreement with our hypothesis, enhanced proprioception accuracy was observed when active joint repositioning was performed with a below-knee compression garment and when participants were required to conduct a secondary task concurrently with repositioning. Despite the lack of an interaction between the secondary task and the compression conditions, repositioning accuracy was highest when both were present, resulting in average repositioning errors of 3.3° ± 3° and 4.1° ± 3.1° for the dominant and non-dominant leg, respectively.

Conventional knee compression garments are common in sports and rehabilitation settings (Fu et al., 2013). These garments have demonstrated their capability for enhancing proprioception by increasing cutaneous afferent feedback (Herrington et al., 2005), musculoskeletal activation (Lin et al., 2011), and stability perception (Lien et al., 2014). Improved proprioception has been reported in samples of sedentary and sports populations while executing active repositioning tasks with complete knee compression garments (Herrington et al., 2005; Van Tiggelen et al., 2008b). However, the recent popularity of below-knee compression garments in sport raises questions about the physiological benefits these garments possess in terms of support/stability (Armstrong et al., 2015). Our findings demonstrate that below-knee compression garments may also facilitate proprioceptive accuracy. We speculate that the anatomical positioning of the proximal portion of the below-knee compression garment over major knee muscle insertion sites (i.e. the tibial tuberosity) may amplify Golgi tendon organ activation (Hall, 2004), thereby providing improved proprioceptive feedback. The position of the garment below the knee may also offset the restrictive disadvantages of complete knee garments, which in earlier studies have been shown to disrupt mobility (Lien et al., 2014). Below-knee garments may therefore improve proprioception without affecting range of motion.

Our findings are consistent with claims that increased conscious awareness may adversely impact proprioception accuracy when participants are instructed to precisely anticipate joint position (Han et al., 2015), but only when participants did not conduct a secondary task. When a secondary task was imposed, proprioceptive accuracy was better. Other work has demonstrated improvements in motor behavior under secondary task loading (Schaefer, Jagenow, et al., 2015). Improved postural stability has been demomstrated, for example (Resch et al., 2011). The theory of reinvestment (Masters, 1992; Masters & Maxwell, 2008), suggests that conscious attention to movements can disrupt their automaticity if the performer tries to consciously control the movements in order to ensure their efficiency, so the secondary task may have protected the automaticity of the repositioning movements by eating into information processing resources necessary for conscious control (see also constrained action hypothesis, (Wulf et al., 2001)).

In conclusion, our findings suggest that below-knee compression garments may improve proprioception of the knee regardless of leg dominance, and that secondary tasks that direct attention away from proprioceptive judgments may also improve proprioception, regardless of the presence of compression. The findings inform clinical implications for preventive and rehabilitative use of below-knee compression garments, both when accurate proprioceptive judgments are important and when range of motion needs to be unimpeded at the knee joint. Since our repositioning method of gauging proprioceptive capabilities was clinically oriented, we recommend that future research studies use a more dynamic, practical protocol, which mimics real-life settings.

Chapter 5

The effects of applying a secondary task on proprioception and jump performance following exercise

Preface

The previous chapter revealed promising results of secondary tasks and below-knee compression on proprioceptive measures in a clinical setting. In this chapter, a counterbalanced, quasi-experimental study was performed to analyse the use of secondary tasks in a practical setting. Twenty-two recreational runners took part in a study where the effects of secondary tasks were studied on proprioception, peak jump velocity and peak jump height, before and after exercise. The findings from the study reveal important implications that apply to real-life settings. This chapter relates to the following objectives of the thesis.

1. Systematic investigation of research-based literature pertinent to joint stabilizers, secondary task interventions and their effects on proprioceptive, performance and stability measures.
2. Development of novel methodological protocols for assessing clinical and dynamic aspects of proprioceptive measures, with the use of joint stabilizers and secondary task interventions.
3. Suggest practical applications from the research that can be incorporated in the activities of daily living.
4. Provide directions for future research work.

Abstract

Objective: The purpose of the study was to assess proprioception accuracy, peak jump velocity and peak jump height, with and without a secondary task, before and after exercise.

Methods: In a counterbalanced, randomized crossover trial, 22 healthy recreational runners (11 male/11 female) with a mean (± SD) age of 37 ± 12 years performed modified squat jumps, with and without (control) a secondary task, before and after exercise induced by a 12km run. Peak jump height (m) and velocity ($m.s^{-1}$) were measured using a linear position transducer and proprioception accuracy was measured while re-positioning the knee joint to 90° during modified squat jumps.

Results: Significant enhancements ($p<0.05$) were found in proprioception accuracy when a secondary task was performed, pre (ES ±90%CI; -1.05 ±0.46; *large*) and post (ES; -0.6 ±0.4; *moderate*) exercise, compared to control. *Small* effects were also observed for peak jump velocity pre (ES; 0.27 ±0.08) and post (0.24 ±0.06) exercise, in the secondary task trial when compared to control. There were no significant differences ($p>0.05$) and *trivial* effects observed for peak jump height between trials at both time points.

Conclusion: The current study is the first to evaluate the effects of differential information processing constraints on knee joint proprioception and jump performance pre and post exercise. Proprioception accuracy of the knee joint and peak jump velocity is significantly enhanced when a secondary task is performed during a modified squat jump, both pre and post exercise in recreational runners. These findings suggest that secondary tasks that direct attention away from proprioceptive judgments may improve knee proprioception and peak jump velocity.

Introduction

Studies suggest that higher conscious attention may adversely impact performance during sports (Masters & Maxwell, 2008) and rehabilitation (Pohl, McDowd, Filion, Richards, & Stiers, 2006). More specifically, studies have shown that higher conscious attention to a motor task disrupts performance while maintaining posture (Hunter & Hoffman, 2001; Resch et al., 2011), gait (Schaefer, Schellenbach, et al., 2015), and skilled sports activities (Masters & Maxwell, 2008), such as, golf putting (Beilock & Carr, 2001).

Typically, activities performed under stressful conditions, such as in clinical environments (Han et al., 2015) or sports settings (Masters & Maxwell, 2008), are likely to promote high levels of conscious awareness, given that participants have to perform as effectively as possible. DeCaro, Thomas, Albert, and Beilock (2011) speculated that this occurs in high-stakes situations, which further generate "performance pressure" or lead to "choking under-pressure". Furthermore, the researchers postulated "distraction theory" (Beilock & DeCaro, 2007), and "theory of re-investment" (Masters & Maxwell, 2008), to be two possible underlying theories for this alleviated conscious awareness. Firstly, the distraction theory proposes high-stakes situations to effectively divert an individual's attention towards task irrelevant thoughts, for instance, worries and consequences regarding the situation (Beilock & DeCaro, 2007). Secondly, the theory of reinvestment postulates that directing attention internally to control movements that are normally automatic can disrupt their performance (Masters, 1992; Masters & Maxwell, 2008). Recent studies have argued for adverse impacts of higher conscious involvement on proprioception (Yasuda et al., 2014), and motor performance (Masters & Maxwell, 2008). Secondary tasks are often used under such circumstances to 'soak up' information processing resources that otherwise would be available for the primary task (Beilock and Carr (2001); Masters (1992)), thus limiting conscious attention to the motor task, and enhancing performance.

Therefore, the present study is the first to investigate proprioception accuracy (through a knee joint repositioning task), peak jump height and peak jump velocity under conditions of high and low conscious attention (with and without a secondary task), before and after exercise. We hypothesize that proprioception accuracy, peak jump height, and peak jump velocity would be enhanced when accompanied by a secondary task irrespective of exercise.

Methods

Participants

Twenty-two recreational runners (11 female/11 male; mean ± SD; age: 36.7 ± 11.8 years; body mass: 78.7 ± 16.8 kg; 12km run time: 72.2 ± 16.5 min) volunteered to participate in the study, during a community running event. Participants represented a wide range of athletic abilities and ages. All participants self-reported as healthy with no history of significant hip, knee or back injury. Written informed consent was obtained from each participant, and ethical approval was obtained from the Human Research Ethics Committee of the Institution.

Experimental Design

Participants were asked to perform three modified squat peak jumps. The first squat peak jump was performed as a familiarisation. Following familiarisation, in a randomized, counterbalanced order, participants performed a control peak jump (no secondary task) and a peak jump while concurrently performing a secondary task. Initially, the participants were instructed by the researcher, a physiotherapist, to squat until their thighs were parallel to the ground in order to attain 90° target angle at the knee joint. Thereafter, the researcher manually corrected the squat angles for the knee joint using a handheld goniometer (RBMS®, USA). The participants were then asked to hold the squat position for 3 seconds, before performing a maximal vertical peak jump. A high-resolution camera (Canon Inc., Japan) was utilized to capture the knee joint angle from the sagittal plane and a linear position transducer (Gymaware, Australia) was used to assess the peak jump performance parameters. A linear position transducer, such as the Gymaware device, has been suggested to effectively and reliably measure kinematic measurements during short duration, ballistic resistance exercises, such as countermovement peak jumps (Hori & Andrews, 2009). The concurrent secondary task involved performing a simple arithmetic equation on a piece of paper while at the same time, adopting the 90° squat position (e.g. 3+2-1=?). The researchers utilized different equations before and after the exercise conditions to limit subjective biasing. The control task required the participant to look at a cross or a circle on a piece of paper.

Procedure

Participants were required to report to the testing facility 30-minutes prior to the start time of a 12km run. Participants were instructed to perform their own self-selected warm-up prior to taking part in the pre-testing. During the pre-run testing session, the participants were asked to stand comfortably with their legs positioned at shoulder width apart. Each participant was instructed to perform three modified squat peak jumps with 10 seconds between squat jumps. A standard repositioning angle for each squat was set at 90°. The selection of 90° angle was justified as research has shown that squat jumps initiated from a 90° squat position produce maximum jump performance (Argus & Chapman, 2014). Each modified peak jump initially consisted of performing a squat with a linear position transducer attached to a bar that was placed across the participant's shoulders. The participants were then instructed to squat until they felt that the target angle 90° was achieved, hold for 3 seconds, and perform a maximal vertical jump. Following the pre-tests, all participants took part in an organised 12km run event at 10:00 am. Immediately following the race, before warming-down, participants were instructed to return to the testing facility located at the start/finish line to perform the post-testing session. A high-resolution camera captured the squat movement at the knee joint. Repositioning errors (degrees) from the target angle were then analysed using biomechanical software (Siliconcoach, New Zealand). Repositioning error was calculated as the difference from target angle in magnitude but not direction (Ju et al., 2010). Data regarding the maximal attained peak jump height and the maximum peak jump velocity were attained using the Gymaware software (Kinetic performance, Australia). High levels of reliability and validity for the squat peak jump (Markovic, Dizdar, Jukic, & Cardinale, 2004), and video graphic repositioning error evaluation using siliconcoach software (Cronin, Nash, & Whatman, 2006).

Statistical Analysis

Statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL). Descriptive statistics are shown as means ± standard deviations unless stated otherwise. Magnitudes of the standardized effects were calculated using Cohen's *d* and interpreted using thresholds of 0.2, 0.5, 0.8 for *small, moderate and large*, respectively (Cohen, 1988b). An effect size of ±0.2

was considered the smallest worthwhile effect with an effect size of <0.2 considered to be *trivial*. The effect was deemed *unclear* if its 90% confidence interval overlapped the thresholds for *small* positive and negative effects (Batterham & Hopkins, 2006). Students paired t-tests were used to compare secondary task and control both pre and post exercise for all measured variables. Statistical significance was set at $p<0.05$ for all analyses.

Results

Repositioning error

Descriptive statistics for repositioning error are shown in Table 9. Significantly bnetter proprioception accuracy was reported pre ($p<0.01$) and post exercise ($p<0.05$) when the secondary task was completed, when compared to the control group. A *large* effect size was also observed between trials, both pre and post exercise conditions.

Peak jump velocity

Descriptive statistics for peak jump performance measures are shown in Table 10. A significant enhancement in peak jump velocity was reported pre ($p<0.01$) exercise, whereas no significant enhancement was reported post ($p>0.05$) exercise, in secondary task conditions compared to the control group. This was associated with a *small* effect size between trials for both the pre and post exercise conditions.

Peak jump height

No significant differences were observed in peak jump height pre and post exercise ($p>0.05$), between secondary task and control trials. A *trivial* effect size was observed between trials for both the pre and post exercise conditions.

Table 9 Pre and post exercise change in the repositioning error measures (mean ± SD). Effect sizes (Cohens *d*) for each pre to post comparison are shown with 90% confidence intervals (CI)

Repositioning error	Control (mean ± SD)	Secondary task (mean ± SD)	Secondary task-control Effect size (±90%CI)

Pre-exercise	5.6° ± 2.5°	2.8° ± 2.2°	-1.05 ±0.46 *large*
Post-exercise	7° ± 3.4°	4.9° ± 2.5°	-0.6 ±0.4 *moderate*

Table 10 Pre and post exercise change in the peak jump performance measures (mean ± SD). Effect sizes (Cohens d) for each pre to post comparison are shown with 90% confidence intervals (CI) peak jump

Performance measures	Control (mean ± SD)	Secondary task (mean ± SD)	Secondary task-control Effect size (±90%CI)
Peak jump velocity Pre-exercise (m/sec)	2.28 ±0.47	2.41 ±0.44	0.27 ±0.08 *small*
Peak jump velocity Post- exercise (m/sec)	2.38 ±0.42	2.49 ±0.42	0.24 ±0.06 *small*
Peak jump height Pre-exercise (m)	0.73 ±0.15	0.76 ±0.14	0.15 ±0.15 *trivial*
Peak jump height Pre-exercise (m)	0.73 ±0.19	0.75 ±0.18	0.06 ±0.13 *trivial*

Discussion

This study aimed to further our understanding of the effects of high and low conscious attention on knee proprioception and jump performance, before and after exercise. In agreement with our hypothesis, enhanced proprioception accuracy (lower repositioning error) was observed when a 90° squat position was performed concurrently with a secondary task, both pre and post exercise induced by a 12 km run. The study reported knee proprioception accuracy to be significantly ($p<0.05$) enhanced in the secondary task trial (pre: 2.8 ± 2.2°, post: 5.6 ± 2.5°) both pre and post exercise when compared to the control trial (pre: 4.9° ± 2.5°, post: 7.0° ± 3.4°). These improvements in proprioception were associated with *large* and *moderate* effect sizes pre and post exercise, respectively. Significant enhancements ($p<0.01$) were also reported for peak jump velocity in between trials pre and post exercise.

Our findings are consistent with claims that increased conscious awareness may adversely impact proprioception accuracy (Yasuda et al., 2014) and motor performance (Masters & Maxwell, 2008) when participants are instructed to precisely anticipate joint position and movements in clinical (Han et al., 2015) and sporting environments (Masters & Maxwell, 2008). When a secondary task was imposed, proprioceptive accuracy and peak jump velocity were significantly enhanced. These results are consistent with previous work demonstrating improvements in motor behaviour under secondary task loading. Resch et al. (2011) demonstrated enhancements in static and dynamic postural stability when a sensory organization test was performed consecutively with an auditory switch task. Likewise, Beilock and Carr (2001) reported improved sports performance, among young participants when an alphabet arithmetic task was performed simultaneously during golf putting. The theory of reinvestment (Masters, 1992; Masters & Maxwell, 2008), suggests that increased conscious attention towards a motor task can disrupt its automaticity if the performer tries to consciously control the movements to ensure efficiency. In the present study, the secondary task may have protected the automaticity of the repositioning movements by eating into information processing resources necessary for conscious control (see also constrained action hypothesis, (Wulf et al., 2001)). Moreover, inferring from the enhancements reported in peak jump velocity post exercise, the authors postulate that the 12km run may have acted as a warm-up, which in several studies have shown to enhance jump performance (Cervantes & Snyder, 2011; Chattong, Brown, Coburn, & Noffal, 2010; Pagaduan, Pojskić, Užičanin, & Babajić, 2012). Future research should ensure that the exercise modality selected, is adequate to cause fatigue to the neuromuscular system.

In conclusion, our findings suggest that secondary tasks that direct attention away from proprioceptive judgments may improve knee joint proprioception and peak jump velocity before and after exercise. On the contrary, peak jump height remains largely unaffected by the application of secondary tasks pre and post exercise. The findings inform implications for preventive, rehabilitative and performance enhancement through the use of secondary tasks, especially under clinical and sporting environments, where accurate movement-specific judgments are necessary.

Chapter 6

Conclusion & Practical Applications

Conclusion

Interference in the physiological and psychological aspects of performance occur during activities of daily living (Schaefer, Jagenow, et al., 2015), sporting environments (Masters & Maxwell, 2008), and injury rehabilitation settings (Choi et al., 2015). These interferences adversely impact automatic processes imperative for co-ordinated execution of motor activities, including proprioception. In this thesis, published literature pertinent to the effects of joint stabilizers and secondary task interventions on proprioception and postural stability was analysed in a systematic order. Thereafter, experimental studies were designed and carried out according to the pertained gaps in the literature. The research studies evaluated the clinical and practical aspects of proprioception, stability and performance by utilizing joint stabilizers under higher and lower information processing constraints.

First, a systematic review, level of evidence and meta-analysis conducted to evaluate the effects of joint stabilizers on different joint segments and population group's revealed their beneficial effects for enhancing proprioception and postural stability. The included studies were critically appraised using a PEDro methodological scale, and an overall score of 6.1 (good) was obtained for all the included 50 studies. This systematic narrative analysis also analysed the neurophysiological mechanism of joint stabilizers and revealed a multifaceted approach for enhancements of proprioception and perception of stability. The first approach contemplates the enhancement of cutaneous afferent inputs to enhance proprioception. The second approach revealed an enhanced underlying musculoskeletal activation rate, supported by electromyographic studies. The third and relatively new approach supported by neuroimaging studies suggests subtle changes in cerebral haemodynamics to additionally enhance proprioception and perception of enhanced stability pertained by participants post joint stabilizer application. In addition, 1a PEDro level of evidence suggested beneficial effects of compression garments for enhancing postural stability. Likewise, a 1b PEDro level of evidence suggested beneficial effects of taping for enhancing postural stability and knee joint proprioception. The meta-analysis included in between pooled studies revealed beneficial effects of joint stabilizers on the knee (95%CI: 0.35° to 0.61°) and ankle (at 10°: 0.1° to 0.65°) joint proprioception, and negligible effects on postural stability (-0.28° to 0.19°).

Second, another systematic review and a level of evidence analysis evaluated effects laid by secondary task interventions for enhancing postural stability amongst population group differentiated on the basis of age, and neurological ailments. The review followed the PRISMA guidelines and was critically appraised using a PEDro methodological scale, and an overall score of 5.8 (fair) was obtained for all the included 29 studies. The review study incorporated two excellent quality randomized controlled trials evaluating the effects of secondary task training and revealed their beneficial effects for enhancing the automaticity in postural stability and secondary task performance. The review further revealed enhanced postural stability in participants without a prior predisposition to fall, as compared to participants with a history of falls. A level of evidence analysis revealed a level 1b PEDro evidence suggested beneficial effects of secondary task training on postural stability among elderly. Moreover, a 2 PEDro level of evidence suggested no significant effects of secondary task on postural stability amongst participants affected by neurological disorders, such as Parkinson's disease, and multiple sclerosis. Likewise, a level 2 PEDro evidence suggested enhanced decrements in postural stability post-secondary task inclusion among elderly participants with a history of falls as compared to healthy young and elderly participants. Moreover, the review study also suggested incorporation of a "posture-first" strategy inorder to reduce the incidence of fall and increase postural stability. Furthermore, deducing practical implications from the review studies viable methodological approaches were formulated to evaluate the effects of joint stabilizers and secondary task intervention on proprioception and associated performance measures.

Third, a research study was designed and included a counterbalanced application of a below-knee compression garment and secondary task upon forty-four healthy participants, to evaluate knee proprioception accuracy. This novel research for the first time evaluated the effects of information processing constraints on proprioception. Active-joint repositioning tasks performed under lower information processing constraints with below-knee compression garments were found to be most accurate. Statistical analysis of variance revealed significant main effects of compression garment and secondary task but not of the group. Thereby, displaying beneficial effects pertained by the variables for enhancing proprioception. Furthermore, advancing these findings a second research study evaluating the dynamic aspects of proprioception and performance was conducted to evaluate the practical applications of the research study.

Fourth, the second research incorporated a modified squat jump performed before and after exercise, to essentially analyse proprioception and jump performance. Proprioception accuracy was analysed during the squat, whereas the jump performance measures, namely peak jump height and peak jump velocity were measured during the squat jump in three consecutive, counterbalanced trials. The study revealed considerable enhancements in proprioception accuracy and peak jump velocity whereas no difference was noted in peak jump height, pre and post exercise. Magnitudes of the standardized effects were calculated within this study. *Large*, *small* and *trivial* effect sizes were calculated for proprioception accuracy, peak jump velocity and peak jump height measures, between trials, both pre and post exercise conditions, respectively.

In support of previous literature, our findings are consistent with claims that increased conscious awareness may adversely impact proprioception accuracy and performance, when participants are instructed to perform under high-stress conditions, such as clinical environments. When a below-knee compression garment and secondary task was imposed, proprioceptive accuracy and peak jump velocity measures were significantly enhanced. The obtained results are also in concordance with postulations made by Beilock, Wierenga, and Carr (2002) and Schaefer, Jagenow, et al. (2015), where the researchers suggested efficient execution of automatized motor performance under divided attention.

Practical Applications

Study 1 Effects of joint stabilizers on proprioception and stability

In the first study, a systematic review, PEDro level of evidence analysis and meta-analysis was conducted on fifty research studies. The studies evaluated the effects of various joint stabilizers (brace, compression garment, tape) on postural stability, neurological activity, joint proprioception, kinematics across healthy and injured population groups. The practical applications of this study are as follows:

- Application of joint stabilizers enhances cerebral hemodynamics in the areas associated with the perception of coordination and proprioception.
- Psychological benefits pertinent to the perception of stability and confidence are also enhanced post-application of joint stabilizers.
- Performance and perception of stability are directly associated with comfort and fitting of the joint stabilizer.
- The practical application of joint stabilizers, for instance, compression garments in sports activities, may provide a significant advantage over opponents.
- A *large* effect size was calculated for the effects of compression garments and taping on knee and ankle joint proprioception.
- Incorporating joint stabilizers in rehabilitation protocols for knee, ankle joint injuries might significantly enhance the prognosis and re-injury risks.

Study 2 Effects of secondary tasks on stability

In the second study, a systematic review and PEDro level of evidence analysis was conducted on twenty-nine research studies. The studies evaluated the effects of various secondary tasks, secondary task training on static and dynamic postural stability across healthy and population groups affected from neurological disorders. The practical applications of this study are as follows:

- A level 1b of evidence suggested beneficial effects of secondary task training on postural stability among elderly.
- A 2 PEDro level of evidence suggested no significant effects of secondary task on postural stability amongst participants affected by neurological disorders, such as Parkinson's disease, and multiple sclerosis.
- Secondary tasks pertain detrimental effects on postural stability amongst participants with a prior history of falls as compared to their healthy counterparts.
- Secondary task training smoothens up cognitive abilities that are essential for preventing falls.
- The complexity of the secondary task is directly associated with decrements in postural stability.

- Incorporation of secondary task training in rehabilitation protocols for participants with a higher predisposition to fall might enhance their stability.
- Performing easy secondary tasks, for instance, silent backward counting task might provide performance increments in postural stability.

Study 3 Effects of below-knee compression garment and secondary tasks on knee proprioception

In the third study, a counterbalanced, quasi-experimental study was conducted on forty-four healthy participants. The study analysed knee joint proprioception using an active joint repositioning task, with and without below-knee compression and with and without conducting a secondary task (random word generation). The practical applications of this study are as follows:

- Statistical analysis revealed no main effects of group, however, a main effect was evident for both the below-knee compression garment and the secondary task.
- Below-knee compression garments and secondary task enhance knee joint proprioception, regardless of the leg dominance.
- The practical applications of this study could be transferred to “highly-stressful” clinical and sports settings, where accurate proprioceptive judgments are required, such as repositioning trials, gait analysis.
- Below-knee compression garments can also be incorporated in sporting activities where prophylactic properties of joint stabilizers without any restraint on range of motion are imperative, such as football.
- Adopting below-knee compression in rehabilitation protocols of knee injuries such as anterior cruciate ligament injury, osteoarthritis might improve the prognosis of the disability.

Study 4 Effects of secondary tasks on proprioception, jump performance following exercise

In the fourth study, a counterbalanced, quasi-experimental study was conducted on twenty-two recreational runners. The study analysed knee joint proprioception, peak jump velocity, peak jump height during a modified squat jump, with and without a secondary task (arithmetic task), pre and post exercise. The practical applications of this study are as follows:

- Statistical analysis revealed significant enhancement in proprioception accuracy and peak jump velocity with a secondary task, pre, and post exercise.
- No significant differences were observed in peak jump height post a secondary task inclusion, pre, and post exercise.
- *Large*, *small* and *trivial* effect sizes were calculated for proprioception, peak jump velocity and peak jump height in between trials, pre and post exercise.
- The practical application of these results could be transferred to any sporting activity where a similar time-frame and intensity is procured, for instance, hockey.
- Performing secondary tasks during a sports activity might provide performance increments and prevent the risks of sports injuries.

Overall key practical applications

- Joint stabilizers and secondary tasks can be incorporated in conditions proprioceptive deficits and alleviated self-conscious attention present.
- A well fitted joint stabilizer can provide physical (e.g. stability, agility) and psychological (e.g. perception of stability) benefits within a sporting and/or rehabilitation environment.
- Incorporating an easy secondary task in rehabilitation protocols might provide stabilizing and proprioceptive benefits.
- Secondary task training is an effective rehabilitative approach for managing falls.
- Application of secondary task can offset alleviated conscious attention under stressful conditions that require a participant to perform as "precisely as possible" such as clinical and sporting environments.
- Below-knee compression garments might be effective in rehabilitation settings where prophylactic properties of joint stabilizers are required

without any restrains on range of motion, for instance, re-training phase post sports injury.

- Secondary tasks might provide performance increments related to jump performance and co-ordinated activities during sporting activities that involve running.

Key Points

- Joint stabilizers efficiently enhance proprioception by amplifying afferent inputs, musculoskeletal activation, cerebral haemodynamics, imitating normal joint kinematics and biomechanics.
- Compression garments and taping enhance proprioception accuracy amongst healthy participants at knee and ankle joints, respectively.
- Secondary tasks are beneficial in enhancing postural stability amongst participants with no history of falls as compared to participants with a prior history of falls.
- Increased complexity of secondary task increases the likelihood of poor performance and stability.
- Secondary task interventions effectively utilize conscious information processing resources that can be addressed towards a motor task.
- Secondary task training smoothens up cognitive abilities that are essential for preventing falls.
- Joint stabilizers and secondary task, together allows considerable enhancement of proprioception accuracy in a clinical environment, while performing an active joint knee re-positioning task.
- The lower information processing constraints induced by secondary tasks allow enhancement of proprioception accuracy, peak jump velocity, irrespective of physical activity induced during exercise.

References

Aman, J. E., Elangovan, N., Yeh, I.-L., & Konczak, J. (2015). The effectiveness of proprioceptive training for improving motor function: a systematic review. *Frontiers in Human Neuroscience, 8* doi:10.3389/fnhum.2014.01075

Andersson, G., Hagman, J., Talianzadeh, R., Svedberg, A., & Larsen, H. C. (2002). Effect of cognitive load on postural control. *Brain Research Bulletin, 58*(1), 135-139.

Argus, C. K., & Chapman, D. W. (2014). The effect of initial knee angle on the reliability of variables derived from a squat jump. *Medicina Sportiva, 18*(4), 125-130.

Armatas, V., Chondrou, E., Yiannakos, A., Galazoulas, C., & Velkopoulos, C. (2007). Psychological aspects of rehabilitation following serious athletic injuries with special reference to goal setting: A review study. *Physical Training, 8*(1), 1-15.

Armstrong, S. A., Till, E. S., Maloney, S. R., & Harris, G. A. (2015). Compression socks and functional recovery following marathon running: a randomized controlled trial. *Journal of Strength and Conditioning Research, 29*(2), 528-533.

Augustine, G. J., Fitzpatrick, D., Katz, L. C., LaMantia, A.-S., & McNamara, J. O. (2001). The spinal cord circuitry underlying muscle stretch reflexes. In D. Purves & S. M. Williams (Eds.), *Neuroscience* (2nd ed.). Sunderland, MA: Sinauer Associates.

Barrett, G. B. (2003). *The effects of neoprene sleeve application on knee joint proprioception in adolescent female athletes* (Master's thesis). East Tennessee State University, Johnson, TN. Retrieved from http://dc.etsu.edu/cgi/viewcontent.cgi?article=1996&context=etd

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance, 1*(1), 50-57.

Baumeister, J., Reinecke, K., & Weiss, M. (2008). Changed cortical activity after anterior cruciate ligament reconstruction in a joint position paradigm: an EEG study. *Scandinavian Journal of Medicine & Science in Sports, 18*(4), 473-484.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: what governs choking under pressure? *Journal of Experimental Psychology: General, 130*(4), 701-725.

Beilock, S. L., & DeCaro, M. S. (2007). From poor performance to success under stress: working memory, strategy selection, and mathematical problem solving under pressure. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(6), 983–998.

Beilock, S. L., Wierenga, S. A., & Carr, T. H. (2002). Expertise, attention, and memory in sensorimotor skill execution: Impact of novel task constraints on dual-task performance and episodic memory. *Quarterly Journal of Experimental Psychology: Section A, 55*(4), 1211-1240.

Bernhardt, T., & Anderson, G. S. (2003). *Compression shorts and sports performance: Help or hindrance*. Ottawa, Canada: Sport Information Research Centre. Retrieved from http://morrisonvein.org/2012/compression-shorts-and-sports-performance/

Bernhardt, T., & Anderson, G. S. (2005). Influence of moderate prophylactic compression on sport performance. *Journal of Strength & Conditioning Research*, *19*(2), 292-297.

Bero, L., Grilli, R., Grimshaw, J., Harvey, E., Oxman, A., & Thomson, M. (1998). The Cochrane Effective Practice and Organization of Care Review Group. Closing the gap between research and practice: an overview of systematic reviews of interventions to promote the implementation of research findings. *BMJ, 317*(7156), 465-468.

Bicici, S., Karatas, N., & Baltaci, G. (2012). Effect of athletic taping and kinesiotaping® on measurements of functional performance in basketball players with chronic inversion ankle sprains. *International Journal of Sports Physical Therapy*, *7*(2), 154-166.

Birmingham, T., Kramer, J., Kirkley, A., Inglis, J., Spaulding, S., & Vandervoort, A. (2001). Knee bracing for medial compartment osteoarthritis: effects on proprioception and postural control. *Rheumatology, 40*(3), 285-289.

Birmingham, T. B., Inglis, J. T., Kramer, J. F., & Vandervoort, A. A. (2000). Effect of a neoprene sleeve on knee joint kinesthesis: influence of different testing procedures. *Medicine and Science in Sports and Exercise, 32*(2), 304-308.

Birmingham, T. B., Kramer, J. F., Inglis, J. T., Mooney, C. A., Murray, L. J., Fowler, P. J., & Kirkley, S. (1998). Effect of a neoprene sleeve on knee joint position sense during sitting open kinetic chain and supine closed kinetic chain tests. *American Journal of Sports Medicine, 26*(4), 562-566.

Bloem, B. R., Grimbergen, Y. A., van Dijk, J. G., & Munneke, M. (2006). The “posture second” strategy: a review of wrong priorities in Parkinson's disease. *Journal of the Neurological Sciences*, *248*(1), 196-204.

Boes, M. K., Sosnoff, J. J., Socie, M. J., Sandroff, B. M., Pula, J. H., & Motl, R. W. (2012). Postural control in multiple sclerosis: effects of disability status and dual task. *Journal of the Neurological Sciences, 315*(1), 44-48.

Bolier, L., Haverman, M., Westerhof, G. J., Riper, H., Smit, F., & Bohlmeijer, E. (2013). Positive psychology interventions: a meta-analysis of randomized controlled studies. *BMC public health*, *13*(1), 119.

Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2005). Comprehensive meta-analysis (Version 2) [Computer software]. Englewood, NJ: Biostat.

Bottoni, G., Heinrich, D., Kofler, P., Hasler, M., & Nachbauer, W. (2014). Effect of knee supports on knee joint position sense after uphill and downhill walking. A test using a hiking simulation method. *Journal of Ergonomics, 4*, 132. doi:10.4172/2165-7556.1000132

Bottoni, G., Herten, A., Kofler, P., Hasler, M., & Nachbauer, W. (2013). The effect of knee brace and knee sleeve on the proprioception of the knee in young non-professional healthy sportsmen. *The Knee, 20*(6), 490-492.

Brauer, S., Woollacott, M., & Shumway-Cook, A. (2002). The influence of a concurrent cognitive task on the compensatory stepping response to a perturbation in balance-impaired and healthy elders. *Gait & Posture, 15*(1), 83-93.

Brauer, S. G., Woollacott, M., & Shumway-Cook, A. (2001). The interacting effects of cognitive demand and recovery of postural stability in balance-impaired elderly persons. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 56*(8), M489-M496.

Brown, L. A., Shumway-Cook, A., & Woollacott, M. H. (1999). Attentional demands and postural recovery: the effects of aging. *The Journals of*

Gerontology Series A: Biological Sciences and Medical Sciences, 54(4), M165-M171.

Callaghan, M. J., McKie, S., Richardson, P., & Oldham, J. A. (2012). Effects of patellar taping on brain activity during knee joint proprioception tests using functional magnetic resonance imaging. *Physical Therapy, 92*(6), 821-830.

Callaghan, M. J., Selfe, J., Bagley, P. J., & Oldham, J. A. (2002). The effects of patellar taping on knee joint proprioception. *Journal of Athletic Training, 37*(1), 19-24.

Callaghan, M. J., Selfe, J., McHenry, A., & Oldham, J. A. (2008). Effects of patellar taping on knee joint proprioception in patients with patellofemoral pain syndrome. *Manual Therapy, 13*(3), 192-199.

Cameron, M. L., Adams, R. D., & Maher, C. G. (2008). The effect of neoprene shorts on leg proprioception in Australian football players. *Journal of Science and Medicine in Sport, 11*(3), 345-352.

Centre for Reviews and Dissemination. (2009). *Systematic reviews: CRD's guidance for undertaking reviews in health care*: Centre for Reviews and Dissemination.

Cervantes, S. J., & Snyder, A. R. (2011). The effectiveness of a dynamic warm-up in improving performance in college athletes. *Journal of Sport Rehabilitation, 20*(4), 487-493.

Chattong, C., Brown, L. E., Coburn, J. W., & Noffal, G. J. (2010). Effect of a dynamic loaded warm-up on vertical jump performance. *The Journal of Strength & Conditioning Research, 24*(7), 1751-1754.

Cho, H.-y., Kim, E.-H., Kim, J., & Yoon, Y. W. (2015). Kinesio Taping Improves Pain, Range of Motion, and Proprioception in Older Patients with Knee Osteoarthritis: A Randomized Controlled Trial. *American Journal of Physical Medicine & Rehabilitation, 94*(3), 192-200.

Choi, J. H., Kim, B. R., Han, E. Y., & Kim, S. M. (2015). The effect of dual-task training on balance and cognition in patients with subacute post-stroke. *Annals of Rehabilitation Medicine, 39*(1), 81-90.

Cholewicki, J., Shah, K. R., & McGill, K. C. (2006). The effects of a 3-week use of lumbosacral orthoses on proprioception in the lumbar spine. *Journal of Orthopaedic & Sports Physical Therapy, 36*(4), 225-231.

Chu, J. C., Kane, E. J., Arnold, B. L., & Gansneder, B. M. (2002). The effect of a neoprene shoulder stabilizer on active joint-reposition sense in subjects with stable and unstable shoulders. *Journal of Athletic Training, 37*(2), 141–145.

Cohen, J. (1988a). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: L, Erlbaum Associates.

Cohen, J. (1988b). *Statistical power analysis for the behavioral sciences* (Vol. 2). Hillsdale, NJ: Lawrence Earlbaum Associates.

Collins, A. T., Blackburn, J. T., Olcott, C. W., Dirschl, D. R., & Weinhold, P. S. (2009). The effects of stochastic resonance electrical stimulation and neoprene sleeve on knee proprioception. *Journal of Orthopaedic Surgery and Research, 4*(3)

Collins, A. T., Blackburn, J. T., Olcott, C. W., Miles, J., Jordan, J., Dirschl, D. R., & Weinhold, P. S. (2011). Stochastic resonance electrical stimulation to improve proprioception in knee osteoarthritis. *The Knee, 18*(5), 317-322.

Collins, D. F., & Prochazka, A. (1996). Movement illusions evoked by ensemble cutaneous input from the dorsum of the human hand. *Journal of Physiology, 496*(3), 857-871.

Cronin, J., Nash, M., & Whatman, C. (2006). Assessing dynamic knee joint range of motion using siliconcoach. *Physical Therapy in Sport, 7*(4), 191-194.

Dault, M. C., Geurts, A. C., Mulder, T. W., & Duysens, J. (2001). Postural control and cognitive task performance in healthy participants while balancing on different support-surface configurations. *Gait & posture, 14*(3), 248-255.

Davidoff, J. (2000). *Brain and behaviour: Critical concepts in psychology* (Vol. 1). London: Psychology Press.

Davies, V., Thompson, K. G., & Cooper, S.-M. (2009). The effects of compression garments on recovery. *Journal of Strength and Conditioning Research, 23*(6), 1786-1794.

de Morton, N. A. (2009). The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Australian Journal of Physiotherapy, 55*(2), 129-133.

DeCaro, M. S., Thomas, R. D., Albert, N. B., & Beilock, S. L. (2011). Choking under pressure: Multiple routes to skill failure. *Journal of Experimental Psychology: General, 140*(3), 390-406.

Deeks, J., Higgins, J., & Altmann, D. (2013). Incorporating heterogeneity into random-effects models. *Cochrane handbook for systematic reviews of interventions*. Hoboken, NJ: Wiley-Blackwell.

Donker, S. F., Roerdink, M., Greven, A. J., & Beek, P. J. (2007). Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. *Experimental Brain Research, 181*(1), 1-11.

Dorrestijn, O., Stevens, M., Winters, J. C., van der Meer, K., & Diercks, R. L. (2009). Conservative or surgical treatment for subacromial impingement syndrome? A systematic review. *Journal of Shoulder and Elbow Surgery, 18*(4), 652-660.

Driller, M. W., & Halson, S. L. (2013). The effects of wearing lower body compression garments during a cycling performance test. *International Journal of Sports and Physiology Performance, 8*, 300-306.

Edin, B. B. (2001). Cutaneous afferents provide information about knee joint movements in humans. *The Journal of Physiology, 531*(1), 289-297.

Ellapen, T. J., Acampora, N., Dawson, S., Arling, J., Van Niekerk, C., & Van Heerden, H. (2014). Comparison of the effect of semi-rigid ankle bracing on performance among injured v. non-injured adolescent female hockey players. *South African Journal of Sports Medicine, 26*(3), 73-76.

Eng, J. J., Teasell, R., Miller, W. C., Wolfe, D. L., Townson, A. F., Aubut, J.-A., . . . Konnyu, K. (2007). Spinal cord injury rehabilitation evidence: methods of the SCIRE systematic review. *Topics in spinal cord injury rehabilitation, 13*(1), 1.

Faraji, E., Daneshmandi, H., Atri, A. E., Onvani, V., & Namjoo, F. R. (2012). Effects of prefabricated ankle orthoses on postural stability in basketball players with chronic ankle instability. *Asian Journal of Sports Medicine, 3*(4), 274-278.

Feltz, D. L. (1988). Self-confidence and sports performance. In K. B. Pandolf (Ed.), *Exercise and sports sciences reviews* (pp. 423-457). New York, NY: MacMillan.

Freiman, J. A., Chalmers, T. C., Smith Jr, H., & Kuebler, R. R. (1978). The importance of beta, the type II error and sample size in the design and interpretation of the randomized control trial: survey of 71 negative trials. *New England Journal of Medicine, 299*(13), 690-694.

Fu, W., Liu, Y., & Fang, Y. (2013). Research advancements in humanoid compression garments in sports. *International Journal of Advanced Robotic Systems, 10*(66), 1-6.

Fujita, H., Kasubuchi, K., Wakata, S., Hiyamizu, M., & Morioka, S. (2016). Role of the Frontal Cortex in Standing Postural Sway Tasks While Dual-Tasking: A Functional Near-Infrared Spectroscopy Study Examining Working Memory Capacity. *BioMed Research International, 2016*

Gilleard, W., McConnell, J., & Parsons, D. (1998). The effect of patellar taping on the onset of vastus medialis obliquus and vastus lateralis muscle activity in persons with patellofemoral pain. *Physical Therapy, 78*(1), 25-32.

Grigg, P. (1994). Peripheral neural mechanisms in proprioception. *Journal of Sport Rehabilitation, 3*(1), 2–17.

Hadadi, M., Mousavi, M. E., Fardipour, S., Vameghi, R., & Mazaheri, M. (2014). Effect of soft and semirigid ankle orthoses on Star Excursion Balance Test performance in patients with functional ankle instability. *Journal of Science and Medicine in Sport, 17*(4), 430-433.

Haggerty, S., Jiang, L.-T., Galecki, A., & Sienko, K. H. (2012). Effects of biofeedback on secondary-task response time and postural stability in older adults. *Gait & posture, 35*(4), 523-528.

Hall, W. C. (2004). Lower motor neuron circuits and motor control. In D. Purves, G. J. Augustine, D. Fitzpatrick, L. C. Katz, A.-S. LaMantia, J. O. McNamara & S. M. Williams (Eds.), *Neuroscience* (3rd ed.). Sunderland, MA: Sinauer Associates.

Halseth, T., McChesney, J. W., DeBeliso, M., Vaughn, R., & Lien, J. (2004). The effects of Kinesio™ taping on proprioception at the ankle. *Journal of Sports Science & Medicine, 3*(1), 1-7.

Han, J., Waddington, G., Adams, R., Anson, J., & Liu, Y. (2015). Assessing proprioception: A critical review of methods. *Journal of Sport and Health Science*, Advance online. doi:10.1016/j.jshs.2014.10.004

Hassan, B. S., Mockett, S., & Doherty, M. (2002). Influence of elastic bandage on knee pain, proprioception, and postural sway in subjects with knee osteoarthritis. *Annals of the Rheumatic Diseases, 61*(1), 24-28.

Herrington, L., Simmonds, C., & Hatcher, J. (2005). The effect of a neoprene sleeve on knee joint position sense. *Research in Sports Medicine, 13*(1), 37-46.

Hettle, D., Linton, L., Baker, J., & Donoghue, O. (2013). The effect of kinesiotaping on functional performance in chronic ankle instability-preliminary study. *Clinical Research on Foot & Ankle, 1*(1), 1-5.

Higgins, J. P., & Green, S. (2008). *Cochrane handbook for systematic reviews of interventions* (Vol. 5): Wiley Online Library.

Hiyamizu, M., Morioka, S., Shomoto, K., & Shimada, T. (2012). Effects of dual task balance training on dual task performance in elderly people: a randomized controlled trial. *Clinical rehabilitation, 26*(1), 58-67.

Holmes, J. D., Jenkins, M. E., Johnson, A. M., Adams, S. G., & Spaulding, S. J. (2010). Dual-task interference: The effects of verbal cognitive tasks on upright postural stability in Parkinson's disease. *Parkinson's Disease, 2010*(Article ID 696492), 1-10. doi:10.4061/2010/696492

Hori, N., & Andrews, W. (2009). Reliability of velocity, force and power obtained from the Gymaware optical encoder during countermovement jump with and without external loads. *Journal of Australian Strength and Conditioning, 17*(1), 12-17.

Hunter, M. C., & Hoffman, M. A. (2001). Postural control: Visual and cognitive manipulations. *Gait & Posture, 13*(1), 41-48.

Huxhold, O., Li, S.-C., Schmiedek, F., & Lindenberger, U. (2006). Dual-tasking postural control: Aging and the effects of cognitive demand in conjunction with focus of attention. *Brain Research Bulletin, 69*(3), 294-305.

Iris, M., Monterde, S., Salvador, M., Salvat, I., Fernandez-Ballart, J., & Judith, B. (2010). Ankle taping can improve proprioception in healthy volunteers. *Foot & ankle international, 31*(12), 1099-1106.

Jacobi, H., Alfes, J., Minnerop, M., Konczak, J., Klockgether, T., & Timmann, D. (2015). Dual task effect on postural control in patients with degenerative cerebellar disorders. *Cerebellum & Ataxias, 2*(1), 6. doi:10.1186/s40673-015-0025-z

Janssen, K. W., & Kamper, S. J. (2013). Ankle taping and bracing for proprioception. *British Journal of Sports Medicine, 47*(8), 527-528.

Jerosch, J., & Prymka, M. (1995). Propriozeptive Fähigkeiten des gesunden Kniegelenks: Beeinflussung durch eine elastische Bandage. *Sportverletzung· Sportschaden, 9*(03), 72-76.

Jerosch, J., & Prymka, M. (1996). Proprioception and joint stability. *Knee Surgery, Sports Traumatology, Arthroscopy, 4*(3), 171-179.

Johnson, E., Babis, G., Soultanis, K., & Soucacos, P. (2007). Functional neuroanatomy of proprioception. *Journal of Surgical Orthopaedic Advances, 17*(3), 159-164.

Ju, Y.-Y., Wang, C.-W., & Cheng, H.-Y. K. (2010). Effects of active fatiguing movement versus passive repetitive movement on knee proprioception. *Clinical Biomechanics, 25*(7), 708-712.

Kaminski, T. W., & Perrin, D. H. (1996). Effect of prophylactic knee bracing on balance and joint position sense. *Journal of Athletic Training, 31*(2), 131–136.

Krishnamoorthy, V., Slijper, H., & Latash, M. L. (2002). Effects of different types of light touch on postural sway. *Experimental Brain Research, 147*(1), 71-79.

Lee, H.-J., Lim, K.-B., Jung, T.-H., Kim, D.-Y., & Park, K.-R. (2013). Changes in balancing ability of athletes with chronic ankle instability after foot orthotics application and rehabilitation exercises. *Annals of Rehabilitation Medicine, 37*(4), 523-533.

Lephart, S. M., Pincivero, D. M., Giraido, J. L., & Fu, F. H. (1997). The role of proprioception in the management and rehabilitation of athletic injuries. *American Journal of Sports Medicine, 25*(1), 130-137.

Lien, N., Steel, K. A., Graham, K., Penkala, S., Quinn, J., Dogramaci, S., & Moresi, M. (2014). What is the effect of compression garments on a novel kick accuracy task? *International Journal of Sports Science and Coaching, 9*(2), 357-366.

Lim, J., Amado, A., Sheehan, L., & Van Emmerik, R. E. A. (2015). Dual task interference during walking: The effects of texting on situational awareness and gait stability. *Gait & Posture, 42*(4), 466-471. doi:10.1016/j.gaitpost.2015.07.060

Lin, J. j., Hung, C. J., & Yang, P. L. (2011). The effects of scapular taping on electromyographic muscle activity and proprioception feedback in healthy shoulders. *Journal of Orthopaedic Research, 29*(1), 53-57.

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical therapy, 83*(8), 713-721.

Marchese, R., Bove, M., & Abbruzzese, G. (2003). Effect of cognitive and motor tasks on postural stability in Parkinson's disease: A posturographic study. *Movement Disorders, 18*(6), 652-658.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *The Journal of Strength & Conditioning Research, 18*(3), 551-555.

Marsh, A. P., & Geel, S. E. (2000). The effect of age on the attentional demands of postural control. *Gait & Posture, 12*(2), 105-113.

Masters, R. S. W. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology, 83*(3), 343-358.

Masters, R. S. W., & Maxwell, J. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology, 1*(2), 160-183.

McCloskey, D. I. (1978). Kinesthetic sensibility. *Physiological Reviews, 58*(4), 763-820.

McNair, P. J., Stanley, S. N., & Strauss, G. R. (1996). Knee bracing: effects on proprioception. *Archives of Physical Medicine and Rehabilitation, 77*(3), 287-289.

Melzer, I., Benjuya, N., & Kaplanski, J. (2001). Age-related changes of postural control: effect of cognitive tasks. *Gerontology, 47*(4), 189-194.

Michael, J. S., Dogramaci, S. N., Steel, K. A., & Graham, K. S. (2014). What is the effect of compression garments on a balance task in female athletes? *Gait & Posture, 39*(2), 804-809.

Miyamoto, N., Hirata, K., Mitsukawa, N., Yanai, T., & Kawakami, Y. (2011). Effect of pressure intensity of graduated elastic compression stocking on muscle fatigue following calf-raise exercise. *Journal of Electromyography and Kinesiology, 21*(2), 249-254.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Annals of Internal Medicine, 151*(4), 264-269.

Mokhtarinia, H., Ebrahimi-Takamjani, I., Salavati, M., Goharpay, S., & Khosravi, A. (2008). The effect of patellar taping on knee joint proprioception in patients with patellofemoral pain syndrome. *Acta Medica Iranica, 46*(3), 183-190.

Mori, S., Stuart, D. G., Wiesendanger, M., & Pierce, P. A. (2004). *Brain mechanisms for the integration of posture and movement*. Amsterdam: Elsevier.

Munoz, F., Salmochi, J.-F., Faouen, P., & Rougier, P. (2010). Low back pain sufferers: Is standing postural balance facilitated by a lordotic lumbar brace? *Orthopaedics & Traumatology: Surgery & Research, 96*(4), 362-366.

Negahban, H., Mofateh, R., Arastoo, A. A., Mazaheri, M., Yazdi, M. J. S., Salavati, M., & Majdinasab, N. (2011). The effects of cognitive loading on balance control in patients with multiple sclerosis. *Gait & Posture, 34*(4), 479-484.

Newcomer, K., Laskowski, E. R., Yu, B., Johnson, J. C., & An, K.-N. (2001). The effects of a lumbar support on repositioning error in subjects with low back pain. *Archives of Physical Medicine and Rehabilitation, 82*(7), 906-910.

Olsson, L., Lund, H., Henriksen, M., Rogind, H., Bliddal, H., & Danneskiold-Samsøe, B. (2004). Test-retest reliability of a knee joint position sense measurement method in sitting and prone position. *Advances in Physiotherapy, 6*(1), 37-47.

Pagaduan, J. C., Pojskić, H., Užičanin, E., & Babajić, F. (2012). Effect of various warm-up protocols on jump performance in college football players. *Journal of Human Kinetics, 35*(1), 127-132.

Peat, J., & Barton, B. (2008). *Medical statistics: a guide to data analysis and critical appraisal*. New York, NY: John Wiley & Sons.

Pellecchia, G. L. (2003). Postural sway increases with attentional demands of concurrent cognitive task. *Gait & Posture, 18*(1), 29-34.

Perlau, R., Frank, C., & Fick, G. (1995). The effect of elastic bandages on human knee proprioception in the uninjured population. *American Journal of Sports Medicine, 23*(2), 251-255.

Pohl, P. S., McDowd, J., Filion, D., Richards, L., & Stiers, W. (2006). Implicit learning of a motor skill after mild and moderate stroke. *Clinical Rehabilitation, 20*(3), 246-253.

Prasansuk, S., Siriyananda, C., Nakorn, A., Atipas, S., & Chongvisal, S. (2004). Balance disorders in the elderly and the benefit of balance exercise. *Journal of the Medical Association of Thailand= Chotmaihet thangphaet, 87*(10), 1225-1233.

Prosperini, L., Castelli, L., Sellitto, G., De Luca, F., De Giglio, L., Gurreri, F., & Pozzilli, C. (2015). Investigating the phenomenon of “cognitive-motor interference” in multiple sclerosis by means of dual-task posturography. *Gait & Posture, 41*(3), 780-785.

Ramenzoni, V. C., Riley, M. A., Shockley, K., & Chiu, C.-Y. P. (2007). Postural responses to specific types of working memory tasks. *Gait & posture, 25*(3), 368-373.

Ramsey, L., Winder, R. J., & McVeigh, J. G. (2014). The effectiveness of working wrist splints in adults with rheumatoid arthritis: A mixed methods systematic review. *Journal of Rehabilitation Medicine, 46*(6), 481-492.

Resch, J. E., May, B., Tomporowski, P. D., & Ferrara, M. S. (2011). Balance performance with a cognitive task: a continuation of the dual-task testing paradigm. *Journal of Athletic Training, 46*(2), 170.

Robinson, R. H., & Gribble, P. A. (2008). Support for a reduction in the number of trials needed for the Star Excursion Balance Test. *Archives of Physical Medicine and Rehabilitation, 89*(2), 364-370.

Ruthruff, E., Pashler, H. E., & Hazeltine, E. (2003). Dual-task interference with equal task emphasis: Graded capacity sharing or central postponement? *Perception & Psychophysics, 65*(5), 801-816.

Ryan, R., Hill, S., Broclain, D., Horey, D., Oliver, S., & Prictor, M. (2009). *Cochrane consumers and communication review group.* Retrieved from http://www.latrobe.edu.au/chcp/assets/downloads/StudyQualityGuide050307.pdf

Sackett, D. L., Straus, S. E., Richardson, W. S., Rosenberg, W., & Haynes, R. B. (2000). *Evidence-based medicine: How to practice and teach EBM* (2nd ed.). Edinburgh: Churchill Livingstone.

Sawkins, K., Refshauge, K., Kilbreath, S., & Raymond, J. (2007). The placebo effect of ankle taping in ankle instability. *Medicine and Science in Sports and Exercise, 39*(5), 781-787. doi:10.1249/MSS.0b013e3180337371

Schaefer, S., Jagenow, D., Verrel, J., & Lindenberger, U. (2015). The influence of cognitive load and walking speed on gait regularity in children and young adults. *Gait & Posture, 41*(1), 258-262.

Schaefer, S., & Lindenberger, U. (2013). Thinking while walking: Experienced high-heel walkers flexibly adjust their gait. *Frontiers in Psychology, 4*, 1-7.

Schaefer, S., Schellenbach, M., Lindenberger, U., & Woollacott, M. (2015). Walking in high-risk settings: Do older adults still prioritize gait when distracted by a cognitive task? *Experimental brain research, 233*(1), 79-88.

Schinka, J. A., Velicer, W. F., & Weiner, I. B. (2003). *Handbook of psychology: Volume 2: Research methods in psychology*. Hoboken, NJ: Wiley.

Seidler, R. D., Bernard, J. A., Burutolu, T. B., Fling, B. W., Gordon, M. T., Gwin, J. T., . . . Lipps, D. B. (2010). Motor control and aging: links to age-related brain structural, functional, and biochemical effects. *Neuroscience & Biobehavioral Reviews, 34*(5), 721-733.

Sherrington, C. (1906). *The integrative action of the nervous system*. New Haven, CT: Yale University Press.

Shumway-Cook, A., & Woollacott, M. (2000). Attentional demands and postural control: the effect of sensory context. *Journals of Gerontology-Biological Sciences and Medical Sciences, 55*(1), M10.

Shumway-Cook, A., Woollacott, M., Kerns, K. A., & Baldwin, M. (1997). The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 52*(4), M232-M240.

Simoneau, G. G., Degner, R. M., Kramper, C. A., & Kittleson, K. H. (1997). Changes in ankle joint proprioception resulting from strips of athletic tape applied over the skin. *Journal of Athletic Training, 32*(2), 141.

Skinner, H. B., Barrack, R. L., & COOK, S. D. (1984). Age-related decline in proprioception. *Clinical orthopaedics and related research, 184*, 208-211.

Son, J., Ashton-Miller, J. A., & Richardson, J. K. (2010). Do ankle orthoses improve ankle proprioceptive thresholds or unipedal balance in older persons with peripheral neuropathy? *American Journal of Physical Medicine & Rehabilitation, 89*(5), 369.

Spanos, S., Brunswic, M., & Billis, E. (2008). The effect of taping on the proprioception of the ankle in a non-weight bearing position, amongst injured athletes. *The Foot, 18*(1), 25-33.

Steindl, R., & Ulmer, H. (2004). Standstabilität im kindes-und jugendalter. *HNO, 52*(5), 423-430.

Swan, L., Otani, H., & Loubert, P. V. (2007). Reducing postural sway by manipulating the difficulty levels of a cognitive task and a balance task. *Gait & Posture, 26*(3), 470-474.

Swan, L., Otani, H., Loubert, P. V., Sheffert, S. M., & Dunbar, G. L. (2004). Improving balance by performing a secondary cognitive task. *British Journal of Psychology, 95*(1), 31-40.

Talelli, P., Ewas, A., Waddingham, W., Rothwell, J., & Ward, N. (2008). Neural correlates of age-related changes in cortical neurophysiology. *Neuroimage, 40*(4), 1772-1781.

Teasdale, N., Bard, C., LaRue, J., & Fleury, M. (1993). On the cognitive penetrability of posture control. *Experimental Aging Research, 19*(1), 1-13.

Teasdale, N., & Simoneau, M. (2001). Attentional demands for postural control: the effects of aging and sensory reintegration. *Gait & Posture, 14*(3), 203-210.

Teasell, R. (2008). Evidence-based review of stroke rehabilitation (EBRSR).

Teasell, R. W., Marshall, S., Cullen, N., Rees, L., Bayley, M., Weiser, M., . . . Welch-West, P. (2005). *Evidence based review of moderate to severe acquired brain injury*. Toronto, Ontario: Ontario Neurotrauma Foundation.

Thijs, Y., Vingerhoets, G., Pattyn, E., Rombaut, L., & Witvrouw, E. (2010). Does bracing influence brain activity during knee movement: An fMRI study. *Knee Surgery, Sports Traumatology, Arthroscopy, 18*(8), 1145-1149.

Ulkar, B., Kunduracioglu, B., Cetin, C., & Güner, R. (2004). Effect of positioning and bracing on passive position sense of shoulder joint. *British Journal of Sports Medicine, 38*(5), 549-552.

Van Tiggelen, D., Coorevits, P., & Witvrouw, E. (2008a). The effects of a neoprene knee sleeve on subjects with a poor versus good joint position sense subjected to an isokinetic fatigue protocol. *Clinical Journal of Sport Medicine, 18*(3), 259-265.

Van Tiggelen, D., Coorevits, P., & Witvrouw, E. (2008b). The use of a neoprene knee sleeve to compensate the deficit in knee joint position sense caused by muscle fatigue. *Scandinavian Journal of Medicine & Science in Sports, 18*(1), 62-66.

Vaugoyeau, M., Viel, S., Amblard, B., Azulay, J., & Assaiante, C. (2008). Proprioceptive contribution of postural control as assessed from very slow oscillations of the support in healthy humans. *Gait & Posture, 27*(2), 294-302.

Vogt, L., Pfeifer, K., Portscher, M., & Banzer, W. (2000). Lumbar corsets: their effect on three-dimensional kinematics of the pelvis. *Journal of Rehabilitation Research and Development, 37*(5), 495-500.

Vuillerme, N., Isableu, B., & Nougier, V. (2006). Attentional demands associated with the use of a light fingertip touch for postural control during quiet standing. *Experimental Brain Research, 169*(2), 232-236.

Weightman, A. L., & Williamson, J. (2005). The value and impact of information provided through library services for patient care: a systematic review. *Health Information & Libraries Journal, 22*(1), 4-25.

Wikstrom, E. A., Tillman, M. D., Smith, A. N., & Borsa, P. A. (2005). A new force-plate technology measure of dynamic postural stability: The dynamic postural stability index. *Journal of Athletic Training, 40*(4), 305-309.

Wong, M., To, W., & Lam, I. (2001). SCIENTIFIC PAPER Effect of elastic bandages and ankle weights on knee proprioception in uninjured female dancers: a prospective study. *Hong Kong Journal of Orthopaedic Surgery, 5*(1), 52-57.

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Quarterly Journal of Experimental Psychology: Section A, 54*(4), 1143-1154.

Yasuda, K., Sato, Y., Iimura, N., & Iwata, H. (2014). Allocation of attentional resources toward a secondary cognitive task leads to compromised ankle proprioceptive performance in healthy young adults. *Rehabilitation Research and Practice*(Article ID 170304) doi:10.1155/2014/170304

Appendices

Appendix 1 Research consent form: Effects of below-knee compression garment and secondary cognitive task on knee joint proprioception

<u>Informed Consent form</u>

Project Title: Effects of below-knee compression garment and secondary cognitive task on knee joint proprioception/ the validity of blood lactate predicting devices in monitoring athletic performance

Principal Researchers: Dr. Matt Driller, Prof. Rich Masters, Nattai Borges, Shashank Ghai

This is to certify that I, hereby agree to participate as a volunteer in a scientific investigation as an authorized part of the research program of the Waikato University Sport and Leisure Department under the supervision of .

The investigation and my part in the investigation have been defined and fully explained to me by and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions and inquires have been answered to my satisfaction.

- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage to myself.

- I understand that I am free to withdraw my data up until the point of analysis without disadvantage to myself.

- I understand that any data will remain anonymous with regard to my identity through a coding system. The data will be made publishable, so every effort will be made to ensure confidentiality, however this cannot be guaranteed.

- I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participation in this investigation.

- I am participating in this project of my (his/her) own free will and I have not been coerced in any way to participate.

Signature of Subject: ____

Date: ____/____/____

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ____________________________________

Date:___/____/____

Appendix 2 Participant information sheet- Effects of below-knee compression garment and secondary cognitive task on knee joint proprioception

<u>Participant Information:</u>

Dear participant,

You are being invited to take part in a research study, which will help the Waikato University Sport and Leisure Department determine the effect of below-knee compression and secondary cognitive tasks on knee joint proprioception. Before you volunteer to take part in the study please take the time to read the following information carefully and if there is anything that is not clear or you would like more information, please feel free to contact us.

Purpose

The aim of the study is to determine the effects of below-knee compression and secondary cognitive tasks on knee joint proprioception. Also lactate thresholds were identified using the below-knee compression garment.

Significance

The findings from this research will help us enrich our knowledge on the effects of secondary task interventions and below-knee compression garment on knee joint proprioception. The research will serve as an educational tool to highlight the importance of joint compression and lower information processing constraints to enhance musculoskeletal stability, within a clinical context.

Selection Criteria and Information

To be eligible in this study you must be:

Over 18 years of age

And NOT have the following:

Injury, illness or health issue which would disrupt the subject's performance and/or

Injury, illness or health issue which would endanger the subject's health.

If you meet all of these criteria then you can choose to participate in this research project.

It is up to you to decide whether or not to take part and non-participation in the study. If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason

Information

You would be required to perform two active knee joint re-positioning tests. The test will require you to re-perform two pre-determined target angles from the knee joint, which will be introduced by a researcher. You will then be randomly asked to wear a below-knee compression sleeve on wither your dominant or non-dominant leg. Thereafter, you would have to perform the knee re-positioning task. Also, within one of the two re-positioning trials you would be asked to perform a secondary distracting task for instance, random letters or backward counting tasks. Knee-repositioning angles will be duly noted by the researcher, a physiotherapist using a handheld goniometer.

What will you gain from participating in the study?

As a participant, you will benefit from experience with the research process and gain knowledge about the area of research. You will be involved in innovative research, which will provide valuable information on the role of secondary task interventions and below-knee compression for enhancing knee joint proprioception.

All information collected during the course of the research project will be kept strictly confidential. A code number will identify you and all of your personal information (demographic information i.e. age, gender, weight, height, proprioception accuracy) will be kept private.

Any inquiries regarding requirements and procedures used in this study are encouraged. Please contact Shashank Ghai if you have any questions.

Researcher Contact Details

Shashank Ghai

Email: sghai@waikato.ac.nz

Contact no. : 0220206429

Appendix 3 Research consent form: Effects of secondary cognitive task on dynamic knee joint proprioception and jump performance, before and after fatigue

Project Title: How would secondary task interventions and induced fatigue influence proprioception, musculoskeletal flexibility, stiffness and vertical jump height?

Location: Round the Bridges Run, Hamilton

Time required: 10 minutes

Principal Researchers: Dr. Matt Driller, Shashank Ghai

This is to certify that I, hereby agree to participate as a volunteer in a scientific investigation as an authorized part of the research program of the Waikato University, Te Oranga – School of Human Development and Movement Studies under the supervision of .

The investigation and my part in the investigation have been defined and fully explained to me by and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

I have been given an opportunity to ask whatever questions I may have had and all such questions and inquires have been answered to my satisfaction.

I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage to myself.

I understand that I am free to withdraw my data up this the point of final data collection without disadvantage to myself.

I understand that any data will remain anonymous with regard to my identity through a coding system. The data will be made publishable, so every effort will be made to ensure confidentiality, however, this cannot be guaranteed.

I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participation in this investigation.

I am participating in this project of my (his/her) own free will and I have not been coerced in any way to participate.

Signature of Participant: ____

Date: ____/____/____

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: __________________ Date: ___/____/____

Appendix 4 Participant information sheet: Effects of below-knee compression garment and secondary cognitive task on knee joint proprioception

Dear participant,

You are being invited to take part in a research study, which will help the University of Waikato study the effects of a secondary task intervention on musculoskeletal flexibility, stiffness and vertical jump height. Before you volunteer to take part in the study please take the time to read the following information carefully and if there is anything that is not clear or you would like more information, please feel free to contact us.

Purpose

The aim of the study is to determine the effects of secondary task interventions and induced fatigue on proprioception, musculoskeletal flexibility, stiffness and vertical jump height?

Significance

The findings from this research will help us enrich our knowledge on the effects of secondary task interventions on proprioception, musculoskeletal flexibility, stiffness and vertical jump height. The research will serve as an educational tool to highlight the importance of minimal cognitive processing to enhance musculoskeletal performance, stability, before and after exercise (pre and post 12km run).

Selection Criteria and Information

To be eligible in this study you must be:

Over 18 years of age

And NOT have the following:

Injury, illness or health issue which would disrupt the subject's performance and/or

Injury, illness or health issue which would endanger the subject's health.

If you meet all of these criteria then you can choose to participate in this research project.

It is up to you to decide whether or not to take part and non-participation in the study. If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason

Information

You would be required to perform a number of tests both pre and post the 12km run event (pre and post-run). The tests that will be measured both pre and post run include a squat jump (x3 attempts), a sit and reach test (x 3 attempts), and a muscle stiffness-hopping test (x 2 attempts). The squat jump test will be assessed by a Gymaware linear position transducer (evaluating vertical jump height). You will be required to first squat to an angle of 90 degrees (thighs parallel to the ground), then you would have to hold this position for 2 seconds and perform a maximal jump. During one of the three attempts, while getting into the squat position, you will be asked to perform a secondary task. The secondary task will involve a simple arithmetic calculation while you are getting into your self-perceived 90 degree position (e.g. 3+5/2=?). The jump attempt in which the secondary task is performed will be randomly allocated to minimize biasing. The measurement of joint angle during the squatting will be measured using a goniometer.

Moreover, in order to assess the changes in flexibility and muscle stiffness pre and post-run, a standard sit and reach test and a hopping test will be performed. The sit and reach test will involve sitting on the ground with your legs together, straight and out stretched. You'll then reach towards your toes i.e. as far as you can, while pushing a dial on a sit and reach box. The muscle stiffness test will involve hopping on a force plate for 5 seconds on each foot, and the measurements obtained will be analysed to assess the stiffness in the lower-leg muscles.

What will you gain from participating in the study?

As a participant, you will benefit from experience with the research process and gain knowledge about the area of research. You will be involved in innovative research, which will provide valuable information on the role of secondary task interventions for enhancing knee joint proprioception, and jump kinematics before and after fatigue. Likewise, the participants will gain knowledge about the effects of musculoskeletal fatigue on muscle stiffness and flexibility.

All information collected during the course of the research project will be kept strictly confidential. A code number will identify you and all of your personal information (demographic information i.e. age, gender, weight, height, proprioception accuracy) will be kept private.

Any inquiries regarding requirements and procedures used in this study are encouraged. Please contact Shashank Ghai if you have any questions.

Researcher Contact Details

Shashank Ghai

Email: sghai@waikato.ac.nz

Contact no. : 0220206429

Appendix 5 Pre-Test Medical Questionnaire

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

First Name/s ___________________________________ Surname ___________________________________

Date of Birth _____/______/_____ Gender (circle) Male Female

Please answer the following questions by circling the appropriate response, or filling in the blank.

1. How would you describe your present level of activity?
   Sedentary Moderately Active Active Highly Active

2. How would you describe your present level of fitness?
   Unfit Moderately Fit Trained Highly Trained

3. How would you consider your present body weight?
   Underweight Ideal Slightly Over Very Overweight

4. Smoking habits:
   Are you currently a smoker? **Yes** **No**
   How many do you smoke? ……per day

   Are you a previous smoker? **Yes** **No**
   How long is it since you stopped? ……..years

   Were you an occasional smoker? **Yes** **No**

   ……per day

   Were you a regular smoker? **Yes** **No**

……per day

5. Do you drink alcohol? **Yes** **No**

If you answered **Yes**, do you have?

An occasional drink A drink everyday

More than one drink a day

6. Have you had to consult your doctor in the previous six months?

If you have answered **Yes**, please give details…………………………………………………………………….

……………………………………………………………………………………

……………………………………

7. Are you presently taking any form of medication?

If you have answered **Yes**, please give details…………………………………………………………………….

……………………………………………………………………………………

……………………………………

8. As far as you are aware, do you suffer from or have you ever suffered from?(circle if yes to any)

a. Diabetes	b. Asthma
c. Epilepsy	d. Bronchitis
d. Any form of heart complaint*	e. Raynaud's Disease
f. Marfans Syndrome*	h. Aneurysm/embolism*
i. Anaemia	j. Haemophilia*

Please continue filling form over the page.

9. *Is there a history of heart disease in your family?

Yes **No**

10. ***Do you currently have any form of muscle or joint injury?**

    Yes No

11. **Have you had to suspend your normal training in the previous two weeks?**

    Yes No

12. **Please read and answer the following questions:**

    a. Are you suffering from any known serious infections?

       Yes No

    b. Have you had jaundice within the previous year?

       Yes No

    c. Have you ever had any form of hepatitis?

       Yes No

    d. Are you HIV antibody positive?

       Yes No

    e. Have you ever been involved in intravenous drug use?

       Yes No

    f. For females, are you currently, or in the previous 6 months, pregnant? **Yes**

       No

13. As far as you are aware, is there anything that might prevent you from successfully completing the tests that have been outlined to you?

If the answer to any of the above questions is yes then: **a. Discuss with the clinic personal the nature of the issue**

Consent of Athlete/Participant

___________________________ ______/_______/______

Athlete/Participant Signature Date

____

____________________________ _____/_______/_____

Guardian name (required if age less than 16 years) Athlete/Participant Signature Date

____

______________________________ ____/_______/____

Witness name Signature Date

Appendix 6 UOW laboratory informed consent form

I (print name) ____________________________ consent to participate in physiological assessment on the following terms:

1. I have read the Explanation of Physiological Assessment Procedures attached and have understood what I will be required to do. I have had the opportunity to ask questions and received satisfactory explanations about the assessment/s to be conducted.

2. I understand that I will be undertaking physical exercise at or near the extent of my physical capacity and there is possible risk in the physical exercise at that level, such as episodes of transient light-headedness, fainting, abnormal blood pressure, chest discomfort.

3. I understand that this may occur although the staff in this laboratory will take all proper care in the conduct of the assessment, and I fully assume that risk.

4. I understand that I can withdraw my consent, freely and without prejudice, at any time before, during or after testing.

5. I have told the person conducting the assessment of any illness or physical defect I have that may contribute to the level of that risk.

6. I understand that the information obtained from the test will be treated confidentially with my right to privacy assured. However, the information may be used for statistical or scientific purposes with privacy retained.

7. I release this laboratory and its employees from any liability for any injury or illness that I may experience during the assessment as well as any subsequent injury or illness that is connected to or to any extent influenced by the assessment.

8. I will indemnify this laboratory in respect to any liability it may incur in relation to any other person in connection with the assessment.

9. I hereby agree that I will present myself for testing in a suitable condition and have abided by any requirements for diet and activity prescribed to me by laboratory staff.

_________________________ _____/______/_____

Athlete/Participant Signature Date

____ __________________________ ____/______/____

Guardian name (required if age less than 16 yrs) Athlete/Participant Signature Date

____ __________________________ ____/______/____

Witness name Signature Date

From Australian Institute of Sport, 2013, *Physiological tests for elite athletes*, 2nd ed. (Champaign, IL: Human Kinetics).

Appendix 7 Ethics approval: Effects of below-knee compression garment and secondary cognitive task on knee joint proprioception/ the validity of blood lactate predicting devices in monitoring athletic performance

Dean's Office
Faculty of Education
Te Kura Toi Tangata
The University of Waikato
Private Bag 3105
Hamilton, New Zealand

Phone +64 7 838 4500
www.waikato.ac.nz

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

MEMORANDUM

To:	**Shem Rodger**
cc:	Dr Matt Driller
From:	**Dr Nicola Daly** Chairperson (Acting), Research Ethics Committee
Date:	14 January 2015
Subject:	Supervised Postgraduate Research – Application for Ethical Approval (EDU116/14)

Thank you for submitting the amendments to your application for ethical approval for the research project:

The validity of power and blood lactate measuring devices in monitoring athletic performance

I am pleased to advise that your amended application has received ethical approval.

Please note that researchers are asked to consult with the Faculty's Research Ethics Committee in the first instance if any changes to the approved research design are proposed.

The Committee wishes you all the best with your research.

Nicola Daly

Dr Nicola Daly
Chairperson (Acting)
Research Ethics Committee

Appendix 8 Ethics approval: Participant information sheet: Effects of below-knee compression garment and secondary cognitive task on knee joint proprioception

FEDU005/15 **Approved : 11 November, 2015**

Ethics Research Application

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Effects of a secondary task and fatigue on proprioception, musculoskeletal flexibility, stiffness and vertical jump height.

Shashank Ghai

Te Oranga - School of Human Development and Movement Studies

Overview

Principal Supervisor

Principal supervisor: Dr Matt Driller

Interest in Topic

My area of interest is to develop strategic protocols to efficiently enhance the neuromuscular system and reduce the risks of injuries encountered during sport and/or exercise activities. The proposed study aims to evaluate the effects of a secondary task interventions (mental distraction task) and fatigue on musculoskeletal flexibility, stiffness and vertical jump performance. The findings obtained in the study will not only provide significant information related to the decline in muscular performance after a fatiguing run but will also aid in formulating ergonomic and efficient methods for enhancing rehabilitation and prevention of sports injuries.

Research Timetable

Proposed date of commencement of data collection:

15 November, 2015 - Round the Bridges event day

Expected date of completion of data collection:

15 November, 2015

Informing Relevant Departmental Chair/s

Is your proposed research about papers or programmes within the University of Waikato Faculty of Education?

No

If yes, have you informed the relevant Head of School?

N/A

Applicant Agreement

Please include a signed PDF containing your supervisor's signature

File Attachment : Ghai S Supervisor Signature (pdf)

Approval Date: 11 November, 2015
Chair: John Williams

Appendix 8 Sample search strategy across EMBASE database

DATABSE	**EMBASE**
DATE	**10/06/2015**
STRATEGY	**#1 AND #2 AND #3 AND #4 AND #5 AND #6 AND #7 AND #8 AND #9**
#1	(‘joint’ OR ‘shoulder’ OR ‘knee’ OR ‘hip’ OR ‘ankle’ OR ‘elbow’ OR ‘wrist’ OR ‘spine’)/de OR (joint OR shoulder OR knee OR hip OR ankle elbow OR wrist OR spine):ti,ab
#2	(‘proprioception’ OR ‘kinaesthesia’ OR ‘joint position sense OR ‘movement detection’ OR ‘force perturbation’ OR ‘JPS’)/de OR (proprioception OR kinaesthesia OR joint position sense OR movement detection OR force perturbation OR JPS);ti,ab
#3	(‘proprioceptive tests’ OR ‘repositioning test’ ‘active joint position sense’ OR ‘active joint repositioning task’ OR ‘passive joint position sense test’ OR ‘passive joint repositioning test’ OR ‘active reproduction test’ OR ‘passive reproduction test’ OR ‘active angle reproduction’ OR ‘passive angle reproduction’ OR ‘threshold for passive detection of motion’ OR ‘active movement extent discrimination apparatus’ OR ‘proprioceptive feedback magnitude’ OR ‘biodex’ OR ‘biodex-system’ OR ‘wilcox’ OR ‘quad-logger’ OR ‘AMEDA’ OR ‘TDPM’ OR ‘AJRT’ OR ‘PJRT’ OR ‘RE’ OR AAR OR PAR)/de OR (proprioceptive tests OR repositioning test OR active joint position sense OR active joint repositioning task OR passive joint position sense test OR passive joint repositioning test OR active reproduction test OR passive reproduction test OR active angle reproduction OR passive angle reproduction OR threshold for passive detection of motion OR active movement extent discrimination apparatus OR proprioceptive feedback magnitude OR biodex OR biodex-system OR wilcox OR quad-logger OR AMEDA OR TDPM OR AJRT OR PJRT OR RE OR AAR OR PAR);ti,ab
#4	(‘postural stability’ OR ‘ OR ‘balance stability’ OR ‘static stability’ OR ‘dynamic stability’)/de OR (postural stability OR balance stability OR static stability OR dynamic stability);ti,ab

#5	(‘joint stabilizers’ OR ‘brace’ ‘tape’ OR ‘compression garments’ OR ‘neoprene sleeves’ OR ‘bandages’ OR ‘corsets’ OR ‘orthosis’ OR ‘orthotics’)/de OR (joint stabilizers OR brace OR tape OR compression garments OR neoprene sleeves OR bandages OR corsets OR orthosis OR orthotics);ti,ab
#6	(‘injury’ OR ‘strain’ OR ‘sprains’ OR ‘tendinopathy’ OR ‘repeated stress injuries’ OR ‘tendinitis’ OR ‘bursitis’ ‘low back pain’ OR ‘low back ache’ OR ‘disability’ OR ‘arthritis’ OR ‘osteoarthiritis’ OR ‘neuropathy’ OR ‘RSI’ OR ‘LBP’)/de OR (injury OR strain OR sprain OR tendinopathy OR repeated stress injury OR tendinitis OR bursitis OR low back pain OR disability OR arthitis OR osteoarthiritis OR neuropathy OR RSI OR LBP);ti,ab
#7	(‘rehabilitation’ OR ‘treatment’ OR ‘rehab’ OR ‘management’ OR ‘therapy’ OR ‘physiotherapy’ OR ‘physical therapy’ OR ‘prevention’ OR ‘risk prevention’)/de OR (rehabilitation OR treatment OR rehab OR management OR therapy OR physiotherapy OR physical therapy OR prevention OR risk prevention);ti,ab
#8	(‘age groups’ OR ‘adolescent’ OR ‘young’ OR ‘elderly’ OR ‘old’ AND (‘gender’ OR ‘male’ OR ‘female’) AND (‘athlete’ OR ‘elite athlete’ OR ‘recreational athlete’ OR ‘novice athlete’ OR ‘trained athlete’ OR ‘sedentary’))/de OR (age groups OR adolscent OR young OR elderly OR old AND (gender OR male OR female) AND (athlete OR elite athlete OR recreational athlete OR novice athlete OR trained athlete OR sedentary));ti;ab
#9	clinical trial/exp OR (‘intervention study’ OR ‘cohort analysis’ OR ‘longitudnal study’ OR ‘cluster analysis’ OR ‘crossover trial’ OR ‘cluster analysis’ OR ‘randomized trial’ OR ‘major clinical study’)/de OR (longitudinal OR cohort OR crossover trial OR cluster analysis OR randomized trial OR clinical trial OR controlled trial);ti,ab

Appendix 9: PEDro score: Effects of joint stabilizers on proprioception

Studies

Pedro	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1	•	•	•	•	•	-	-	-	-	•	•	•	•	•	-	•	•	•	•	•	•	•	•	•	•	•	•	•	-	-	-	•	-	•	•	-	•	•	•	-	•	•	•	•	-	•	•	•	•	•
2	•	•	-	•	-	-	-	-	-	-	-	•	•	•	•	•	•	•	•	•	-	-	•	•	-	-	-	-	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	-	•	•	•	-	•
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	•	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	•	•	-	-	-
4	•	•	•	-	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	-	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
5	•	•	-	•	-	-	-	•	-	-	-	-	-	-	-	•	•	-	-	-	-	-	•	•	•	-	•	-	-	-	-	-	-	-	-	-	-	•	-	-	-	-	-	-	-	-	•	•	-	-
6	•	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	•	-	-	-	-	-	-	-	-	-	-	-	-	•	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	•	-	•	•	•	•	•	•	•	-	-	-	-	-	-	-	-	-	-	-	-	-	-	•	•	•	•	•	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	-	•	•
10	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
11	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Total	9	8	6	7	6	5	5	6	5	5	5	6	6	6	6	7	7	6	6	6	5	5	7	8	8	5	7	6	5	5	5	6	5	6	6	5	6	7	6	5	6	6	6	6	4	7	8	6	5	6

Studies & Characteristics

1. Michael, Dogramaci, Steel, and Graham 2014: RCT, Australia.
2. Nakajima & Baldridge, 2013: RCT, USA.
3. Munoz, Salmochi, Faouen, & Rougier, 2010: CCT, France, Europe.
4. Cameron, Adams, & Maher, 2008: RCT, Australia.
5. Vogt, Pfeifer, Portscher, & Banzer, 2000: CCT, Germany, Europe.
6. Callaghan, McKie, Richardson, & Oldham, 2012: CCT, United Kingdom, Europe.
7. Thijs, Vingerhoets, Pattyn, Rombaut, & Witvrouw, 2010: CCT, Belgium, Europe.
8. Lin, Hung, & Yang, 2011: CCT, Taiwan.
9. Ulkar, Kunduracioglu, Cetin, & Güner, 2004: CCT, Turkey, Europe.
10. Chu, Kane, Arnold, & Gansneder, 2002: CCT, USA.
11. Khabie et al., 1998: CCT, USA.
12. Cholewicki, Shah, & McGill, 2006: RCT, USA.
13. Newcomer, Laskowski, Yu, Johnson, & An, 2001: RCT, USA.
14. McNair & Heine, 1999: RCT, New Zealand.
15. Lien et al., 2014: RCT, Australia.
16. Bernhardt & Anderson, 2005: RCT, Canada.
17. Cho, Kim, Kim, & Yoon, 2015: RCT, South Korea.
18. Bottoni, Heinrich, Kofler, Hasler, & Nachbauer, 2014: RCT, Austria, Europe.
19. Karimzadehfini, Zolaktaf, & Vahdatpour, 2014: RCT, Iran.
20. Bottoni, Herten, Kofler, Hasler, & Nachbauer, 2013: RCT, Austria, Europe.
21. Collins et al., 2011: CCT, USA.
22. Collins, Blackburn, Olcott, Dirschl, & Weinhold, 2009: CCT, USA.
23. Callaghan, Selfe, McHenry, & Oldham, 2008: RCT, United Kingdom, Europe.
24. Damien Van Tiggelen, P Coorevits, & Erik Witvrouw, 2008a: RCT, Belgium, Europe.
25. Damien Van Tiggelen, Pascal Coorevits, & Erik Witvrouw, 2008b: RCT, Belgium, Europe.

26. Mokhtarinia, Ebrahimi0Takamjani, Salavati, Goharpay, & Khosravi, 2008: CCT, Iran.
27. Herrington, Simmonds, & Hatcher, 2005: CCT, United Kingdom, Europe.
28. Kruger, Coetsee, & Davies, 2004: CCT, South Africa.
29. Barrett, Cobb, & Bentley, 1991: RCT, USA.
30. Hassan, Mockett, & Doherty, 2002: RCT, United Kingdom, Europe.
31. Callaghan, Selfe, Bagley, & Oldham, 2002: RCT, United Kingdom, Europe.
32. T. Birmingham et al., 2001: RCT, Canada.
33. Wong, To, & Lam, 2001: RCT, Hong Kong.
34. T. B. Birmingham, Inglis, Kramer, & Vandervoort, 2000: RCT, Canada.
35. Beynnon et al., 1999: RCT, USA.
36. T. B. Birmingham et al., 1998: RCT, Canada.
37. Jerosch & Prymka, 1995: RCT, Germany, Europe.
38. Ellapen et al., 2014: RCT, South Africa.
39. Hadadi, Mousavi, Fardipour, Vameghi, & Mazaheri, 2014: RCT, Iran.
40. Hettle, Linton, Baker, & Donoghue, 2013: RCT, United Kingdom, Europe.
41. Lee, Lim, Jung, Kim, & Park, 2013: RCT, South Korea.
42. Faraji, Daneshmandi, Atri, Onvani, & Namjoo, 2012: RCT, Iran.
43. Ambegaonkar et al., 2011: RCT, USA.
44. Iris et al., 2010: RCT, Spain, Europe.
45. Son, Ashton0Miller, & Richardson, 2010: CCT, USA.
46. Spanos, Brunswic, & Billis, 2008: RCT, Greece, Europe.
47. Sawkins, Refshauge, Kilbreath, & Raymond, 2007: RCT, Australia.
48. Halseth, McChesney, DeBeliso, Vaughn, & Lien, 2004: RCT, USA.
49. Mumford, 2003: CCT, Australia.
50. Simoneau, Degner, Kramper, & Kittleson, 1997: RCT, USA.

Appendix 10 PEDro score: Postural stability & awareness

	Studies																												
Pedro	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
2	•	•	-	-	-	•	-	-	•	•	-	•	-	-	-	-	-	-	-	•	-	-	-	-	-	•	•	•	-
3	-	•	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	•	•	•	-	•	•	-	•	•	•	•	•	•	•	-	•	-	•	-	•	•	-	•	•	•	•	•	•	•
5	•	•	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	•	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	•	-	-	•	•	•	-	-	•	•	•	•	•	•	-	-	-	•	•	•	-	-	•	-	-	•	•	•	•
8	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
9	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
10	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Total	8	9	5	5	6	7	4	5	7	7	6	7	6	5	4	5	4	6	5	7	5	4	6	5	5	7	7	7	6

Studies & characteristics

1. Choi JH, Kim BR, Han EY, Kim SM, 2015: RCT.
2. Hiyamizu M, Morioka S, Shomoto K, Shimada T, 2012: RCT.
3. Jacobi H, Alfes J, Minnerop M, Konczak J, Klockgether T, Timmann D, 2015: CCT.
4. Prosperini L, Castelli L, Sellitto G, De Luca F, De Giglio L, Gurreri F, Pozzilli C, 2015: CCT.
5. Boes MK, Sosnoff JJ, Socie MJ, Sandroff BM, Pula JH, Motl RW, 2012: CCT.
6. Negahban H, Mofateh R, Arastoo AA, Mazaheri M, Yazdi MJS, Salavati M, Majdinasab N, 2011: CCT.
7. Holmes J, Jenkins M, Johnson AM, Adams S, Spaulding S, 2010: CCT.
8. Marchese R, Bove M, Abbruzzese G, 2003: CCT.
9. Resch JE, May B, Tomporowski PD, Ferrara MS, 2011: CCT.
10. Ramenzoni VC, Riley MA, Shockley K, Chiu C-YP, 2007: CCT.
11. Donker SF, Roerdink M, Greven AJ, Beek PJ, 2007: CCT.
12. Swan L, Otani H, Loubert PV, Gait Posture. 2007: CCT.
13. Vuillerme N, Isableu B, Nougier V, 2006: CCT.
14. Pellecchia GL, 2003: CCT.
15. Andersson G, Hagman J, Talianzadeh R, Svedberg A, Larsen HC, 2002: CCT.
16. Dault MC, Geurts AC, Mulder TW, Duysens J, 2001: CCT.
17. Hunter MC, Hoffman MA, 2001: CCT.
18. Haggerty S, Jiang L-T, Galecki A, Sienko KH, 2012: CCT.
19. Huxhold O, Li S-C, Schmiedek F, Lindenberger U, 2006: CCT.
20. Swan L, Otani H, Loubert PV, Sheffert SM, Dunbar GL, 2004: CCT.
21. Brauer S, Woollacott M, Shumway-Cook A, 2002: CCT.
22. Melzer I, Benjuya N, Kaplanski J, 2001: CCT.
23. Teasdale N, Simoneau M, 2001: CCT.
24. Brauer SG, Woollacott M, Shumway-Cook A, 2001: CCT.

Appendix 11 Cochrane risk of bias assessment

Studies	Random sequence generation	Concealed allocation	Blinding of key personnel	Incomplete outcome data addressed	Free of selective outcome reporting	Free of other bias
Choi, Kim, Han, and Kim (2015)	●	●	-	●	●	●
Hiyamizu, Morioka, Shomoto, & Shimada (2012)	●	●	●	●	●	●