Compression garments do not influence static and dynamic balance performance

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Statement of Authenticity

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

…… [redacted] …….

Nathan Washington

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III. Abbreviations

AP	Anterior posterior
BOS	Base of support
CG	Compression garment
CMJ	Counter movement jump
CNS	Central nervous system
COM	Centre of mass
COP	Centre of pressure
DPSI	Dynamic postural stability index
EC	Eyes closed
EO	Eyes open
FP	Force Plate
GRF	Ground reaction force
ICC	Intraclass-correlation coefficient
KT	Kinesio Tape
ML	Medio-lateral
N	Newtons
NP	No garment pressure recorded
ROM	Range of motion
RPE	Rated of perceived exertion
SEBT	Star excursion balance test
SLB	Single leg balance
TTS	Time to stabilization
vGRF	Vertical ground reaction force
YBT	Y-balance test

IV. Abstract

Balance is the ability to maintain equilibrium during static and dynamic contexts. This quality assists an individual to optimise their body positioning (posture) to effectively perform daily tasks, improve exercise and sport performance as well as reduce the risk of injury. While several interventions and devices are used to improve balance, a particular device that is gaining interest in various exercise/sport domains, is the use of compression garments (CGs). Researchers have suggested that the textile properties of CGs increase the stimulation of skin mechanoreceptors and proprioceptive feedback, thus enhancing movement patterns. Although CGs can provide physiological, mechanical and psychological benefits to sport and exercise performance and recovery, there is conflicting evidence regarding their influence on balance. The limitations may be attributed to research design, testing in non-ecological settings and varied pressure measurement. Therefore, the aim of this study was to explore CGs further with specific reference to the effect of wearing lower body CGs on performance in a range of balance protocols.

A within-subject repeated measures design was applied to fourteen healthy males (age: 27 ± 3 years; body weight: 81± 8.5 kg; and height: 175.3 ± 3.6 cm) who completed a battery of common balance tests that assessed both static and dynamic balance. These tests included a single leg static balance test (eyes open and eyes closed), two jump landing tasks, a balance stabilometer task and a Y-Balance test. Three trials were performed for each test in the following conditions: compression garment, no garment and a sham condition. Condition order was randomised within each test. Derived dependent variables included the Dynamic Postural Stability Index (DPSI), Centre of Pressure (COP) pathway length and ground reaction force time to stabilisation (TTS) in x, y and z directions from the jump-landing tasks. Additionally, COP pathway length from the single leg static balance, distance reached (normalised to leg length) from the Y-Balance Test (YBT) and time in the centre of the stabilometer were also measured. A survey was completed to assess participant perceived benefit immediately following the performance of all tests for each condition. Survey questions pertained to comfort, enjoyment, support, stability and perceived performance effect.

A repeated-measures analysis of variance (ANOVA) was performed to compare each derived variable between the three garment conditions. Significance was accepted at $p < 0.05$. A Greenhouse Geisser correction was applied if sphericity was violated. No significant performance differences were found across conditions for all balance tests. There were little to no differences in subjective measures. No evidence of any impact of wearing CGs in maintaining balance was found. It is postulated that the proprioceptive input may not have been adequate enough to impact performance. Further, this may be due to the balance tests not challenging the participants neuromuscular system to a degree where the garments could aid in performance. Future research should investigate whether CGs may aid populations with compromised balance capacity such as those that are fatigued, injured or elderly.

CHAPTER 1. INTRODUCTION

Balance can be classified into two categories, static and dynamic. Static balance is characterised on the individuals capacity to maintain equilibrium whilst motionless, whereas dynamic balance refers to maintaining equilibrium during rapid perturbations (Hrysomallis, 2011; Tsigilis, Zachopoulou, & Mavridis, 2001). In order to achieve and sustain the goal of balance, the individual's body segments need to be in proper alignment, otherwise known as posture (Cech & Suzanne, 2012, pp.263). When equilibrium is disturbed, this disrupts the individual's posture placing them in a compromised position. The way in which the body adapts and re-aligns for better positioning to better maintain equilibrium is known as postural control. For instance, in both static and dynamic balance, the individual is required to maintain their body's centre of mass (COM) over their base of support (BOS) and utilise postural control to minimise sway and maximise steadiness to prevent falling (Cone, Levy, & Goble, 2015; Emery, 2003). Moreover, the ability to balance relies on the individual's sensory systems, efferent responses and their physical characteristics such as strength and flexibility (Hrysomallis, 2007; Wikstrom, Tillman, Schenker, & Borsa, 2008).

The ability to balance is a key element for the execution of motor skills, postural control and to reduce the risk of falling, especially amongst the elderly (Qiu, Cole, Davids, Hennig, Silburn, Netscher, & Kerr, 2012; Tsigilis et al., 2001). The requirements of balance reach beyond daily tasks where clear relationships between balance, sport performance and injury risk have been well established (Hrysomallis, 2011). This is shown in studies where athletes with superior balance ability demonstrated superior kicking accuracy (Tracey, Anderson, Hamel, Gorelick, Wallace, & Sidaway, 2012), skating speed (Behm, Wahl, Button, Power, & Anderson, 2005), change of direction agility scores (Pau, Arippa, Leban, Corona, Ibba, Todde, & Scorcu, 2015), single-leg counter-movement jump performance (Gualtieri, Cattaneo, Sarcinella, Cimadoro, & Alberti, 2008; Sekulic, Spasic, Mirkov, Cavar, & Sattler, 2013), and significantly less anterior-cruciate ligament (ACL) and ankle injuries in comparison to their counterparts (Hrysomallis, 2007, 2011; Sekulic et al., 2013; Tropp, Ekstrand, & Gillquist, 1984;

Willems, Witvrouw, Delbaere, Philippaerts, De Bourdeaudhuij, & De Clercq, 2005; Zech, Hübscher, Vogt, Banzer, Hänsel, & Pfeifer, 2010). Considering this evidence, balance, and more importantly the ability to improve balance, appears to be a key component for an individual's overall health and sporting performance (Hrysomallis, 2007; Zech et al., 2010).

Numerous interventions have been designed and demonstrated to improve balance such as ankle disc training and multifaceted exercise programs that are focused on neuromuscular, agility, plyometric and strength attributes (DiStefano, Clark, & Padua, 2009; Hrysomallis, 2011; McLeod, Armstrong, Miller, & Sauers, 2009). Systematic reviews have found that interventions such as the use of tilt boards, standing on unstable surfaces and dynamic movements while stationary can take up to four (DiStefano et al., 2009) to six weeks (Zech et al., 2010) of training for an effect to occur.

Previous research has also found that the wearing of external prophylactic devices such as knee and ankle braces (Maeda, Urabe, Tsutsumi, Numano, Morita, Takeuchi, Iwata, & Kobayashi, 2016; Shaw, Gribble, & Frye, 2008), Kinesio Tape (KT) (Hosp, Folie, Csapo, Hasler, & Nachbauer, 2017) and textured insoles (Corbin, Hart, McKeon, Ingersoll, & Hertel, 2007; Qiu et al., 2012), have acutely improved balance ability. It is suggested that these devices stimulate skin mechanoreceptors, enhance proprioceptive stimulation and improve attunement to movement information (Kerr, 2013; Orth, Davids, Wheat, Seifert, Liukkonen, Jaakkola, Ashford, & Qiu et al., 2012) therefore initiating corrective action in maintaining balance (Changela & Selvamani, 2012; Hasan, Davids, Chow, & Kerr, 2016; Hosp et al., 2017). Apart from textured insoles, the aforementioned devices also provide a mechanical support to the musculature for joint stability and to prevent excessive ROM (Hosp et al., 2017; Maeda et al., 2016) which are required characteristics for dynamic balance. Although it is plausible that the magnitude of balance improvement would not be as large as an intensive neurophysiological training intervention, these studies demonstrate the vital role proprioceptive acuity contribute in maintaining balance (Changela & Selvamani, 2012; Hosp et al., 2017).

Another device that could influence balance, is the wearing of compression garments (CGs), which contain elastic textile properties that apply a pressure gradient onto the skin (Born, Holmberg, Goernert, & Sperlich, 2014). Compression garments have been suggested to trigger the activities of mechanoreceptors in the skin and muscles to enhance proprioception (MacRae, Cotter, & Laing, 2011). Consequently, movement patterns may improve. Evidence for this assertion is found where athletes wearing CGs have improved their awareness in detecting errors in their kicking technique (Cameron, Adams, & Maher, 2008), achieved a lower squat depth for better propulsion in vertical jumping (Doan, Kwon, Newton, Shim, Popper, Rogers, Bolt, Robertson, & Kraemer, 2003), achieved a deeper tuck position on a skiing simulator (Sperlich, Born, Swarén, Kilian, Geesmann, Kohl-Bareis, & Holmberg, 2013), improved driving distance and accuracy amongst golfers (Hooper et al., 2015) and reduced knee valgus when landing (de Britto, Lemos, dos Santos, Stefanyshyn, & Carpes, 2017; Zamporri, 2017).

Despite evidence supporting the alteration of movement patterns when wearing CGs, only a small number of studies have examined the effects of wearing CGs on balance ability (dynamic and static). These studies have found no significant changes in balance performance when wearing regular training clothes or CGs (Bernhardt & Anderson, 2005; Cavanaugh, Quigley, Hodgson, Reid, & Behm, 2015; Michael, Dogramaci, Steel, & Graham, 2014; Sperlich et al., 2013). In contrast, when female participants were visually occluded, they were more stable in their static balance when wearing CGs compared to a control condition (Michael et al., 2014). However, this finding has not been replicated. Despite a majority of studies demonstrate that CGs have a null effect on balance performance, these findings remain equivocal due to limitations in research design, sample size and population, testing in non-ecological settings, varied garment pressures and designs and not measuring perceived benefits when wearing CGs during performance (MacRae, Laing, & Cotter, 2011). Thus, further robust research is needed to empirically determine the effectiveness of wearing CGs on balance performance.

If wearing a CG is demonstrated to improve balance performance it may lead to a reduction in the risk of injury and improved athletic performance, both of which are associated with superior balance. In addition, manufacturers such as SKINS™ (SKINS, 2018), Body Science ™ (BODYSCIENCE, 2018) and 2XU™ (2XU, 2017) advertise their garments to enhance proprioception with implications for improved balance and athletic performance. However, there is no independent, empirical scientific evidence to support these claims. This can be deceiving for consumers especially with limited experience in assessing the research related to such assertions. Therefore, the purpose of this research was to evaluate the effect CGs have on the balance of recreational and amateur athletes when performing a range of balance tests. The outcomes from this research will assist consumers to make better and more informed decisions regarding the purchasing and wearing of CGs, for the purpose of improving balance.

Aim

The primary aim of this study was to determine if wearing a full-leg length compression garment can influence balance performance when compared to wearing regular training shorts and a sham condition (applied sports tape) across a range of dynamic and static balance tests. These tests include:

- Measuring postural stability and time to stabilisation of a single leg landing from jumping in an oblique angle
- Time in the centre of a balance stabilometer
- Measuring postural stability and time to stabilisation of a single leg landing from jumping anteriorly over a hurdle
- Leg reach distance in the Y-balance test
- Centre of pressure of a static single leg balance test with eyes open and eyes closed

Hypotheses

Two null hypotheses were tested in this study. It was hypothesised that:

I. No difference in balance performance would be found when comparing compression garment, no garment and sham conditions.

II. No perceived benefits would be reported from wearing the compression garment compared to the no garment and sham conditions.

CHAPTER 2. NARRATIVE REVIEW

2.1 Introduction

The ability to balance is needed to execute a host of motor skills that are performed during everyday tasks to complex skills in sport (Hrysomallis, 2011; Qiu et al., 2012). Depending on the proficiency of balance, this has been shown to influence task performance and injury risk (Hrysomallis, 2011). There have been various successful interventions developed that can enhance balance ability (DiStefano, Clark, & Padua, 2009; McLeod et al., 2009; Zech et al., 2010). However, these neurophysiological training interventions can take a considerable amount of time to be beneficial. Alternatively, stimulating somatosensory cues has been found to be an effective passive method for improving balance, this includes the use of knee and ankle braces, KT and textured insoles (Corbin et al., 2007; Hosp et al., 2017; Maeda et al., 2016; Shaw, Gribble, & Frye, 2008; Qiu et al., 2012). More recently, compression garments (CGs) are suggested to stimulate a similar somatosensory response and achieve improved balance performance (Michael et al., 2014). However, the small amount of research examining this concept contains various limitations that confound the effect of wearing a CG on balance.

Therefore, the purpose of this literature review was to explore the somatosensory and neuromuscular mechanisms that CGs may alter and identify the gaps and limitations in the current literature assessing the effectiveness of wearing CGs on balance performance. Within this review, there are two distinct sections. The first section provides a context of what balance is, its implications for sport performance and injury risk, a brief historical account of compression garments and research findings pertaining to altered movement patterns. The second section discusses and critiques compression garment literature that is related to: balance experiments, psychological influences, garment construction and pressure measurements.

Within the literature the terms stability, postural control/stability and balance are used interchangeably. To minimise confusion in this thesis, this concept will be referred to as balance. In addition, the terms expert and novice will be referred to as skilled and less skilled, respectively. Further, balance is a broad ability that applies to the prevention of falls, injury risk, athletic performance and populations from the young, elderly, and those with disability and disease in various contexts. Considering sports compression garments are predominantly targeted at healthy populations who are active in sports and exercise, the scope of this literature review was confined to exploring balance in these respective areas.

2.2 Balance

Balance is defined as an individual's ability to maintain a vertical projection of their centre of mass (COM) within their base of support (BOS) (Figure 2.1) (Watkins, 2014). External and internal perturbations cause the COM to shift away from the BOS which in-turn cause postural sway and compromise stability (Michael et al., 2014). Typically, balance is categorised in two forms, static and dynamic (Davlin, 2004). Static balance refers to an individual maintaining equilibrium in a stationary body position such as standing, whilst dynamic balance is the capacity to maintain equilibrium during motion or re-establishing equilibrium through rapid and successively changing positions (landing from a jump) (Hrysomallis, 2011). Both static and dynamic balance are needed as they are integrated in the execution of motor skills to maintain posture, reduce the risk of falling, and performing complex exercise and sporting skills (Hrysomallis, 2011; Qiu et al., 2012). To balance effectively, an individual must combine the interaction of several sensory, motor and efferent responses (Hrysomallis, 2007; Wikstrom et al., 2008) with adequate levels of muscular strength and flexibility for corrective actions (Williams, Nagai, Sell, Abt, Rowe, McGrail, & Lephart, 2016).

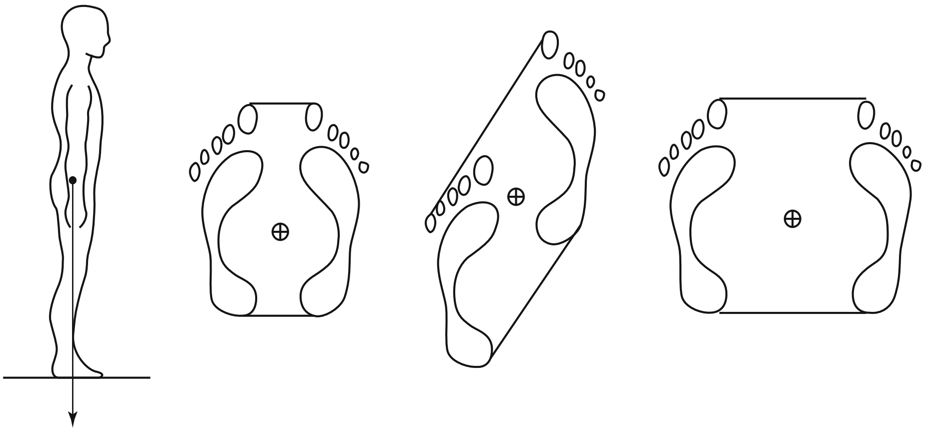

Figure 2.1 Centre of mass in relation to base of support, adapted from Watkins (2014).

2.2.2 The mechanisms of balance

Balance is the product of the integration of a number of system mechanisms. The vestibular system senses head orientation to assist in establishing equilibrium; whereas the visual system provides coherent information to distinguish how the body interacts with the external environment (Riemann & Lephart, 2002). The somatosensory system is a diverse sensory system that is comprised of different sensory modalities (Magill & Anderson, 2014).

Within the somatosensory system, mechanoreceptors are considered an important component in relation to balance (Ghai, 2016; Qiu et al., 2012). Mechanoreceptors are specialised sensory cells that are responsible for providing spatial and temporal awareness of the body and limbs, otherwise known as proprioception (Magill & Anderson, 2014; Riemann & Lephart, 2002). There are various types of these sensory cells that each have a specific function and location. These cell types include: 1): Ruffini endings and Pacini corpuscles that are stimulated when pressure and touch contact the body surface; 2) muscle spindles which detect the stretch and length of the muscle; 3) Golgi tendon organs which sense muscle tension; and 4) joint receptors which detect movement such as joint flexion/extension and rotation (Ghai, 2016; Magill & Anderson, 2014; Qiu et al., 2012; Riemann & Lephart, 2002). The output signals from these cells are rapidly transmitted through afferent pathways to higher neural centres where the perception of movement takes place (Figure 2.2) (Callaghan, McKie, Richardson, & Oldham, 2012;

Riemann & Lephart, 2002). This signalling in turn provides information to the musculoskeletal system to regulate posture and movement (Woo, Davids, Liukkonen, Jaakkola, & Chow, 2014).

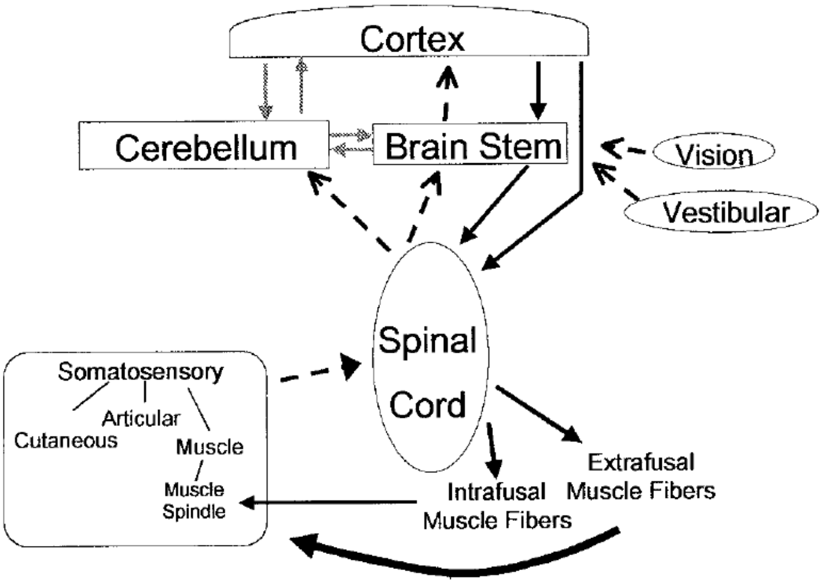

Figure 2.2 Theoretical concept of movement processing, adapted from Riemann and Lephart (2002).

Depending on the task, an individual may refer to individual or several sensory cues to maintain balance (Corbin et al., 2007). For example, in a low difficulty task such as maintaining bipedal stance, a healthy individual may predominantly rely on visual input and consciously make postural adjustments (Corbin et al., 2007; Riemann & Lephart, 2002). However, in a high difficulty or more complex task, a healthy individual may refer to multiple somatosensory cues (Corbin et al., 2007; Ghai, 2016; Riemann & Lephart, 2002). For example, when walking on uneven surfaces, the plantar cutaneous receptors and muscle and joint mechanoreceptors would be stimulated and simultaneously provide ankle joint position feedback. Consequently, a motor program can be modified to make movement adjustments to improve or maintain balance (Corbin et al., 2007; Ghai, 2016; Riemann & Lephart, 2002). This example describes an event where there is sufficient time for the relay of sensory and afferent signals to be activated, without a risk to the individual. This process is known as the closed-loop feedback system (Magill & Anderson, 2014).

In contrast, during time-critical tasks, motor output occurs without conscious awareness to ensure postural adjustments are corrected at a faster rate to prevent injury. Landing from a jump is considered a time-critical task, where reflexes are activated from muscle spindles to co-contract agonist and antagonist muscles to prevent injury and provide balance (Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001; Riemann & Lephart, 2002). Another balance strategy is the use of a feedforward mechanism where activation of muscle stiffness occurs prior to landing to anticipate and absorb high impact forces (McKinley & Pedotti, 1992; Riemann & Lephart, 2002).

Another important mechanistic factor that influences balance is the physical characteristics of the individual. In a recent study, participants were tested on their ability to stabilise from a jump. Those participants with superior ankle range of motion (ROM) and ankle and knee musculature strength produced enhanced performance compared to those with lesser capacity (Williams et al., 2016). The researchers suggested that these characteristics allow the individual to perform greater eccentric work to dissipate ground reaction forces (GRFs) and therefore require less effort to attenuate forces (Williams et al., 2016). Further, strengthening of the lumbopelvic region, otherwise known as the “core”, has been shown to improve an athlete’s balance ability (McLeod et al., 2009). Greater muscle strength in this region is suggested to provide the foundation to support the loads for movement of both the upper and lower extremity, whilst also protecting the spinal cord and nerve roots (Panjabi, 1992). In combination, the above mechanisms are dependent on the individual, the task and the environment, which contribute to the maintenance of balance (Qiu et al., 2012) and can ultimately influence injury risk and sporting performance.

2.2.3 Balance and sport performance

During game play in sports, athletes need to be effective in maintaining balance to execute a range of skills of varying complexity in stationary, unpredictable and dynamic conditions (Hrysomallis, 2011). For example, in some ball sports, athletes frequently support their body weight with one leg whilst manoeuvring and kicking a ball, perform explosive movements, land on uneven surfaces and perform complex decision-making (Hrysomallis, 2007; Pau et al., 2015). Balance is also needed to recover quickly from sprints, jumps and cutting manoeuvres that are repeatedly executed during training and competitions. The need for good balance is shown in previous research, where athletes who possess superior balance capacity also exhibited greater kicking accuracy (Tracey et al., 2012), higher single leg counter-movement jump performance (Gualtieri et al., 2008; Sekulic et al., 2013), superior skating speed (Behm et al., 2005) and agility (Pau et al., 2015). These findings highlight the important contribution balance has to other components of performance.

In field sports, many incidents of injuries occur from non-contact movements such as planting, pivoting and landing (Fong, Blackburn, Norcross, McGrath, & Padua, 2011). Poorer balance ability has been correlated to such injuries (Hrysomallis, 2007). For instance, deficiency in balance has been linked to ankle injuries in basketball players (McGuine, Greene, Best, & Leverson, 2000), male physical education students (Willems et al., 2005) and Australian Rules Football players (Hrysomallis, McLaughlin, & Goodman, 2007), as well as an increased risk of recurring ACL rupture following a primary ACL reconstruction (Paterno, Schmitt, Ford, Rauh, Myer, Huang, & Hewett, 2010). Considering that balance is strongly linked with performance proficiency and the risk of injury, improving balance appears appropriate for decreasing injury risk and improving and sporting performance (Engebretsen, Myklebust, Holme, Engebretsen, & Bahr, 2010; Paternoet al., 2010).

2.2.4 Improving balance

A number of training interventions have been shown to successfully enhance balance via the implementation of neuromuscular, plyometric and strength exercises (McLeod et al., 2009; Myer, Ford, Brent, & Hewett, 2006). For instance, when athletes were trained on force dissipation techniques by increasing knee-flexion when landing, reduced centre of pressure (COP) sway after landing from a single-leg hop was demonstrated (Myer et al., 2006). The ability to absorb GRF's through movement can allow the individual to attenuate the forces with less effort (Williams et al., 2016). Research has also shown that participants who engage in strength, flexibility and power-based training programs improve dynamic balance (Bruhn, Kullmann, & Gollhofer, 2004; Herman, Weinhold, Guskiewicz, Garrett, Yu, & Padua, 2008). More specifically, isometric exercises on knee flexors, hip extensors, abdominal muscles and dynamic movements with a bosu ball, swiss ball and kettle bell, produce improved balance (stabilised COP) post intervention (Ondra, Nátěsta, Bizovská, Kuboňová, &

Svoboda, 2017). Developing these characteristics has a direct effect on decelerating the body's COM from a dynamic to a static state (Ebben, VanderZanden, Wurm, & Petushek, 2010; Ross, 2014) and the development of muscle coordination to transmit smooth movement to control the COP (Ondra et al., 2017). However, systematic reviews have found that balance training interventions can take up to four (DiStefano et al., 2009) and six weeks (Zech et al., 2010) for an effect to occur.

Researchers and therapists have also studied and used external devices such as ankle braces to aid in stabilising balance (Maeda, Urabe, Tsutsumi, Numano, Morita, Takeuchi, Iwata, & Kobayashi, 2016; Shaw, Gribble, & Frye, 2008). Dependent on the design, it is proposed that these devices restrict motion and reduce translation during locomotion. Shaw, Gribble and Frye (2008) found participants to have improved anterior-posterior time to stabilisation (APTTS) scores after landing from a jump when wearing a soft-rigid ankle brace. In contrast, when performing the same task in a rigid ankle brace and no brace, APTTS scores were not influenced (Shaw, Gribble, & 2008). This finding may be due to the cutaneous input from the brace that altered neuromuscular function. Other research has found ankle braces to stimulate peroneal motoneuron muscle excitability (Cordova & Ingersoll, 2003; Nishikawa & Grabiner, 1999), which plays a crucial role in preventing inversion forces at the ankle and contributes to maintaining balance (Cordova & Ingersoll, 2003; Nishikawa & Grabiner, 1999). However, the findings in other ankle brace studies are mixed due to wide variations in brace construction. Ankle braces that are too soft may not provide enough support, whereas ankle braces that are too rigid may compromise ROM and be detrimental to performance (Hardy, Huxel, Brucker, & Nesser, 2008; Shaw, Gribble, & Frye, 2008).

Plantar textured shoe insoles are another passive device that has been shown to influence balance (Corbin et al., 2007; Orth et al., 2013; Qiu et al., 2012). Orth et al. (2013) suggest that cutaneous stimulation via plantar surface compression regulates and controls spatial and temporal characteristics of the COM over an individual's BOS (Orth et al., 2013). Textured insoles have been repeatedly found to reduce COP variables in young, healthy and older populations during static balance performance (Corbin et al., 2007; Orth et al., 2013; Qiu et al., 2012), however their effect on dynamic balance is unknown.

Another wearable external device that is purported to improve balance are sporting compression garments (CGs). Sport CGs have been developed from therapeutic compression tights used in medical health care. Currently, they are manufactured and marketed to improve a host of exercise and sport performance variables, including balance. Although recent research has shown CGs to enhance movement patterns in various contexts, the basis of such claims is questionable due to insufficient and contrasting empirical evidence (MacRae, Laing, & Cotter, 2011). Therefore, the following section will explore the evolution of sports CGs and the research investigating the efficacy of wearing CGs on movement performance.

2.3. Compression garments

2.3.1 The evolution of compression materials and garments

The application of externally applied compression to treat disease can be traced back to Hippocrates 450 BC and was mainly focused on treating venous disorders and leg ulcers (Gladfelter, 2007). Subsequent techniques included body wrapping to minimise swelling, oedema and scar tissue formation that occurred from burns (Gladfelter, 2007). It was not until the 1970’s that French medical rehabilitation practices started using external compression as part of the postoperative care regime. The materials used to wrap a patient’s body were known as French tape which contained elastic properties (Gladfelter, 2007). However, problems were experienced with the French tape as it was difficult to apply the pressure uniformly and was quite uncomfortable for patients (Gladfelter, 2007). Progressive development of women’s undergarments that contained synthetic fabrics such as nylon provided a solution to the above limitations and this material began being used for postoperative compression (Gladfelter, 2007). For many years, therapeutic compression has been found to increase haemodynamics by narrowing superficial veins (Partsch, Menzinger, Borst-Krafek, & Groiss, 2002). More specifically, applying 20 mmHg at the thigh and 25 mmHg at the calf has been shown to improve cardiac output and venous return (Watanuki & Murata, 1994).

Today, CGs have extended beyond the medical field and into sport and exercise (Gallaher, 2012). Sport CGs are typically smaller than the limb dimension that is to be covered (MacRae, Laing,

& Partsch, 2016) and have different design variations (Figure 2.3) where full body segments (pants or top) or part of a limb (shorts or sleeves) are covered (Gallaher, 2012). Most commonly, a graduated compression design for lower limbs is adopted where pressure is exerted at its highest at the ankle and progressively decreases up the thigh (Gallaher, 2012).

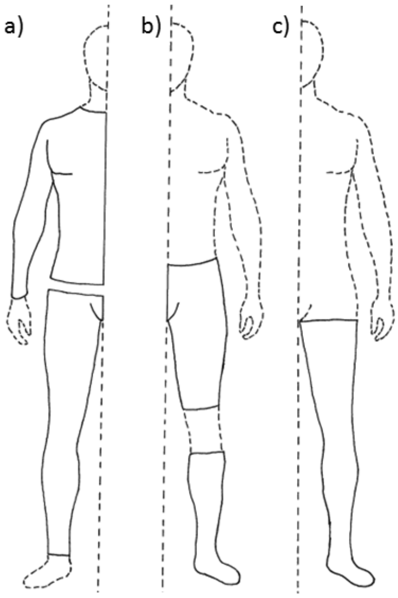

Figure 2.3 Different design variations of CGs: a) full leg length compression pants; b) shorts and knee-high sleeves; and c) stockings. Image adapted from Born et al. (2013).

The construction of a CG is dependent on a number of components such as the type of yarn used, the material knit arrangement used to produce the fabric (Figure 2.4), and the selection of wrapping polyamide and/or cotton around a stretchable core that is made up of latex or elastane/Lycra (Clark & Krimmel, 2006; Gallaher, 2012).

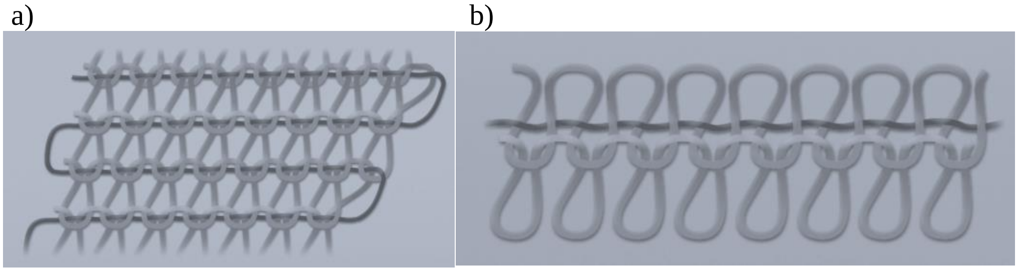

Figure 2.4 Compression garment material fibre arrangements in flat knit (a) and circular knit (b) designs. Adapted from Clark and Krimmel (2006).

The material wrapping that surrounds the elastic core (Figure 2.5) provides the stretchability and stiffness of the yarn. The power rating and the stiffness of the material is determined by how easily it can be stretched (Clark & Kimmel, 2006; Gallaher 2012). The interaction of the above components provides the mechanical compression force acting over the covered area (MacRae, Laing, & Partsch, 2016).

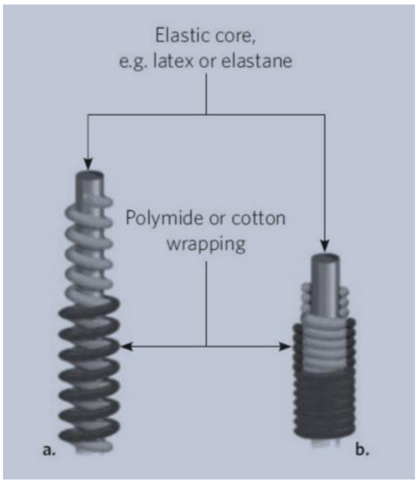

Figure 2.5 Individual fibre construction illustrating the elastic core with loose (a) and tight (b) outer wrapping. Loose wrapping provides more stretch and less compressive force whereas, tight wrapping provides less stretch and greater compressive force. Adapted from Clark and Krimmel (2006).

Manufacturers of sport CGs claim this external pressure can facilitate physiological variables that improve performance and accelerate recovery by using the garment to compress the superficial veins of the body, which then increase blood flow, acting as a passive ‘muscle pump’ (Ali, Creasy, & Edge, 2010). This has been proven effective in studies that have shown an increase in blood oxygenation (Bringard, Perrey, & Belluye, 2006), tissue oxygen saturation during and following running (Ménétrier, Pinot, Mourot, Grappe, Bouhaddi, Regnard, & Tordi, 2013), cycling (Scanlan, Dascombe, RJ Reaburn, & Osborne, 2008) and improved lactate removal (Rider, Coughlin, Hew-Butler, & Goslin, 2014; Rimaud, Messonnier, Castells, Devillard, & Calmels, 2010). Conversely, recent systematic literature reviews and meta-analyses have determined that CGs have limited effects on physiological variables and performance parameters in endurance based sports such as running, triathlon, cross-country skiing and kayaking (da Silva, Helal, da Silva, Belli, Umpierre, & Stein, 2018; Engel, Holmberg, & Sperlich, 2016).

Despite these conflicting findings, there is a growing body of research investigating the use of compression garments to enhance proprioception and optimise movement patterns. However, there is a paucity of research specifically assessing the impact of CGs for balance (Donath & Faude, 2016). The following sections of this literature review will examine relevant research pertaining to the effects of CGs on movement patterns, balance performance, psychological influences and the efficacy of measuring the garment pressure.

2.3.2 The effect of compression garments on movement patterns

Proprioception provides an awareness of where the body segments are in space as well as the direction and speed of movement and force applied, all of which play a crucial role in performing day-to-day tasks and especially complex movements in sports (Bernhardt & Anderson, 2005; Birmingham, Kramer, Inglis, Mooney, Murray, Fowler, & Kirkley, 1998). This concept was first discovered when studies began finding patients and athletes were altering their movement patterns when wearing sports tape and ankle and knee braces (joint stabilisers) (Birmingham et al., 1998) The mechanism proposed to explain this phenomenon was that the activity of the mechanoreceptors underneath the skin would increase due to increased sensitivity to the application of touch and pressure, which ultimately strengthens the afferent input from peripheral nervous system sources (Figure 2.6) (Callaghan, 1997; Simoneau, Degner, Kramper, & Kittleson, 1997). This mechanoreceptor feedback is thought to provide additional information to the central nervous system (CNS), enhancing the perception of movement and help individuals attend to these cues that would have otherwise been unnoticed without the application of external pressure (Ghai, 2016; Hasan et al., 2016; Qiu et al., 2012).

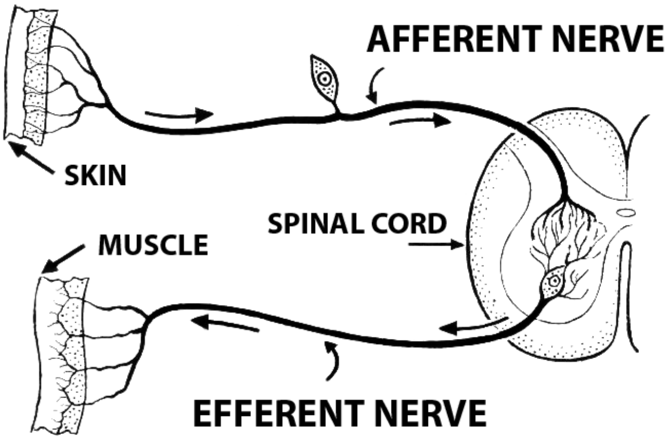

Figure 2.6 Sensorimotor feedback system loop

Compression garments have different designs that cover full or half limb segments, which should stimulate a greater volume of mechanoreceptors than sports tape and produce enhanced proprioceptive feedback. Several studies have demonstrated improved or optimised movement patterns when wearing CGs compared to no garment conditions. For example, when athletes wore high (40 mmHg) and medium (20 mmHg) CG shorts, they optimised their tuck position by executing greater knee flexions (-10°) compared to less optimal positioning during the control condition (no compression garment) (Sperlich et al., 2013). Similarly, healthy participants produced lower squat depths, increased vertical impulses and jumped significantly higher in comparison to the control condition, when performing maximal vertical jumps with and without CGs (no garment pressures recorded (NP)) (Doan et al., 2003). Notably, no garment pressure was recorded or reported in this study. Thus, the ability to assess this and other study findings without this information is limited because garment pressure is likely linked with their effectiveness. This notion will be discussed in detail later in this review.

When lesser skilled soccer players wore a compressive sock (NP), they demonstrated improved kicking technique by producing greater hip extension and flexion towards the ball in the contact phase (Hasan et al., 2016). In contrast, this finding was not evident in a more highly skilled cohort (Hasan et al., 2016). This finding was corroborated in a study by Cameron, Adams, and Maher (2008), who assessed athlete ability to detect and control movement in a leg swinging task, referred to as a movement discrimination test. Participants with a lower baseline score significantly improved their scoring when wearing CG shorts (NP). However, participants with a superior baseline score were unable to improve their performance when wearing CG shorts.

A further study has shown that lesser skilled athletes improved their kicking accuracy when wearing full length CGs (NP) (Lien, Steel, Graham, Penkala, Quinn, Dogramaci, & Moresi, 2014). Interestingly, the higher skilled athlete's in this study demonstrated decreased performance when wearing CGs. The authors suggested that the additional tactile feedback may have been unfamiliar to the athlete and disrupted the automation of movement (Lien et al., 2014). These findings demonstrate that additional somatosensory feedback can alter movement patterns variably on different populations and skill levels.

More recently, CGs have been demonstrated to improve landing kinematics in women. de Britto et al. (2017) found that in a series of four different jump-landing tasks including forward jumping, forward jumping with a counter-movement jump (CMJ), and twenty and forty cm drop jumps with a CMJ, participants produced significant reductions in knee flexion and knee valgus ROM when wearing CG shorts (garment pressure range 8.3 – 11.3 mmHg) compared to to regular training shorts (de Britto et al., 2017). However, there was no significant change in counter-movement jump height. The authors highlighted that the CGs could be used as a potential strategy to prevent knee injury but this concept warrants further research (de Britto et al., 2017).

Zampporri and Aguinaldo (2017) conducted a kinematic analysis on college-aged female athletes performing drop vertical jumps from a 27 cm tall box when wearing compression tights (NP) and regular training shorts. They found significant reductions in average ROM in hip internal rotation of 1.9°, hip abduction angle of 2.4°. At initial contact, hip abduction angle was reduced by 2.7° and knee valgus by 1.7° when wearing compression tights (Zamppori & Anguinaldo, 2017). The findings from these aforementioned landing studies demonstrate that CGs can be effective in restricting excessive motion and provide more control for joint motion to optimise movement (Schween, Gehring, & Gollhofer, 2015).

Despite some evidence to support the proposition that CGs enhance proprioception and optimise movement patterns, more research is required (Donath & Faude, 2016). It is also suggested that CGs may serve as a mechanical support for the limbs and/or simply influence psychological outcomes for improved performance (Doan et al., 2003; Kraemer et al., 1993; MacRae, Laing, & Partch, 2016; Rugg & Sternlicht, 2013; Zamporri & Anguinaldo, 2017), all of which could be factors that influence and improve balance performance.

2.3.3 The impact of compression garments on balance performance

Research examining the relationship between CGs and balance performance has elicited mixed findings. A double-blinded study by Micheal et al. (2014) found no difference in unipedal static balance performance when active female participants wore correctly fitted CG leggings (NP), oversized (sham) and regular training shorts (control). In contrast, when the participants performed the same test with their eyes closed and wearing the correctly fitted garment, they had significantly less centre of pressure (COP) variability than the sham and control conditions (Michael et al., 2014). This study demonstrates that when visual feedback is not available, other sensory cues are relied upon more, particularly the mechanoreceptors which have been stimulated by the tightly fitted CGs. Greater reliance and input from other sensory cues afford the athletes with more feedback to maintain stability (Michael et al., 2014). However, this finding may only benefit those in an activity that consumes all their visual feedback. For instance, individuals playing field sports such as soccer and will need to maintain ball/player tracking and thus require the individual to rely on other somatosensory cues. This concept has not been extensively examined and further research is warranted before any conclusions can be made.

The above finding contradicts those from Bernhardt and Anderson (2005) and Sperlich et al. (2013) who found no differences in eyes closed balancing tasks for both CG and no CG conditions. Bernhardt and Anderson (2005) timed male and female participants on their ability to maintain a stork stand with their eyes closed for one trial. However, considering this balance measurement requires subjective observations, which is prone to error, an increased number of trials is needed to increase performance measure reliability and confidence in comparing trial scores (Vogt, Gardner, & Haeffele, 2012). This therefore questions the validity of this study and findings. Further, Sperlich et al. (2013), had elite male alpine skiers stand on a moving platform with a single leg, their hands on their hips and eyes closed (Posturomed; Haider-Bioswing, Pullenreuth, Germany) and monitored how long they can maintain this position without opening their eyes, touching the security bar or putting the opposing leg down. There were no differences between CG and no CG performances.

Cavanaugh et al. (2015) examined male and female active university students performing a dynamic balance task pre and post fatigue whilst wearing a knee CG (NP), KT and regular training shorts. Participants performed single leg drop landings from a 50 cm box, held a static position for five seconds and then measured their reach distance on a Star Excursion Balance Test (SEBT). Across all conditions and test time comparisons, no significant COP excursion length and SEBT score differences were observed (Cavanaugh et al., 2015). This suggests that wearing CGs does not enhance balance in these tests and do not influence performance when fatigued. However, it is likely the fatiguing protocol in this study did not induce enough fatigue or impact these tests because no difference in pre-and post-fatigue scores were reported in the control condition. Therefore, whether CGs can influence balance when in a fatigued state remains unknown.

The study by Cavanaugh et al. (2015) represents the most dynamic assessment of balance reported in this review so far. However, only assessing vertical drop landings may be misleading and overlook other mechanisms involved in dynamic balance (Ross & Guskiewicz, 2004; Wikstrom et al., 2008). For instance, when forward jumping, time to stabilisation (TTS) values are longer in the anterior-posterior (AP) direction, but the medio-lateral (ML) seems to be less affected (Krklejas, 2017; Liu & Heise, 2013; Wikstrom et al., 2008). This is also true when jumping in diagonal or horizontal directions whereby ML TTS and dynamic postural stability index (DPSI) values are greatly affected as opposed to the AP values (Krklejas, 2017; Liu & Heise, 2013; Wikstrom et al., 2008). Therefore, measuring dynamic balance in a variety of jumping and landing directions is needed to assess dynamic balance in all planes of movement (Liu & Heise, 2013).

The majority of the literature examining the relationship between CGs and balance have used a single balance test, making direct comparison of findings between studies difficult. Individual balance tests assess participants on their ability in that specific task. Other balance tests may assess other balance capacity or rely on different sensory inputs, which can provide varied results depending on the recruited population (Hrysomallis, 2011). For example, Riemann and Schmitz (2012) measured forty-six recreationally active college students on their static balance ability via SLB test on a firm and multiaxial surface with their eyes open and eyes closed as well as dynamic balance via an SEBT and single-leg hop stabilisation (SLH) tasks. They found no correlation in performance between the static and dynamic balance tests. Riemann and Schmitz (2012), suggested that despite the requirement to hold their COM over their BOS in all tasks, the dynamic tasks also require attentional focus on stabilising after landing or reaching for distance in the SEBT. Krkelijas (2017) also found no significant correlation in forward jump landing and lateral jump landing TTS scores and performance on a biodex balance stabilometer (BBS) among forty-four amateur soccer players. They suggested that the jump-landing task requires simultaneous neuromuscular and somatosensory control, full body coordination, strength and power whereas the BBS challenges the mechanoreceptors around the joints of the ankle to control the tilt limits. The above studies demonstrate that the sensorimotor mechanisms required to balance vary and are dependent on the static and dynamic conditions of the task (Krkeljas, 2017; Pau et al., 2015). Therefore, to comprehensively assess the effectiveness of wearing CGs on balance performance, a single cohort study with a battery of field and laboratory balance tests is needed.

2.4 Psychological influences from wearing CGs

2.4.1 Perceived benefits

In addition to physical benefits, the perception individuals have regarding the comfort, feel, aesthetic appearance and expectations of the CGs, is another factor that influences performance (Donath & Faude, 2016; Jakeman, Byrne, & Eston, 2010; MacRae, Laing, & Cotter, 2011; Rugg & Sternlicht, 2013). This is shown in CG studies who have used a standard borg scale, a common tool allowing participants to rate their perceived effort (RPE) to inform the researchers the level of intensity experienced by the participant within a condition or performance protocol. Previous research has demonstrated that when participants wear CGs, their RPE values are lower than the no garment conditions.

For example, Sperlich et al. (2013) found that athletes performed a deeper tuck position on a skiing simulator and reported a lower RPE as opposed to the control condition where less knee flexion was demonstrated. Despite the athletes exerting more effort in the CG condition to achieve a lower depth, they found the task to be less demanding. This finding is consistent with studies that have implemented induced muscle damage exercises such as submaximal running, sprinting and jumping in their research design.

In a counter-balanced order, Rugg and Sternlicht (2013) compared maximum CMJs pre and post a fifteen-minute submaximal running protocol of track and field, triathletes and recreational runners, in CG leggings (18 mmHg at ankle, 12.6 mmHg at calf and 7.2 mmHg at thigh) and regular training shorts (control). Although there were no performance differences between the conditions in the pre-test, there was a significant improvement in jump height with the garment condition in the post-test, this change in performance did not occur in the control condition (Rugg & Sternlicht, 2013). In addition, the participants reported significantly lower RPE and higher comfort levels when wearing a CG in comparison to the control condition.

In agreement to Rugg and Sternlicht (2013), Faulkner, Gleadon, McLaren and Jakeman (2013) conducted a repeated measures design and had active male participants complete a 400m sprint in three conditions such as CG leggings (13.2 mmHg at mid-calf and 7.1 mmHg at mid-thigh), a combination of CG hip to knee shorts (7.1 mmHg mid-thigh) and calf CG (19.9 mmHg at mid-calf) and regular training shorts. The researchers found no differences in participant sprint time and 100m split time across all conditions, however there was a trend of reduced blood lactate concentrations levels for both garment conditions and not for the control. In addition, participants reported a significantly lower RPE in both garment conditions in comparison to the control condition (Faulkner et al., 2013). Despite there being no differences in athletic performance, this reduced perception of exertion when wearing CGs has potential to alter the volume of work by maximising performance potential as wearers may find the tasks to be easier (Faulkner et al., 2013). Future research is warranted for this to be conclusive.

In contrast, in endurance exercises such as running and cycling, no differences in RPE have been reported between CG and no garment conditions (Ali, Caine, & Snow, 2007; Ali et al., 2010; Sperlich, Haegele, Achtzehn, Linville, Holmberg, & Mester, 2010). Sperlich et al. (2010) suggests that heavy eccentric loading tasks such as repeated CMJs and sprinting induce greater muscle soreness markers, where such outcomes occur to a lesser extent in endurance paced activities. It may be in these cases that the garments mechanical properties work as a protective mechanism (de Britto et al., 2017).

Previous research has found significant reductions in muscle oscillation when landing from a maximal jump (Doan et al., 2003) and repeated CMJs (Kraemer et al., 1998). Reduction in muscle oscillation in other studies has found wearers to have a reduced amount of histological muscle damage when downhill running on a treadmill (Valle, Til, Drobnic, Turmo, Montoro, Valero, & Artells, 2013) and reduced muscle fibre recruitment, demonstrating efficiency on a skiing simulator (Sperlich et al., 2013) in comparison to no garment conditions. This may explain why RPE was more noticeable in CMJ and sprinting studies, however, this is yet to be determined.

In addition to reduced effort, participants in a previous study were asked to rate if they felt that the CG shorts (NP) had assisted them in their repetitive CMJ performance without providing them knowledge of results (Kraemer et al., 1998). While their mean jump height improved significantly with the garment condition so too was their ‘perception of improvement’ in favour of the CG as opposed to the control condition (Kraemer et al., 1998). This was corroborated by Birmingham et al. (1998) where participants in their study wore a neoprene knee sleeve (NP) and were tested on limb repositioning in open and closed kinetic chains. Despite no measurable differences in leg position being observed between condition, participants reported a perceived level of improvement when wearing the sleeve.

Interestingly, Hooper et al. (2015) found golfers and baseball pitchers to have conflicting views of garment influence on performance. Golfers were assessed on their driving distance and accuracy as well as approach shot and putting accuracy and the experienced pitchers were assessed for fastball accuracy and velocity when wearing an upper body CG (NP) and control condition (no CG). In addition to performance-based measures, participants were required to rate their level of comfort for each condition. They found significant improvements in the respective performance variables for each task in the CG compared to the control condition. The golfers reported increased comfort in the CG but did not perceive the garment to have an effect on their improved performance (Hooper et al., 2015). Whereas, the baseball pitchers did not report any differences in comfort levels between the conditions but reported that they perceived the garment to have improved their performance and found it more enjoyable to wear (Hooper et al., 2015). The researchers concluded that the improved performance may be attributed to proprioceptive enhancement from the garment, but this was not directly measured.

Importantly, previous research has shown alternate results where participants expressed to have different perceptions of how they performed across various fitness tests such as 20 m sprint, t-test, 20 m multi-stage shuttle run, Max vertical jump height and joint angle replication in CG and no garment conditions (Bernhardt & Anderson, 2005). Despite there being no significant differences across both conditions in the mentioned variables, the participants that found the garment to be a proper fit had this perception of improvement, whereas those that did not find it to be a proper fit, felt as though the garment hindered their performance (Bernhardt & Anderson, 2005). The discrepancies of comfort levels are likely due to there only being a one sized garment for all of the participants. A plausible explanation behind these altered positive perceptions may be due to a placebo effect.

Placebo is a result of an individual who believes they have received a beneficial treatment (Clark, Hopkins, Hawley, & Burke, 2000) which can alter their expectations and motivations. This psychological state change can then influence a positive outcome (Beedie & Foad, 2009; Gallaher, 2012). Unfortunately, many CG studies have failed to implement a placebo condition in the research design, which makes it difficult to rule out whether improvements in physical performance and perceived benefits were due to the effects of placebo and/or the proposed sensory, neuromuscular mechanisms that are enhanced by CGs (MacRae, Laing, & Cotter, 2011). There are limited studies that have included a placebo condition that have had participants wear looser fitted tights in a randomised order see MacRae, Laing and Partsch (2016) review. There is a likelihood that participants will be able to recognise that it is not a ‘true’ condition, especially if they have had experience wearing CGs (Driller & Halson, 2013; Gallaher, 2012). To examine the links with psychological and physical performance parameters that occur in garment conditions (Engel, Stockinger, Woll, & Sperlich, 2016) future research will need to implement a sham condition in the study design, as there are few to date (MacRae, Laing & Partsch, 2016; Driller & Hanson, 2013). Although, the garment may also indicate a placebo effect (Duffield & Kalkhoven, 2016; MacRae, Cotter, & Laing, 2011) in this reduction of perceived effort. Coaches and trainers can prescribe CGs to reduce the athletes perceived level of exertion which could prolong their perceived fatigue and maximise physiological variables (Faulkner et al., 2013). However, psychological variables are lacking in current literature where more research investigating wearer acceptability is needed (MacRae, Cotter, & Laing, 2011).

2.5 Compression garment development and construction

2.5.1 Measuring compression garment pressure values

Commercial compression garments are fitted based on the height and weight of an individual. Many studies have relied on manufacturer guidelines that provide expected millimetres of mercury that is applied from the garment (MacRae, Laing, & Partsch, 2016) rather than conducting in vivo measurements of CG interface pressures (Beliard, Chauveau, Moscatiello, Cros, Ecarnot, & Becker, 2015; Brophy-Williams, Driller, Shing, Fell, & Halson, 2015; Hill, Howatson, van Someren, Davidson, & Pedlar, 2015). In vivo measurements require the use of reliable pressure sensor instruments, to accurately measure pressure gradients that are applied to each participant (MacRae, Laing, & Partsch, 2016).

Many studies that have measured garment and skin interface pressure have utilised the Kikuhime™ (Figure 3.3) pressure sensor. This device requires the placement of the pressure sensor underneath the garment, which is connected to the pressure transducer and displays pressure readings in real time, in 1 mmHg increments (Brophy-Williams et al., 2015). In 2014, Brophy-Williams, Driller, Halson, Fell and Shing conducted a study to determine the device's validity and intra-class coefficient (ICC) reliability. To examine inter- and intra-test reliability, two testers measured pressure values at six different landmarks on a single participant. Each tester individually performed one measure at each site, then removed all sensor pads and identifiable land markings prior to the other tester performing their measurements. This process was alternately repeated five times each and was found to produce an intra-class coefficient (ICC) reliability of 0.996. The typical error of measurement (TEM) for the intra- and inter-tester reliability was low, scoring 1.3 ± 0.9 and 1.8 ± 0.9 mmHg respectively. When expressed as a coefficient of variation, the results were 4.9 ± 2.4 and 7.4 ± 5.4 %, respectively (Brophy-Williams et al., 2014).

Based on their findings, Brophy-Williams et al. (2014) concluded that this device is reliable and valid for measuring CG pressure. However, despite CG pressure being measured and reported in numerous published investigations, many of these studies fail to report their intra-tester reliability. Intra-tester reliability could vary greatly depending on individual experience and skill level and thus, limits the accuracy and credibility of reported CG pressure values. Therefore, it is recommended that future investigations examining the effect of wearing CGs incorporate intra-tester reliability analyses to support the accuracy and validity of their pressure value measurements. Further, the study by Brophy-Williams et al. (2014) only tested the one participant. This limits their findings to a sample of one, which is not likely to represent the reliability of measuring sample populations with large variance in body size and shape. Therefore, similar analysis performed on a larger sample size with greater variation in body types and garment sizes is warranted to comprehensively examine the reliability and validity of using the Kikuhime for measuring CG pressures.

2.5.2 Garment pressure and body interactions

Sports CGs are designed to exert a pressure that is progressive, where the highest pressure is applied at the ankle and decreases proximally towards the torso (Born, Sperlich, & Holmberg, 2013; Gallaher, 2012). Often, studies that have measured CG pressure, focus only at the calf and thigh at the positions of maximal girth to assess this graduated compression (Dascombe, Laursen, Nosaka, & Polglaze, 2013). However, Brophy-Williams et al. (2015) measured six different landmarks on the lower limb and found that the garment had elicited pressure in a non-uniform or progressive manner (Brophy-Williams et al., 2015).

Brophy-Williams et al. (2015) investigated the interface pressure differences between full-length sport CG tights (105 denier LYCRA 80% nylon and 20% elastane) and standard leggings (250 denier LYCRA 80% nylon and 20% elastane). Surprisingly, the standard leggings elicited greater mean pressure values than the sports CG tights in undersized, recommended and over-sized garments. Further, with respect to the CG tights, the researchers could not find a significant difference in applied pressures between the recommended and oversized garments in both sitting and standing postures (Brophy-Williams et al., 2015). This finding highlights the problem of applying standard sizing guidelines to non-standard anthropometric populations within similar height and weight categories. Regarding future research, this notion reinforces the importance of measuring interface pressure values to standardise or control pressure levels rather than relying on manufacturer guidelines as they are likely to contain highly variable pressure values across participants (Hill et al., 2015). Apart from fabric composition, body morphology can also have an impact on pressure values in different compression garment brands.

To investigate compression garment brand variability, twenty- nine male participants of similar height and weight were fitted into three different medium sized CGs (Hill et al., 2015). Participants were measured to have thigh and calf circumference ranges of 46.1 - 56.3 cm and 33.0 - 39.5 cm, respectively. Despite participants having different muscle and fat ratios and meeting the manufacturer’s garment selection criteria for size medium, applied pressures varied across all brands from 4 - 16.7 mmHg at the thigh and 10.3 - 15 mmHg at the calf (Hill et al., 2015). However, no significant relationships were found between the individual anthropometric variables and either body composition or the pressure applied to the lower limb (Hill et al., 2015). These differences demonstrate that the interaction between the garment and shape of the body is complex and further investigation to better understand this relationship is warranted (Hill et al., 2015).

Other confounding variables that can influence the pressures applied by a garment include: the design, construction, segment covered and the type of movement activity that can alter pressure values (Brophy-Williams et al., 2015; Hill et al., 2015; Troynikov, Ashayeri, Burton, Subic, Alam, & Marteau, 2010). The findings from Brophy-Williams et al. (2015) and Hill et al. (2015) highlight that standard sizing can be arbitrary and produce inconsistent pressure values. Therefore, applied pressure should be measured prior to testing to ensure each participant is receiving sufficient pressure to induce potential benefits for performance, and not solely rely on manufacturer guidelines, due to the wide pressure variations present when garments are fitted within the same size category (Brophy-Williams et al., 2015; Driller & Halson, 2013). To date, this issue has not been well addressed in the literature. Moreover, this issue has impacted our understanding of the pressure values that are required if movement or performance are to be enhanced.

2.5.3 Required pressures for enhanced movement or performance

There are few studies that have investigated whether CGs have an impact on performance measures whilst also reporting garment applied pressure values. Ali, Creasy and Edge (2010) assessed whether there were any differences in long-distance running and jumping performance when using higher (32 mmHg at the ankle and 23 mmHg at the knee) or lower pressured (15 mmHg at the ankle and 12 mmHg at the knee) calf compression sleeves. Running performance was not affected in both conditions however lower pressured sleeves were reported to be the most comfortable (Ali, Creasy & Edge, 2010).

In contrast, Ali, Creasy and Edge (2011) conducted a similar experiment where competitive runners completed four 10 km time trials with pre and post run CMJ performances in no CG, low (15 mmHg at ankle, 12 mmHg at knee), medium (21 mmHg at ankle and 18 mmHg at knee) and high pressure (32 mmHg at ankle and 23 mmHg at knee) compression sleeves. They found no differences in long-distance running performance across all conditions, however there were significant jump height improvements in the post run test in low and medium pressure CGs (Ali, Creasy, & Edge, 2011). The discrepancies between both running experiments is suggested to be based upon the experimental set up. In Ali, Creasy and Edge (2010), participants were moderately running on a treadmill and the researchers encouraged the participants to pace themselves. Whereas, in Ali, Creasy and Edge (2011), participants ran with maximal effort. The low-grade CG pressure values reported by Ali, Creasy and Edge (2011) were similar to Rugg and Sternlicht (2013) (18 mmHg at ankle, 12.6 mmHg at calf and 7.2 mmHg at thigh) who found improvements in maximal CMJ height following a bout of submaximal running. However, more research repeating these experiments is needed to assess if these or different pressure values have similar effect on other populations.

Pressures applied in specific locations from custom designed full-leg length CGs were found to influence landing kinematics differently when compared to a regular CG (Lee, Kim, Hong, & Lee, 2015). Lee et al. (2015) examined drop landing performance when participants wore regular compression pants (control), compression design 1 (CD1) and compression design 2 (CD2). The CD1 garment applied a moderate amount of pressure of 7.13 - 7.73 mmHg at the knee whereas CD2 applied 12.53 - 15.9 mmHg of pressure on the knee and hamstring. In the CD1 condition, drop-landing performance was altered as there were significant increases in knee and hip flexion in comparison to CD2 and the control condition (Lee et al., 2015). Increasing knee and hip flexion are important movement characteristics to attenuate landing forces and reduce injury risk (Williams et al., 2016). The findings of Lee et al. (2015) demonstrate that not only is the magnitude of pressure important, but where that pressure is applied to the limb could be equally or more important. This notion poses a substantial challenge for researchers to investigate and for the design and manufacture of garments that are proven to enhance performance. With evidence demonstrating that commercial CGs elicit varying applied pressure based on individual morphology (Hill et al., 2015), finding a garment from a retail store that can elicit a particular pressure range would seem unlikely to obtain. A solution to this problem may be the capacity to purchase custom made garments, individually designed and manufactured for each user. However, this would be impractical and prohibitive as it would be too expensive for almost all current and prospective users of CGs.

While several studies have specifically examined the degree of garment applied pressures and performance effects, no studies have explored the magnitude of pressures required to induce balance improvement. This is interesting considering the theory that CGs could stimulate somatosensory mechanisms and responses via appropriately applied pressures. Identifying whether an applied pressure range from CGs has an impact on balance performance would be useful for other researchers and coaches to make comparisons and recommendations for sporting and exercise performance (MacRae, Laing, & Cotter, 2011).

2.6 Summary

The ability to balance plays a critical role in performing motor skills required for everyday living, in addition to sport participation and injury minimisation. Numerous neuromuscular training interventions have been found to improve balance, though often require several weeks to take effect on performance. More recently a body of research has explored the effect of compression garments on the improvement of balance, with the stimulation of the somatosensory system proposed as the mechanism for this change. Specifically, the evidence suggests that like other training interventions, compression garments stimulate sensory and neuromuscular responses that alter movement patterns in a variety of contexts.

Whilst research to date that explores the effect of compression garments on balance performance demonstrate mixed findings, this may be impacted by experimental limitations. This includes: studies focusing on a singular balance measure, inconsistent recordings of garment applied pressures as well as not investigating psychological effects when wearing CGs during performance. While movement related findings are mixed, psychological measures appear to be affected by the wearing of CGs in a more consistent manor. The overall conclusion in this regard is that the wearing of CGs can elicit a perceptual benefit, which suggest that studies that more effectively delineate between movement control and psychological factors may be beneficial in determining CG efficacy. Finally, most of the CG based research has not included measures for skin interface pressures.

Consequently, comparison of the findings from various studies can be limited when examining the effect of CGs and their effect of balance ability improvements.

CHAPTER 3. METHODOLOGY

3.1 Participants

Fourteen males volunteered to participate in this study (Table 3.1). All participants self-reported as healthy and regularly (2 - 5 training sessions per week) engaged in moderate to high intensity recreational exercise or competitive sport. Previous research has shown CG's to improve movement patterns of lesser skilled populations than high skilled counterparts (Cameron, Adams, & Maher, 2008; Hasan et al., 2016; Lien et al., 2014). For this reason, higher skilled populations were excluded from the study. This was controlled by excluding individuals from the study if they have competed above the local level of their chosen sport. Additionally, if participants had any lower limb injuries within the six months prior to testing, they were also excluded. Prior to participation, all prospective participants were provided with a participant information statement (Appendix A), completed a pre-health screen questionnaire (Appendix B) and gave written informed consent (Appendix C). Ethical approval for this investigation was provided by the Western Sydney University Human Research Ethics Committee (H12358) (Appendix D).

Table 3.1 Participant characteristics (Mean and SD).

Participants (N)	Age (years)	Weight (kg)	Height (cm)	Thigh circ. (cm)	Calf circ. (cm)
14	27 ± 3.6	81.8 ± 8.4	174.9 ± 4.1	54.4 ± 2.9	38.5 ± 1.5

3.2 Experimental design and overview

This investigation used a within subject, repeated measures design to explore the effect of wearing a lower limb compression garment on balance performance. Participants performed and repeated five balance tests that assessed their dynamic and static balance ability in three conditions, compression garment (CG), no garment and a sham condition. The CGs used in this study were Body Science V8 Compression Longs™ (26% Lycra and 74% polyester) (Figure 3.1). Garment size selection was performed according to the manufacturer guidelines (Appendix M), which was based on the height and weight of each participant; pressure findings for this can be found in Table 3.2.

Figure 3.1 Body Science garment V8 Compression Longs.

Table 3.2 Pressures applied from Body Science.

	Mid-thigh (mmHg)	Mid-calf (mmHg)
Standing	9.28 ± 0.45	13.85 ± 1.64
Sitting	9.21 ± 0.41	10.42 ± 1.29

The sham condition (Figure 3.2) was consistent with previous research (Gupta, Bryers, & Clothier, 2014) which involved light application of a 5 cm wide sports strapping tape (Body Plus™) from the mid-point of the thigh to the superior border of the patella and the mid-point of the posterior shank to the Achilles tendon. The mid-point of the thigh was identified by measuring from the anterior-iliac spine of the pelvis to the superior border of the patella and the mid-point of the shank was determined from the popliteal fossa to the floor (Gupta, Bryers, & Clothier, 2014). The participants were informed that the tape may stimulate sensory feedback that may assist in their balance performance (Gupta, Bryers, & Clothier, 2014). For the control condition, participants were instructed to supply and wear their own loose-fitted training shorts. Testing conditions were number ordered (1= CG, 2= control and 3= sham) and counter-balanced to control order effects. Participants were tested in the following order: 1, 2, 3; 2, 3, 1; and 3, 1, 2 which was rotated through all participants.

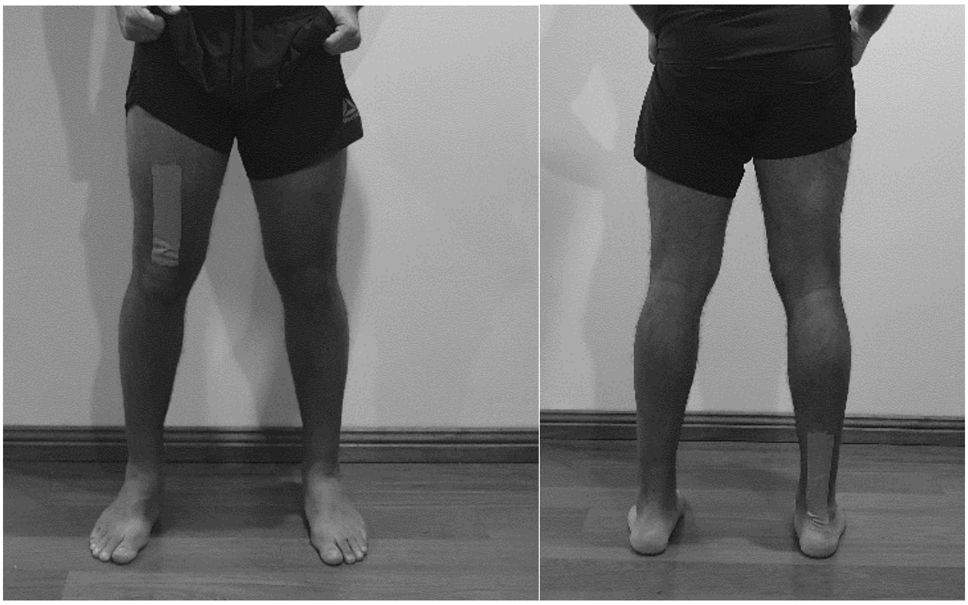

Figure 3.2 Sham condition illustrating the tape applied from the mid-point of thigh (left) and shank (right) to the end of segment.

3.3 Instrumentation

3.3.1 Force plate data

Ground reaction force (GRF) data were collected from a multi-component force plate (Kistler Group, Type 9286AA, Winterthur, Switzerland) and recorded using Bioware software (v5.3.0.7). Force signals were sampled at 1000 Hz and filtered with a 10 Hz low-pass Butterworth filter for the jump-landing and single-leg balance tasks. A low-pass filter for single-leg balance trials was selected, as previous research has found signal frequency to be less than 10 Hz for healthy subjects when performing quiet standing (Duarte & Freitas, 2010). Prior to collecting single-leg balance trials, force plate settings were zeroed to the participant's body weight. For the jump-landing tasks, force plate processing was performed in accordance with previously published methodologies, however low-pass filters ranged from 12-14 Hz (Gribble, Mitterholzer, & Myers, 2012; Liu & Heise, 2013; Zech et al., 2014). It is noted that sample rate and filter setting differences have a small variance for jump-landing tasks, whereas large variances occur for trial length (Fransz, Huurnink, de Boode, Kingma, & Van Dieën, 2014). A software trigger was used such that data collection began when vertical GRF first exceeded 10 N (Sambaher, Aboodarda, Silvey, Button, & Behm, 2016).

3.3.2 Garment-skin interface pressure measurement

Garment and skin interface pressures at the mid-thigh and at the position of maximal calf girth were measured prior to balance testing. The mid-thigh was identified between the anterior superior iliac spine and the superior border of the patella (Gupta, Bryers, & Clothier, 2014). The calf site was located by repeatedly measuring calf circumferences, until the maximum circumference was identified. The pressure sites were selected as they have been found to elicit the highest-pressure values in comparison to various locations on the leg's upper and lower segments (Brophy-Williams et al., 2014).

The Kikuhime ™ (Kikuhime, TT Medi Trade, Søleddet 15, Denmark, DK 4180 Soro) pressure sensor (Figure 3.3) was used to collect pressure readings. The device's pressure sensors consist of air-filled bladders (dimension of 30 x 38 mm and approximately 3 mm thick) that connect to the pressure transducer via silicon tubing. Pressure readings are displayed in real time in 1 mmHg increments with a typical error of measurement of ± 1 mmHg (Brophy-Williams et al., 2015). Previous research has shown the Kikuhime to have a high intra-class correlation (ICC) coefficient reliability of 0.966 and an intra and inter-tester technical error of measurement (TEM) of 1.3 ± 0.9 and 1.8 ± 0.9 mmHg respectively (Brophy-Williams et al., 2014). To assess the measurement reliability of the tester in the current study, a pilot experiment was conducted (Appendix L). Results demonstrated high intra-tester reliability with an ICC of 0.956.

Figure 3.3 Kikuhime pressure sensor, adapted from Varodem (2018).

With participants initially wearing the CGs around their ankles, the pressure sensors were secured with tape on the anterior surface of the mid-thigh and the posterior surface of the calf at the maximal circumference on separate occasions (Figure 3.4). The garments were then carefully pulled up and stretched over the sensors to avoid damage or creasing the sensor or tubing. Pressures were initially recorded with participants standing in the anatomical position. During measurement, pressure values were to stabilise for a duration of 10 seconds in order to qualify for a recorded trial. Participants then sat down on a chair with their hip and knee flexed at 90° (measured with a goniometer), pressure measurements were taken, and values were to stabilise for 10 seconds. Participants would alternate between standing and sitting positions until 3 pressure measurements were recorded for each location of the limb. A 10 second rest was provided between recordings. Mean pressure values were then calculated for each location. Previous research has found CGs to elicit different pressure responses in the standing and sitting positions (Brophy-Williams et al., 2014), therefore the researchers wanted to assess if the testing garment had the same effect.

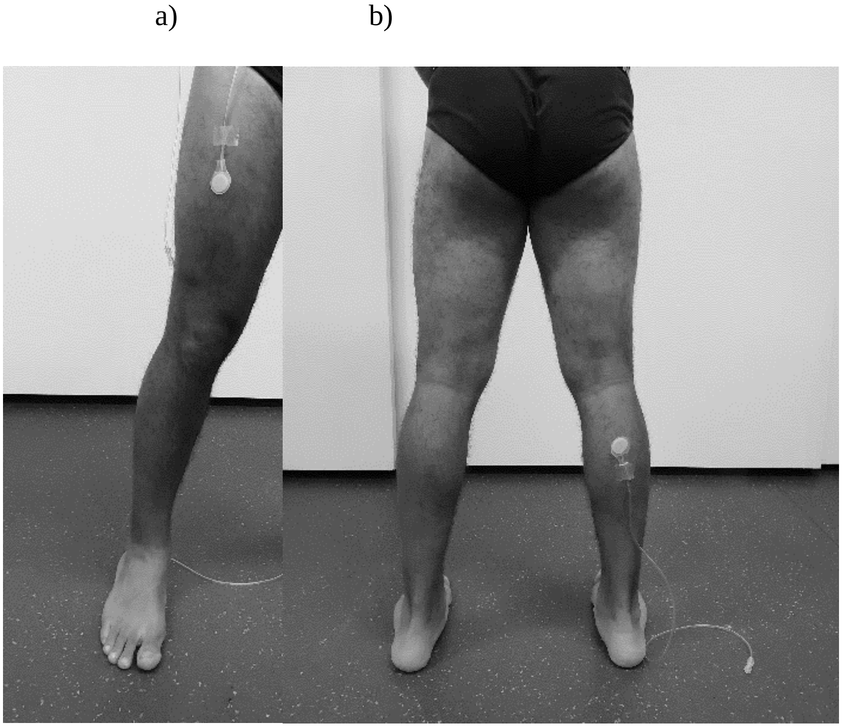

Figure 3.4 Leg locations for garment skin-interface pressure measurements a) mid-thigh b) maximal girth on calf.

3.3.3. Survey administration to record perceptual data

To investigate psychological aspects associated with wearing the CGs, participant subjective data was recorded via a short survey (Appendix E), administered at the completion of the balance tests in each testing condition. Each participant was required to reflect on their experience while performing in each of the conditions and on their overall performance (Driller & Hanson, 2013; Hooper et al., 2015; Kraemer et al., 1998). The survey consisted of questions pertaining to the participant's perception of effort (RPE), stability, support, comfort, enjoyment and whether they felt the condition had an influence on their performance. All questions were derived from surveys used in previous research investigating the effects of CGs and ankle braces on physical performance (Ali et al., 2007; Beriau, Cox & Manning, 1994; Bernhardt & Anderson, 2005; Birmingham et al., 1998; Kraemer et al., 1999). A seven-point Likert scale (Table 3.3) was used to record their responses. Finally, at the end of the survey, participants were asked if they would prefer to wear CGs than regular training shorts/pants when exercising/participating in sports.

Table 3.3 Sample survey question and seven-point Likert rating scale.

Did you feel stable when wearing this condition?						
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
O	O	O	O	O	O	O

3.4 Experimental procedure

Participants performed and repeated five balance tests in the following order for each condition: vertec jump, balance stabilometer, hurdle jump, Y-balance test (YBT) and single leg balance (SLB). These tests have been repeatedly used in studies to measure dynamic and static balance for both clinical and sporting populations (Fullam, Caulfield, Coughlan, & Delahunt 2014; Hosp et al., 2017; Maeda et al., 2016; Michael et al., 2014; Wikstrom et al., 2008). It also allows the researchers to globally measure static and dynamic balance performances in a variety of contexts (Riemann & Schmitz, 2012). Moreover, implementing a variety of tests holistically measures participant static and dynamic balance performance in different contexts (Riemann & Schmitz, 2012). On that basis, the authors deemed that this battery of balance tasks were appropriate to test the hypothesis.

The order of tests was chosen to avoid any potential fatigue related effects from performing repeated single leg tasks. For example, the vertec jump required single leg balance from landing and the following test was the balance stabilometer which required a bilateral stance, the hurdle jump single leg balance, the YBT requires the involvement of both legs and the SLB test requires unilateral balance. All tests were performed barefoot to eliminate shoe variation influences (Cavanaugh et al., 2015; Fullam et al., 2014). Participants only completed a familiarisation period of each task in the first encounter. Participants completed three trials for each balance test and had a two-minute rest between tests. After the completion of all balance tests in a testing condition, a 10-minute rest period was provided to allow participants to recover and change into the next condition (Doan et al., 2003).

Across all static and dynamic balance tests, a total of three successful trials were completed and averaged. This is shown in various studies that have used similar protocols such as the jump-landing tasks (Maeda et al., 2016; Wikstrom et al., 2008), YBT (Cavanaugh et al., 2015; Fullam et al.,2014), balance stabilometer (Hosp et al., 2017) and SLB task (Maeda et al., 2016; Michael et al., 2014). Participants performed the balance tests barefoot to eliminate shoe variation influences (Cavanaugh et al., 2015; Fullam et al., 2014). To distinguish the dominant leg for the unilateral tasks, participants selected the leg which they would kick a ball (Krklejas, 2017). At the completion of all balance tests in a garment condition, participants rated their perceived exertion levels on a 6-20 Borg scale (Borg, 1982) and completed a survey as mentioned in Section 3.3.3.

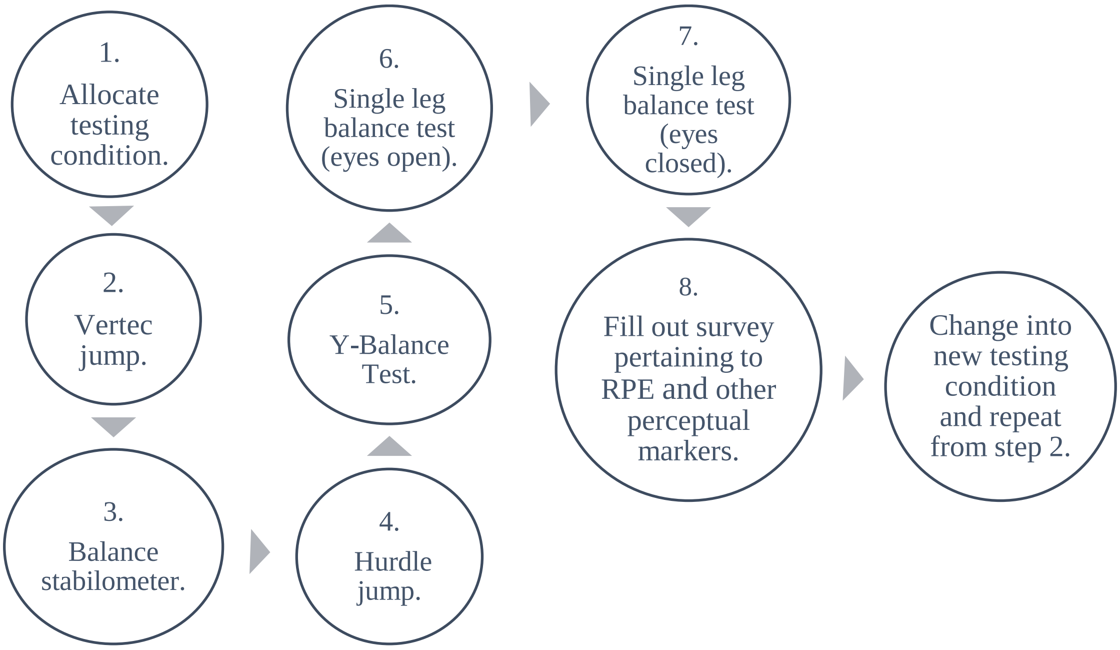

Figure 3.5 Experimental test order.

3.4.1 Vertec Jump

The vertec jump test required participants to perform a two-legged jump at a 45-degree, lateral projection angle, reach a vertical height of at least 50 % their Max counter-movement jump (CMJ) height, land on their dominant leg and maintain static balance for 15-20 seconds post impact. Having participants jump at an oblique angle and land on a single leg challenges their medio-lateral balance and has been found to result in poorer balance scores in comparison to other jumping angles (Wikstrom et al., 2008). An aim of the current study was to assess if CGs could improve participant balance ability in tasks of greater difficulty. The vertec jump test has been widely used across various studies to assess balance performance for athletes (Shaw, Gribble, & Fry, 2008; Sinsurin, Srisangboriboon, & Vachalathiti, 2017) and as a task to differentiate between injured and non-injured populations. The vertec jump test has been found to be reliable with an ICC score of 0.96 (Wikstrom et al., 2005) and able to differentiate between non-injured and injured populations via TTS calculations (Ross & Guskiewicks, 2004). This demonstrates the vertec jump test is an effective task for measurement of balance ability deficits, and suited to the aim of the current study.

Prior to performing the vertec jump test, calculation of each participants 50 % Max jump height was made (Gribble, Mitterholzer, & Myers, 2012; Ross & Guskiewicz, 2004; Wikstrom et al., 2008). This process involved participants standing under the vertec with their body erect (Figure 3.6 left), reaching up with their ipsilateral arm of the dominant leg (testing leg) and touch the highest possible rod whilst both feet were flat on the ground (Figure 3.6 right). Participants then performed two warm up CMJs at maximal effort for familiarisation (Nuzzo, Anning, & Scharfenberg, 2011; Isaac, 1998). To achieve max performance, participants were instructed to start with an upright trunk position with feet parallel and hip to shoulder width apart; flex the hips and knees to a preferred decent; explosively extend the hips and knees and plantar flex at the ankles and during the flight phase to maintain a neutral neck position (not looking upwards) whilst reaching for the highest rod on the vertec (Isaac, 1998; Nuzzo, Anning, & Scharfenberg, 2011).

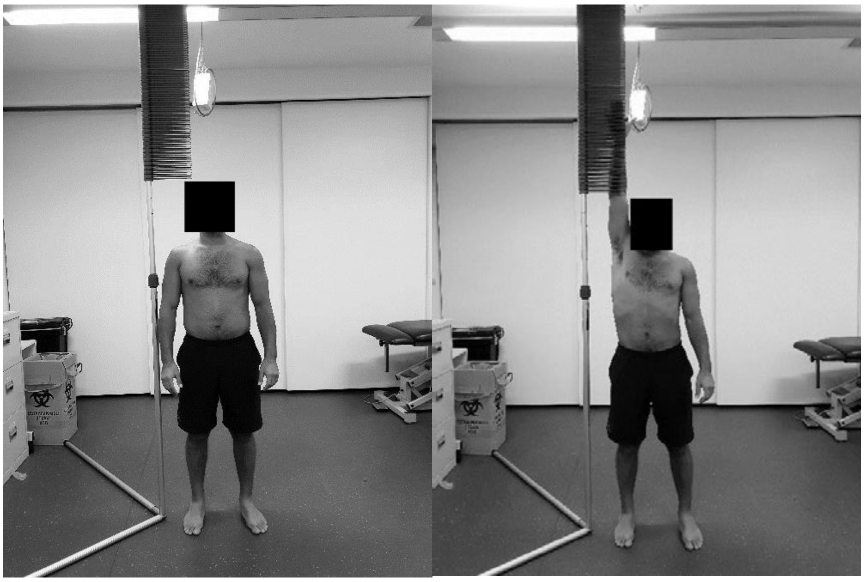

Figure 3.6 Participant positioning for measuring reach height (left) and reaching with their ipsilateral arm (right).

Following the familiarisation trials, each participant performed three maximal effort CMJs with the aim of reaching the highest rod possible on the vertec. The highest score was recorded as their maximum jump height (Gribble, Mitterzolher, & Myers, 2012; Shaw, Gribble, & Fry, 2008). Calculation of each participant’s 50 % jump height was performed by subtracting their reach height from their maximum jump height, then dividing this number by two (Sell, 2011).

The vertec jump balance test required participants to stand at an oblique 45-degree angle, 70 cm from the centre of the force plate, with their feet shoulder width apart and toes adjacent to the marked take-off line (Figure 3.7) (Ross & Guskiewicz, 2004; Sell, 2011; Wikstrom et al., 2008).

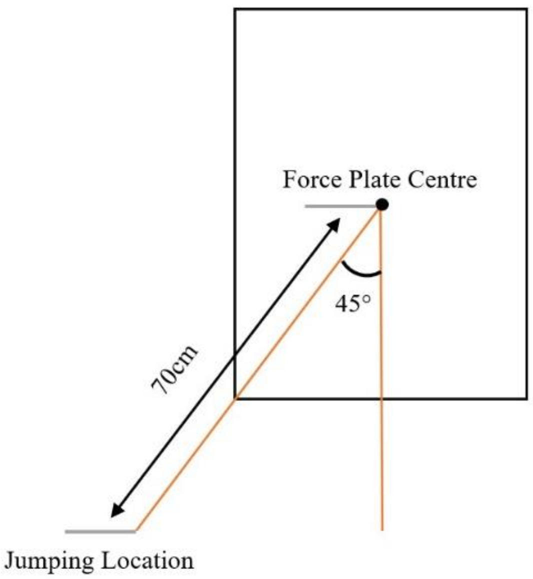

Figure 3.7 Illustration of the jumping angle from the starting location to the force plate for the vertec jump balance test.

Participants were allowed to use their arms to swing prior to performing a double leg take-off jump and extend their ipsilateral arm to touch the vertec rod situated at 50 % of their maximal vertical jump height (Gribble, Mitterholzer, & Myers, 2012). Participants then landed on their dominant leg on the centre of the force plate. The opposing leg was to be held in slight knee flexion and clear from the ground (Cavanaugh et al., 2015). Upon landing, participants were required to stabilise as quickly as possible and hold a static balance position for 15-20 seconds post impact (Wikstrom et al., 2005). During the landing phase, participants were instructed to place their hands-on hips to reduce any coordinative support from the upper extremity and to look straight ahead to standardise the visual influence during postural control (Cavanaugh et al., 2015). After receiving task instructions, participants were afforded three practise trials (Gribble, Mitterholzer, & Mitterzolher, 2012) with a one-minute rest between each trial (Williams et al., 2016), and a two-minute rest prior to commencing the experimental trials, to reduce the influence of fatigue (Gribble, Mitterholzer, & Mitterzolher, 2012). Participants then performed three experimental trials with a one-minute rest between each trial, for each garment condition. No instructions were provided on the landing technique to be used to prevent a coaching effect (Prieske, Muehlbauer, Mueller, Krueger, Kibele, Behm, & Granacher, 2013). Trials were discarded and repeated if a participant: 1) lost balance and fell; 2) their contralateral limb touched the floor; 3) a short hop upon landing was performed; 4) there was excessive swaying of the contralateral limb, trunk and/or arms (Cavanaugh et al., 2015; Ross & Guskiewicz, 2004; Wikstrom et al., 2008).

3.4.2 Balance stabilometer

The balance stabilometer (Lafayette Instruments, Inc) (Figure 3.8), measures the time (s) a person is able to maintain balance on a horizontal platform within a 0-5° horizontal inclination range. The platform will constantly shift angles while the participants stands on it; requiring participants to apply appropriate muscle activations to the random perturbations in order to remain within the 0-5° horizontal inclination range. Superior balance ability is reflected by greater time spent in the specified range (Hosp et al., 2017).

This balance test required participants to stand on the stabilometer with a bipedal stance, their feet positioned hip to shoulder width apart, with their eyes looking straight ahead while aiming to keep the platform as horizontal as possible and avoid contact with the ground for the duration of the trial (Davlin, 2004). Within the test trial period, the stabilometer recorded the aggregate duration the participant held the platform within ± 5° of the neutral position (horizontal). If the platform moved outside this range, the aggregate duration of the platform was positioned with left or right-side inclination beyond 5° was recorded. Participants were afforded one practise trial for as long as possible (Hosp et al., 2017). Participant trials commenced when a neutral platform position was achieved (Figure 3.8). Trial length was for 20 s with a 30 s rest period between each trial. Participants performed three 20 s experimental trials with 30 s rest between each trial, for each garment condition.

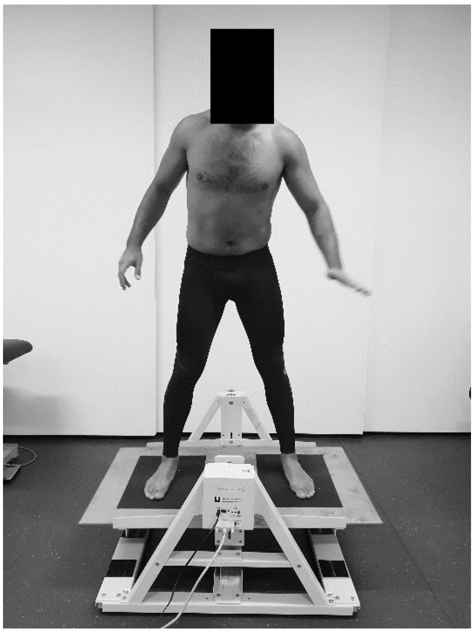

Figure 3.8 Participant on the balance stabilometer in the neutral starting position.

3.4.3 Hurdle jump

The hurdle jump balance test required participants to perform a forward, double-leg jump over a 15 cm high hurdle, travel an anterior distance of 40 % of their standing height, land on their dominant leg on a force platform and hold the static position for 15-20 s post impact (Figure 3.9). While the vertec jump is a shorter jump distance but at a greater height and on an oblique angle, the hurdle jump requires greater forward translation and less jump height. The hurdle jump was selected to assess if participants utilise different jump-landing strategies and whether the CG would be of any benefit in these different contexts. Williams et al. (2016) utilised a similar experiment and suggests that the hurdle jump is an efficient and controlled method to analyse dynamic balance.

The jump movement and landing requirements for the hurdle jump are similar to the vertec jump (Section 3.4.1.) except participants are required to anteriorly jump a distance of 40 % of their standing height from their initial placement, over a 15 cm high hurdle situated half of the jumping distance and land with their dominant leg on the centre of the force plate (Sell, 2011). After participants received task instructions they were then afforded three practise trials with a one-minute rest between each trial (Gribble, Mitterholzer, & Mitterzolher, 2012; Williams et al., 2016). A two-minute rest was then provided prior to commencing experimental trials, to reduce the influence of fatigue (Gribble, Mitterholzer, & Mitterzolher, 2012). Participants then performed three experimental trials with a one-minute rest between each trial, for each garment condition.

As per the vertec jump requirements, no instructions were provided on the landing technique to prevent a coaching effect (Prieske et al., 2013). Trials were discarded and repeated if a participant: 1) lost balance; 2) their contralateral limb touched the floor; 3) a short hop upon landing was performed; 4) there was excessive swaying of the contralateral limb, trunk and/or arms (Cavanaugh et al., 2015; Ross & Guskiewicz, 2004; Wikstrom et al., 2008).

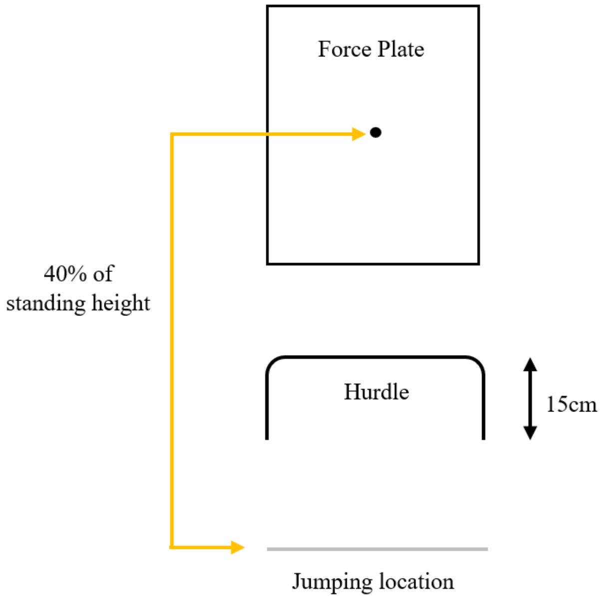

Figure 3.9 Jumping start location; 15 cm vertical height; horizontal distance equal to 40 % of standing height.

3.4.4 Y-Balance Test (YBT)

The YBT assesses balance by requiring participants to stand on their non-dominant leg and reach as far as possible with their contralateral leg and touch the ground in the anterior, posterolateral and posteromedial directions, without falling from their supportive leg. Superior balance performance is indicated by a greater distance reached. To perform the YBT, participants must produce an adequate level of muscle strength, flexibility and coordination. The researchers wanted to assess if the tactile stimulation provided by CGs could alter neuromuscular function and improve participants reach distance. The YBT has been demonstrated to be a valid and reliable method to differentiate between injured and uninjured populations (Gribble, Hertel, & Plisky, 2012) as well as a measuring tool to assess pre-post balance interventions (Nakajima & Baldridge, 2013). Test reliability has been reported with an ICC range of 0.82 – 0.87 (Plisky, Rauh, Kaminski, & Underwood, 2006).

To measure YBT performance, participants were required to stand on the middle of a grid that had 3 lines, one directed anteriorly, one directed 45° posteromedial, and one directed 45° posterolateral (Figure 3.10) (Fullam et al., 2014). To begin the test each participant stood with both feet together with their toes from the foot of their dominant leg positioned at the intersection of the three lines. Participants then transitioned into a unipedal stance with their non-dominant leg as the supporting leg. Using their non-supporting leg, participants then reached out maximally to touch down lightly on the tape line with their toes, before returning the reaching leg to the suspended starting position (Cavanaugh et al., 2015; Fullam et al., 2014). A five second rest period was then provided. Participants repeated this process for the remaining directions in a clock-wise fashion to complete the first trial of the YBT.

During the touch down phase, the maximum reach distance was indicated with a black marker, taking care not to obstruct the participant. When participants commenced the second trial of the YBT, a new coloured marker was used to record the reach distance, which was repeated to differentiate each new trial. Participants performed three YBT trials with 30 s rest between each trial, for each garment condition. Once all three trials were completed, a tape measure was used to measure the marked distances in all three directions. The distances covered in each trial were averaged for each of the three directions.

Four practise trials were provided to complete the YBT to decrease potential learning effects in test performance (Fullam et al., 2014). Following the practise trials, participants received a two-minute rest period prior to commencing the YBT (Fullam et al., 2014). Trials were discarded and repeated if the participant's heel of their standing foot lifted, the reaching foot did not return to the starting position, the touchdown was not on the tape line and/or was not lightly pressed against the floor (Fullam et al., 2014).

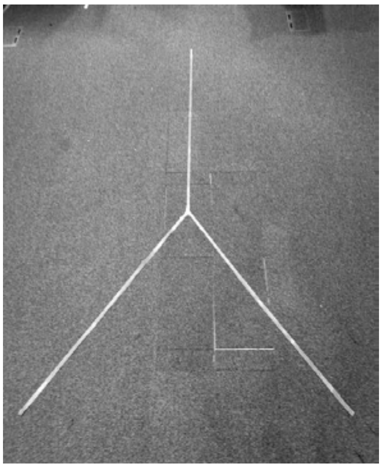

Figure 3.10 Y-balance test reach directions. Image adapted from Fullam et al. (2014).

3.4.5 Single leg balance test (SLB)

The final test was the SLB and required participants to hold a static single leg position on their dominant leg for 20 s with their eyes open (EO) and eyes closed (EC) on separate occasions. The SLB is a widely used balance test that has been significantly correlated to functional performance and injuries (Hrysomallis, 2011). Both EO and EC tasks were selected to assess if there were contrasting performances between the garment and no-garment conditions. Considering that CGs provide tactile stimulation, the authors wanted to assess if participants would benefit from this feedback source while their visual feedback was occluded and remain more stable.

Administering the SLB test required participants to stand on both feet with their dominant leg foot in the centre of the force platform, and with their hands on their hips. When signalled, their non-dominant leg was raised and held off the ground in a slightly flexed position (Figure 3.12). Participants held this position for 20 s while ground reaction force data was collected. A total of three trials for the EO and EC SLB tests were performed with a 30 s rest between each trial, for each testing condition. Trials were discarded and repeated if a participant demonstrated excessive sway in their movement or their opposing leg had touched the ground (Michael et al., 2014).

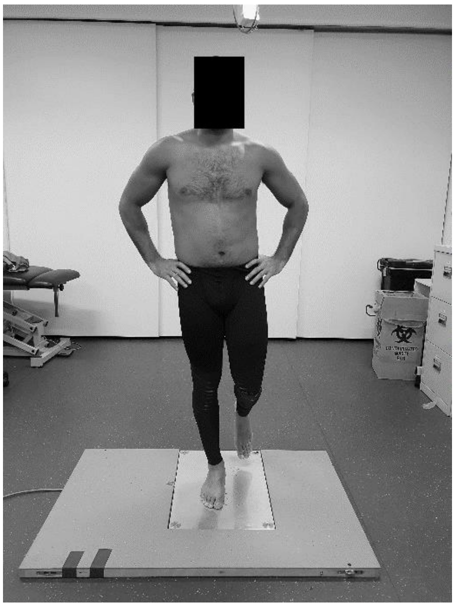

Figure 3.11 Single leg balance stance position.

3.5 Data Processing

Filtered GRF data was collated in Microsoft Excel (Microsoft Corp, Redmond, Washington) and analysed with a custom MATLAB (The Mathworks, Natick, RI, USA) script (Appendices F) to calculate the measures of stability for each trial of the vertec jump, hurdle jump and SLB tasks. The method for calculating each stability measure for these tests are described below. Three trials of each of the aforementioned tests were averaged individually and compared for analysis.

The first stability variable calculated was the dynamic postural stability index (DPSI), which calculates a combined stability indices (SI) based on the force data from three principal directions: medio-lateral: (MLSI), anterior-posterior: (APSI) and vertical (VSI), (Sell, 2011; Wikstrom, et al., 2005). These MLSI and APSI indices indicate the mean square deviations around a 0 point along the frontal and sagittal axes of the force plate, respectively (Sell, 2011; Wikstrom et al., 2005). The VSI standardises the vertical GRF along the vertical axis of the force plate by assessing the fluctuations of the participant's body weight. Dynamic postural stability index is calculated as the root-mean-square of the sum of squares in each direction and normalised to body weight (Equation 3.1) (Sell, 2011; Wikstrom et al., 2005).

$$\text{DPSI} = \left(\sqrt{\frac{\sum\left(0-GRFx\right)^2+\sum\left(0-GRFy\right)^2+\sum\left(bodyweight-GRFz\right)^2}{\text{number of data points}}}\right) \div \text{body weight} \qquad (3.1)$$

Where, DPSI = Dynamic postural stability index; GRF, ground reaction force; x, mediolateral; y, anteroposterior; z, vertical (Sell, 2011).

To calculate the time to stabilization (TTS), filtered force data was cropped from the time of impact (first GRF >10N) to 20 s post impact. An unbound third-order polynomial (UTOP) was then used to calculate TTS in the vertical, AP and ML directions (Ross & Guskiewicz, 2004). The stability threshold was set as the average range of variation once the participant had stabilised, equal to ± 3 SD of the mean force within the 15-20 s window following ground contact. Time to stabilisation was defined as when the UTOP signal intersected, and remained within the stability threshold (Figure 3.12). Both DPSI and TTS calculations were utilised to measure dynamic balance in the vertec and hurdle jumping tasks.

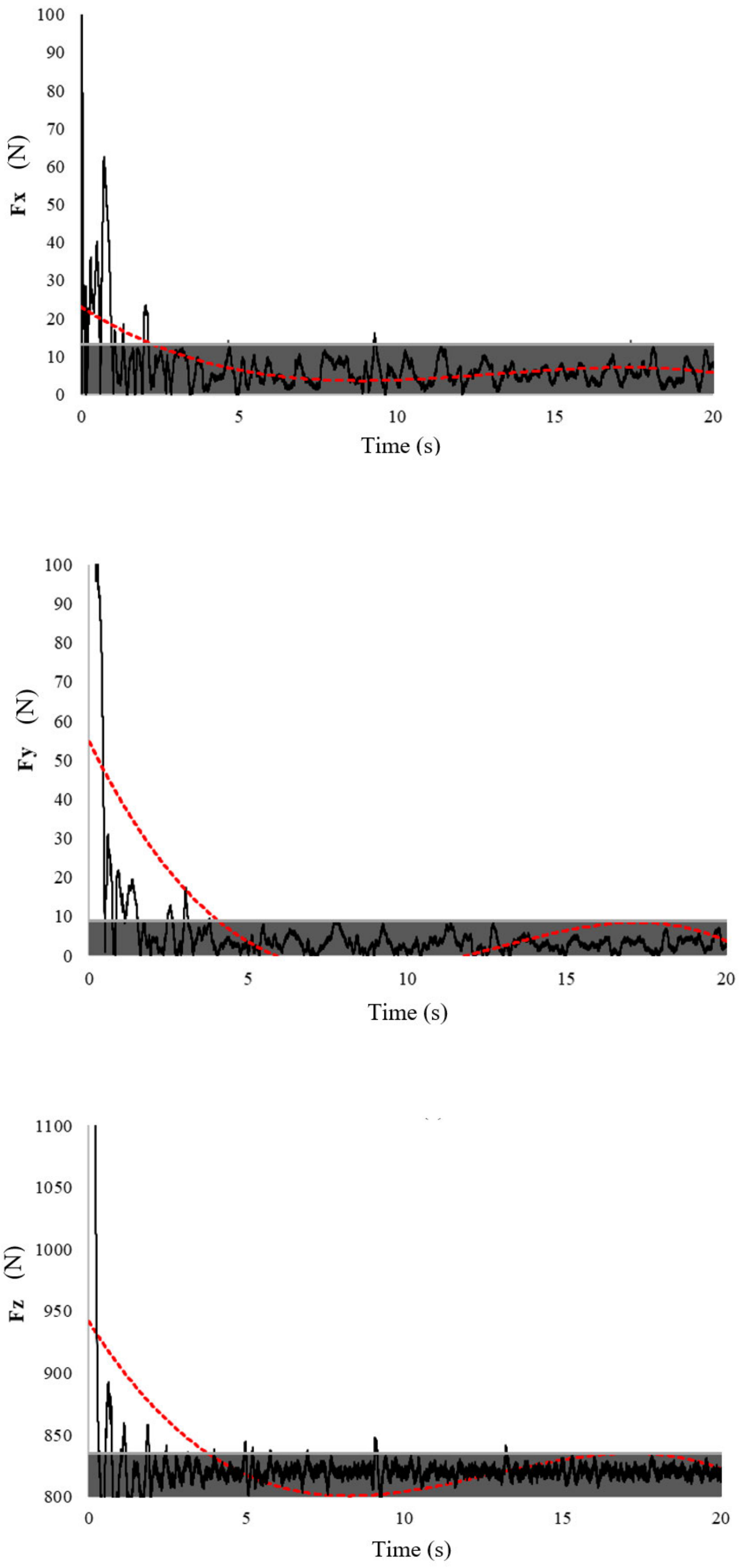

Figure 3.12 Time to Stabilisation calculated using an unbound third-order polynomial (UTOP) in mediolateral (Fx), anteroposterior (Fy) and vertical (Fz) directions. The vertical axis denotes force in Newtons. Horizontal axis indicates time in seconds. The red dashed line is the respective UTOP fit for force data in each direction. Solid grey shading indicates the ± 3 SDs of the mean during the stabilisation period of the landing during the 15-20 seconds post ground contact. TTS is defined as the time is takes until the UTOP signal intersects the ± 3 SDs stabilisation threshold after landing.

Centre of pressure (COP) path length was calculated from the SLB trials as the total excursion distance of moment forces applied from the centre of the individual's foot on the force plate in both AP and ML directions, relative to body weight (Equation 3.2). Smaller COP excursions demonstrates superior static balance (Michael et al., 2014).

$$\sum \sqrt{(Ay_2 + Ay_1)^{\,2} - (Ax_2 + Ax_1)^{\,2}} \qquad (3.2)$$

For the YBT, the following formula was used to normalize the reach distance of the participants limb length (measured from greater trochanter to lateral malleolus): reach distance/limb length x 100 = % maximized reach distance (Robinson & Gribble, 2008). Three trials in each direction were averaged individually and compared for analysis.

3.6 Statistical analysis

The Statistical Package for the Social Science (v24, SPSS Inc., Chicago, IL) was used for all statistical analyses. Data were initially screened using descriptive statistical analyses to assess for missing values, variance and score distributions. Varying degrees of skewness and non-normal distribution of data in some dependent variables were found. The degree of these distribution effects can violate an assumption of performing an Analysis of Variance (ANOVA). Therefore, log transformation was performed on these data sets. This treatment produced little beneficial effect in adjusting for non-normal distribution.

However, ANOVA analysis is suggested to be quite robust and not overly sensitive to deviations from a normal distribution (McDonald, 2019). Various simulation studies utilising multiple forms of non-normally distributed data have shown that the false positive rate is not greatly affected by violation of the normality assumption (Glass et al., 1972; Harwell et al., 1992). Thus, the non-normal distribution observed in some data sets was not considered a serious violation of this assumption, and ANOVA testing was applied.

A one-way repeated measures Analysis of Variance (ANOVA) was used to determine differences between conditions (CG, sham, control) for all dependant variable measures. These were: DPSI and TTS_{UTOP} (x, y, z) for the vertec and hurdle jumps, time (s) on the Stabilometer (STAB) test, reach distance in the $YBT_{anterior}$, $YBT_{posteriorlateral}$ and $YBT_{posteromedial}$ directions and $COP_{pathlength}$ excursion for the EO and EC SLB tests. Statistical significance was set at $p < 0.05$ with Bonferroni correction made for all analyses to reduce the risk of making a type 1 error. Mauchly's test of sphericity was used to assess the homogeneity of variance in the difference scores between groups and a Greenhouse-Geisser correction applied if sphericity was violated.

Survey data were screened using descriptive statistical analyses to assess for missing values, variance and score distributions. Extreme clustering of rating scores, indicated by a substantial lack of variance and severely skewed, non-normally distributed data were found for all survey questions. Due to this finding, the likelihood of violating numerous statistical assumptions and the high probability of producing a type 1 error, statistical analysis was confined to descriptive comparisons of means for this data.

CHAPTER 4. RESULTS

4.1 Results

Mean and standard deviations (SD) for measures in the vertec jump, stabilometer (STAB), hurdle jump, YBT and SLB tests are presented in Table 4.1. No significant between-condition main effect differences were observed for any stability measure (Table 4.1). Mean, standard deviations (SD) and percentages for the survey data are presented in Table 4.2.

Table 4.1 Mean (± SD) scores and between condition repeated measures ANOVA comparison for all stability measures.

Balance test	**Measure**	**NG**	**SH**	**CG**	**df**	**F**	**P**
Vertec jump ⇩	DPSI	0.24 ± .07	0.21 ± .05	0.22 ± 0.07	2, 26	2.420	0.109
Vertec jump ⇩	Fx TTS$_{UTOP}$	3.11 ± 0.85	3.11 ± 0.95	3.49 ± .58	2, 26	2.290	0.121
	Fy TTS$_{UTOP}$	3.66 ± .62	3.60 ± 0.44	3.83 ± .33	2, 26	1.393	0.266
	Fz TTS$_{UTOP}$	3.14 ± 0.73	3.12 ± 0 .59	3.34 ± .45	2, 26	1.421	0.259
STAB ⇧	Time (s)	9.59 ± 3.66	8.38 ± 3.39	9.33 ± 3.56	1.784, 23.196	3.288	0.060$_{GG}$
Hurdle jump ⇩	DPSI	0.23 ± 0.75	0.23 ± 0.06	0.24 ± 0.88	1.190, 15.476	1.435	0.256$_{GG}$
	Fx TTS$_{UTOP}$	2.11 ± 0.81	2.02 ± 0.74	2.10 ± 0.72	2, 26	0.103	0.902
	Fy TTS$_{UTOP}$	4.02 ± 0.21	4.05 ± 0.29	4.14 ± 0.44	1.398, 18.169	0.575	0.513$_{GG}$
	Fz TTS$_{UTOP}$	3.15 ± 0.47	3.22 ± 0.49	3.43 ± 0.52	2, 26	0.982	0.432
YBT ANT ⇧	Reach (%)	67.85 ± 6.74	68.14 ± 6.50	69.50 ± 6.46	1.442, 18.741	3.012	0.087$_{GG}$
YBT PM ⇧	Reach (%)	120.50 ± 6.83	120.92 ± 7.14	121.57 ± 5.94	2, 26	0.832	0.446
YBT PL ⇧	Reach (%)	123.07 ± 9.51	124.35 ± 10.39	124.00 ± 8.60	2, 26	2.157	0.136
SLB EO ⇩	COP$_{pathlength\ (m)}$	0.10 ± 0.03	0.12 ± 0.06	0.10 ± 0.02	1.356, 17.625	0.624	0.487$_{GG}$
SLB EC ⇩	COP$_{pathlength\ (m)}$	0.17 ± 0.12	0.17 ± 0.06	0.14 ± 0.05	1.281, 16.657	0.915	0.377$_{GG}$

Data represents mean ± SD. No significant differences observed between Compression Garment, CG, No Garment, NG and Sham, SH groups. Dynamic Postural Stability Index, DPSI, Time to Stabilisation, TTS; Stabilometer, STAB; Y-Balance test, YBT, Anterior, ANT, Posteromedial, PM and Posterolateral, PL; Single Leg Balance, SLB, Eyes Closed, EC and Eyes Open, EO; Centre of Pressure Pathlength, COP; Greenhouse-Geisser correction, GG. The higher the value for a variable represents superior balance (⇧); The lower the value for a variable represents superior balance (⇩).

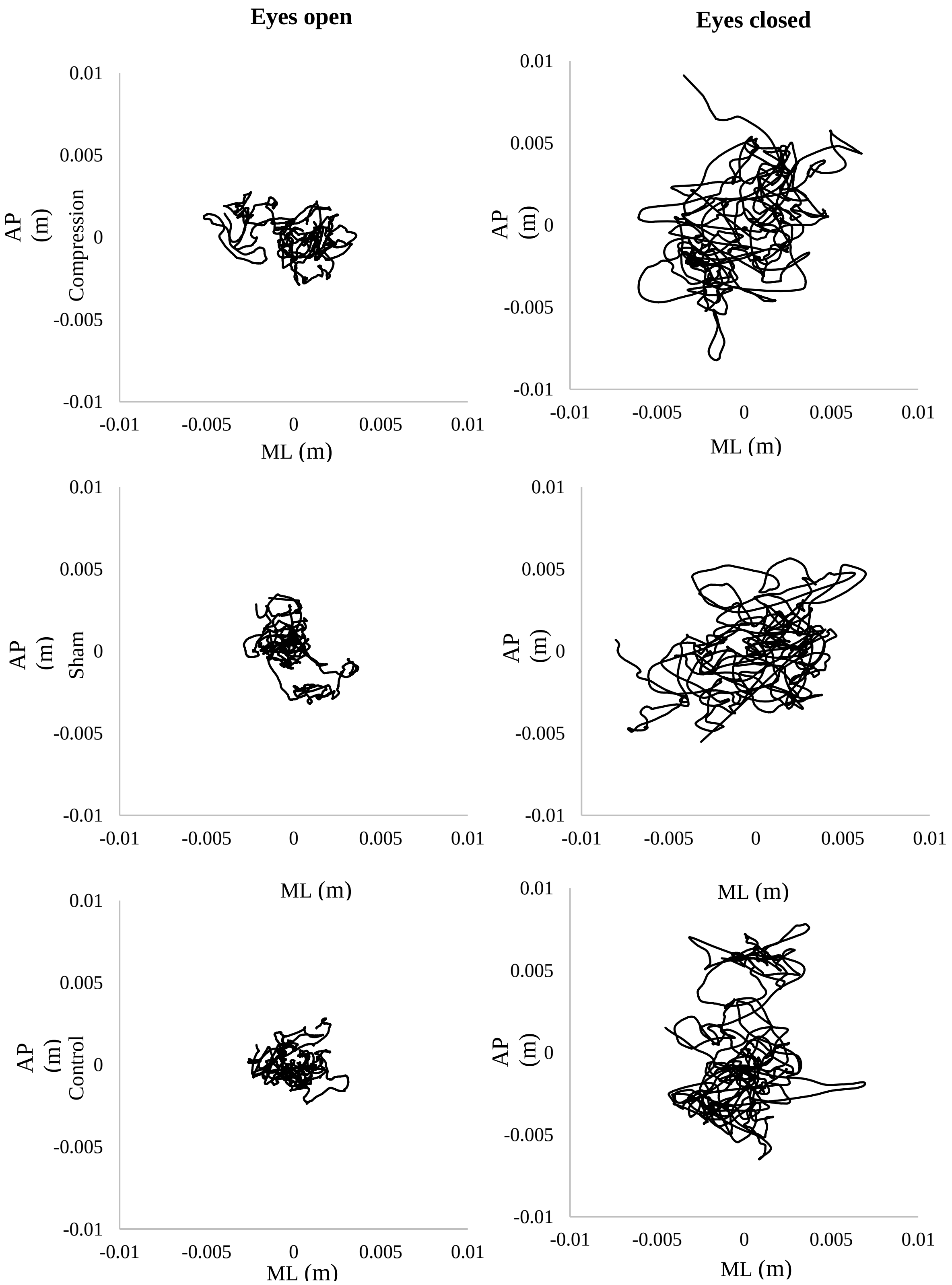

Figure 4.1 COP path length differences between EO and EC performances for the entire sample group across compression, sham and control conditions. EO performances demonstrate greater stability than EC performances due to less moment forces in anterior-posterior (AP) and medio-lateral (ML) directions.

Table 4.2 Comparison of survey responses by garment condition.

	Restriction	**Support**	**Stable**	**Comfort**	**Enjoyment**	**Influence**	**Preference**
NG	4 ± 0	4 ± 0	4 ± 0	3.28 ± 0.88	3.5 ± 0.90	3.5 ± 0.73	71%
Sham	4 ± 0	4 ± 0	4 ± 0	4.57 ± 0.72	5 ± 0.65	3.85 ± 0.34	
CG	3.57 ± 0.97	5.28 ± 0.79	5.35 ± 0.81	4.42 ± 1.34	4.35 ± 1.23	3.78 ± 1.26	29%

Data represents mean ± SD. Survey ratings were scored from 1 (strongly disagree) to 7 (strongly agree). Restriction, refers to feeling restricted (stiff) during movement. Support, lower limbs feel supported (i.e. musculature feels protected from the testing condition). Stable, feeling stable when balancing. Comfort, did participants find the condition comfortable. Enjoyment, feelings of enjoyment/interest of the testing condition. Influence, did participants feel like the testing condition influenced/impacted their performance. Preference, did participants prefer wearing the testing condition rather than the control condition for training environments.

CHAPTER 5. DISCUSSION

Passively stimulating the somatosensory system with CGs has been found to elicit improved movement patterns. However, such improvements are yet to be shown within the context of balance performance. The primary aim of this research was to investigate whether the wearing of CGs used in sport and exercise, affect an individual´s ability to balance during dynamic and static conditions compared to regular training shorts and a sham condition. The current findings supported the null hypothesis as there were no significant differences observed between garment conditions for the vertec jump, stabilometer, hurdle jump, Y-balance test and single leg balance tests. Despite this result, participants reported favourable perceptions of feeling stable and supported when wearing CGs compared to the no garment and sham conditions. However, a majority of the participants reported a preference for wearing regular training shorts rather than CGs.

5.1 Dynamic jump landing tasks

The results of the current study indicate that CGs did not impact dynamic balance and the ability to stabilise faster in the DPSI and TTS measures for both the vertec and hurdle jumping tasks. These findings corroborate those of Cavanaugh et al. (2015), who also examined the effect of an externally applied compression device with jump landing balance performance. They found no COP excursion length differences during an anterior drop-landing, from a platform of 50 cm whilst wearing a knee compressive sleeve (NP), KT and training shorts. Together, these findings suggest that CGs do not provide or stimulate sufficient somatosensory feedback to improve stabilisation following rapid loading, dynamic landing tasks.

Despite evidence to suggest CGs do not enhance landing stability, previous research has demonstrated the use of CGs to reduce peak forces during dynamic landing tasks. For instance, when athletes wore a graduated compression stocking from the mid-foot to below knee (20-30 mmHg at ankle), there were reductions in GRFs upon impact when performing a double leg drop jump from a platform of 50 cm (Sambaher et al., 2016). Further, Maeda et al. (2016) found reductions in vertical GRFs when wearing a soft ankle brace in an experiment similar to the vertec jump in the current study. Though the ankle brace and CG are different types of devices, both are designed to provide prophylactic support and heightened somatosensory feedback (Ghai, 2016). Sambaher et al. (2016) attributed their findings to the elastic properties of the garment eliciting a 'stretch-shortening cycle effect' (SSC).

It is proposed that changes in the SSC while wearing CGs may passively assist ankle ROM to dissipate GRFs and thus promote landing efficiency (Williams et al., 2016). Such an alteration in the SSC is shown in various studies where CGs have altered joint stiffness and improved ROM during dynamic tasks (Cameron, Adams, & Maher, 2008; de Britto et al., 2016; Hasan et al., 2016; Sperlich et al., 2013). In the current study, the notion of enhanced GRF dissipation when landing (Ross, 2014; Williams et al., 2016), is a plausible mechanism for less TTS in the CG condition; however, such an effect was not observed. This finding is not unexpected because attenuation of landing forces by manipulating GRF dissipation and increasing joint ROM would likely increase the time of landing and therefore greater TTS. Thus, whether or not CGs can influence dynamic landing balance may be influenced or determined by the goal of the task; land softly or land and stabilise quickly. Further research examining landing and stabilising kinetics and kinematics with various garment designs is warranted.

It is plausible that within the short wear time, CGs did not influence internal individual capacities such as strength, flexibility and power, which have been found to predict dynamic balance ability (Bruhn et al., 2004; Herman et al., 2008; Myer et al., 2006; Williams et al., 2016). These capacities are required to transition the body's COM from a dynamic state to a static state in a controlled and coordinated manner (Ebben et al., 2010; Ross, 2014). Adaptation in these capacities requires alterations in central nervous system functioning and peripheral muscle pliability (Bruhn et al., 2004; Herman et al., 2008; Myer et al., 2006). The findings of the current study could be further explained by a poor relationship between the applied CG pressure and the primary neuro-motor functions that are utilised to produce dynamic balance. These functions could include the adaptation of muscle stiffness to anticipate and absorb high impact forces, which has been demonstrated to improve balance scores

(McKinley & Pedotti, 1992; Riemann & Lephart, 2002), as well as pre-emptive movement planning which are developed through experience (Magill & Anderson, 2014).

5.2 Balance stabilometer

No significant difference in stabilometer balance performance was observed between the three garment conditions in the current study. As no other published study has examined the effect of CGs on balance stabilometer performance, direct comparison of findings cannot be made. However, the current findings align with Hosp et al. (2017), who found that somatosensory stimulation from the application of KT tape did not elicit improved performance on a biodex balance stabilometer (BSS), compared to a no tape condition. It is possible that the gross movement balance requirements of these tests may extend beyond the effects that CG and KT applied pressures stimulation can provide and may explain the non-significant findings.

During performance on the stabilometer, COM remains within the BOS and participants rely heavily on lower leg muscle strength and coordination to control the tilt limits in a single plane of motion. The participants in the current study were amateur athletes, likely to have developed skill and strength adaptations in the lower limbs, as a result of plyometric movements during training and performing exercises (Fousekis, Tsepis, & Vagenas, 2010; Leong, Fu, & Tsang, 2011). Individuals with these characteristics are believed to have the capacity to learn and control the stabilometer tilt limits relatively quickly (Hinman, 2000; Krkelijas, 2017). As the participant sample in the current study were relatively homogeneous with regard to age and physical activity levels, any learning effect on stabilometer performance was likely consistent across the cohort. Moreover, the balanced randomisation of trial order would wash-out any within-subject learning and therefore, not favour one garment condition over another. Our findings may suggest that balance stabilometer performance is more inclined to the participants physical capacity and motor control learning (Mégrot & Bardy, 2006) with limited influence from somatosensory stimulation from CGs.

5.3 Y-Balance test

In the current study, no significant difference in YBT performance was observed between the three garment conditions. This finding supports that of Cavanaugh et al. (2015) who found no differences in YBT performance when wearing a knee CG sleeve, KT tape and a control condition. Some authors suggest that participants performing the YBT utilise motor control strategies such as feed-forward movement planning (Coughlan et al., 2012) and external focus where the participant can observe their reach distance (Riemann & Schimitz, 2012). This implies that reliance on these internally derived components may be more critical to YBT task performance and success than other elements. As such, the somatosensory stimulus provided by the CGs may not be sufficient to substantially influence these internal components and therefore, performance in the YBT.

To perform well on the YBT, is it suggested that adequate capacities in muscular strength and endurance, neuromuscular control, ROM and flexibility must be attained (Hertel, Miller, & Denegar, 2000). In particular, muscle strength has been found to be a contributing factor in influencing SEBT and YBT scores (Ambegaonkar, Mettinger, Caswell, Burtt, & Cortes, 2014; Robinson & Gribble, 2008). With regards to the SEBT, the anteromedial, medial and posteromedial directions accounted for 62% to 89% of variance of hip and knee flexion strength (Robinson & Gribble, 2008). Whereas for the anterior direction, the vastus lateralis and medialis were most active and for the posterolateral directions, biceps femoris and tibialis anterior were most active (Earl & Hertel, 2001). Additionally, studies have also found core-strengthening programs to be an effective intervention to improve SEBT scores (Filipa, Byrnes, Paterno, Myer, & Hewett, 2010; Imai, Kaneoka, Okubo, & Shiraki, 2014). These studies demonstrate a relationship between muscle strength and YBT performance. Considering there is limited research demonstrating strength enhancements from wearing CGs (MacRae, Laing, & Cotter, 2011), it is unlikely to expect CGs could improve YBT performance on the basis of enhanced strength.

In addition to strength, previous research has found strong correlation between anterior reach distance and ankle dorsi-flexion (Gribble & Hertel, 2003; Hoch, Staton, & McKeon, 2011). Although CGs have been found to influence ROM in some studies, this occurs across various joints with the contribution of other muscle groups (Doan et al., 2003; Hasan et al., 2016; Sperlich et al., 2013). When reaching in the anterior direction in the YBT, ankle-dorsi flexion is predominantly isolated where this motion relies on muscle and tendon flexibility that surround the ankle. Improved ankle ROM requires extended period training intervention and is unlikely to be influenced by wearing a CG. Furthermore, in the current study, CGs were not shown to negatively impact ROM and subsequent performance in the YBT, compared to the other conditions.

Performance scores in both posterior directions in the current study were greater than previous studies (Cavanaugh et al., 2015; Gribble, Mitterholzer, & Myers, 2012). This discrepancy is likely due to the variation in the testing procedures. Participants in other studies have been required to place their hands on their hips throughout the entire protocol (Gribble, Mitterholzer, & Myers, 2012). This action keeps the trunk upright which prevents coordinative support from the upper extremities (Gribble, Mitterholzer, & Myer, 2012). The current study did not constrain participant upper extremities, enhancing coordinative support, which likely allowed an increased reaching capacity.

5.4 Static single-leg balance

There were no differences in COP pathway length between the garment conditions in both EO and EC single leg balance tests. It is commonly believed that when visual feedback is occluded (EC), participants attend to other somatosensory cues to adjust for balance constraints and perturbations (Donath & Faude, 2016; Riemann et al., 2002). This suggests that CGs may provide greater benefit during balancing tasks with the eyes closed. In contrast, the findings of the current study did not demonstrate this effect.

Maeda et al. (2016) also found no differences in static single-leg balance postural sway in both EO and EC performances when comparing ankle braces that were semi-rigid, soft and a no brace condition. When performing a unipedal stance the BOS is more narrow which increases perturbations in ML directions, requiring the ankle to make corrective motion to prevent falling (Jenkins et al., 2014; Qiu et al., 2012). The ankle brace in this case would seem appropriate to stabilise joint mechanics along with tactile feedback to help prevent ML motion. However, no changes in balance performance were observed between the conditions (Maeda et al., 2016).

Conversely, the current findings contradict Michael et al. (2014), who found significant improvements in COP excursion and range when participants had their EC while wearing CGs as opposed to control and sham conditions. Why CGs were more effective in improving SLB performance in their study may be due to differences in the research design. Participants in Michael et al. (2014) held a static SLB position for 60 seconds, whereas in the current study participants balanced for a maximum of 20 seconds. Balancing for an extended period of time may have afforded participants greater opportunity to receive, interpret and process tactile feedback and thus, perform better corrective action. Unfortunately, Michael et al. (2014) did not measure and report CG pressures. This limits comparison with the current study as it cannot be distinguished whether their participants received greater garment pressure and therefore, greater somatosensory stimulation, which contributed to their improved EC performance.

On the other hand, plantar surface stimulation may be a more appropriate method to improve SLB performance. Previous research has found that when textured insoles were applied below the feet, postural sway was reduced in both younger and older participants in EO and EC static SLB performances. These results were more pronounced when participants were balancing on a foam mat, which induced greater perturbations (Corbin et al., 2007; Qiu et al., 2012). Researchers suggest that plantar mechanoreceptor stimulation enhances COP distribution information, therefore improving the execution of accurate postural adjustments (Qiu et al., 2012). It could therefore be argued that the stimulation of plantar mechanoreceptors provides more valuable information for CNS processing than the cutaneous stimulation applied to the leg by the CGs. However, this assertion would require further investigation before any conclusions can be drawn.

Irrespective of the condition, the current study demonstrated noticeable COP length differences (Figure 4.1) between EO and EC SLB performances. Though not statistically analysed, the current findings align with other studies who have repeatedly shown that occluded vision affects COP sway, range and time to stabilise following perturbations in both young adults and seniors (Corbin et al., 2007; Donath et al., 2013; Qiu et al., 2012). For adequate static balance, visual information is considered to be the most critical in comparison to other sensory input (Donath & Faude, 2016). Consequently, the degree of stimulation and somatosensory effect provided by CGs may be insufficient to provide a meaningful effect on balance performance.

5.5 Perceptual markers

Within the current study, most participants reported feeling more stable and supported when wearing CGs compared to the other conditions, with four participants noting increased support around the knee (Appendix K). The CGs and applied pressures were therefore adequate to provide a majority of participants with a perceived mechanical support effect. These findings are consistent with a previous study where 93.31% of participants felt that the CG was supportive during various sprinting and agility tests (Bernhardt & Anderson, 2005). However, the garment in the comparable study consisted of diagonal bands that provide additional tension to mimic the functional anatomy of the hip region, which was different to the garment design in the current study. Further, Bernhardt and Anderson (2005) noted that their garment consisted of elastic materials, similar to Doan et al. (2003), which contain more neoprene characteristics and resistance to increased range of motion. Comparisons of applied pressures cannot be made as these previous studies did not measure CG pressure. The more resistive material and garment design may explain why there were higher ratings of support in Bernhardt and Anderson's (2005) study. Perceptions of improved stability without a proven effect may demonstrate a placebo effect. Such perception of stability may have beneficial implications for assisting sport performance and rehabilitation from injury (Armatas, Chondrou, Yiannakos, Galazoulas, & Velkopoulos, 2007).

Regardless of improved perception of support and stability, participants did not rate the CG to have a beneficial influence on their performance. This is possibly due to wearer acceptability and comfort as 10 of the 14 participants reported a preference for wearing their training shorts instead of the CGs (see Appendix K). Additionally, four participants rated the CG to be slightly uncomfortable and unenjoyable to wear (see Appendix I). A further complaint from numerous participants was related to the initial donning of the CG, whereby two participants reported "putting them on was a pain" and "it would be cumbersome having to do it all the time" (see Appendix K). Previous research has also found that participants who reported CGs to be uncomfortable also perceived their performance to be hindered (Bernhardt & Anderson, 2005). Conversely, the researchers also found associations between participants who felt the garment to be comfortable also perceived their performance to be enhanced (Bernhardt & Anderson, 2005). These favourable or unfavourable perceptions may be due to participant familiarity with wearing of tight clothing. Nonetheless, it may be important for manufacturers to achieve an appropriate mix of comfort and applied pressure when constructing garments, as this may alter self-efficacy during performance.

Participants in the current study did not report a change in perceived exertion whilst wearing CGs (see Appendix J). This finding is consistent with previous studies that have found no RPE changes in runners (Ali, Caine, & Snow, 2007), triathlon athletes (Del Coso et al., 2014) and cross-country skiers (Sperlich, Born, Zinner, Hauser, & Holmberg, 2014). Conversely, other studies have found participants to report lower RPE's during performance (Kraemer et al., 1998; Rugg & Sternlicht, 2013; Sperlich et al., 2014). The disparity may be attributed to research design as the aforementioned studies incorporated repeated CMJs, submaximal and maximal running in the experiment (Kraemer et al., 1998; Rugg & Sternlicht, 2013; Sperlich et al., 2014). These plyometric exercises are suggested to induce greater muscle soreness which results from eccentric contractions and higher impact GRFs (Sperlich et al., 2013). Compression garments have been found to reduce muscle damage and increase muscle efficiency during performance (Borràs et al., 2011; Sperlich et al., 2013; Wang et al., 2013; Valle et al., 2013). Therefore, it is plausible that the relatively low intensity balance tasks in the current study would not have allowed the participants to perceive a notable difference across the garment conditions.

There were no reported perceptual differences between the sham and no garment condition for stability, support and restriction. This sham condition, whereby sports tape strips were lightly applied to the quadriceps and calf muscles, is unlikely to have provided any discernible effect compared to the CG and no garment conditions. On that basis, the sham condition has performed according to its intended use. That is, to compare inactive treatment with an active treatment. However, some researchers believe a true sham condition should mimic the treatment condition, without applying the effect. For example, Hooper et al. (2015) used a sham CG that looked similar to the testing CG, and elicited some pressure. In addition, a CG sham condition that applies some pressure for direct comparisons is believed to allow for a more accurate assessment and further knowledge of the psychological effects of wearing CGs (MacRae, Laing, & Partsch, 2016). Nonetheless, with no performance or perceptual differences found between garment conditions in the current study, a performance enhancing placebo effect was not shown.

5.6 General discussion

Several researchers have suggested that CGs increase cutaneous stimulation of tactile mechanoreceptors and enhance proprioception (Donath & Faude, 2016; Hasan et al., 2016; Lien et al., 2014). It is believed that lesser skilled athletes could benefit from enhanced mechanoreceptor feedback as they may be less attuned to their intrinsic feedback systems (Donath & Faude, 2016). Conversely, enhanced mechanoreceptor feedback is thought to have less of an effect on higher skilled athletes because of more highly developed proprioceptive acuity (Ashton-Miller et al., 2001; Han, Anson, Waddington, & Adams, 2014). There is some evidence to support this proposition whereby lesser skilled athletes had improved their kicking technique (Hasan et al., 2016) and kicking accuracy (Lien et al., 2015) when wearing CGs, compared to more highly skilled counterparts. In contrast, the amateur level sporting population examined in the current study did not demonstrate performance improvement from wearing a CG in any balance test. This outcome suggests the usefulness of enhanced somatosensory feedback from wearing CGs may be task dependent.

It is possible the mean CG pressure applied within the current study was not sufficient to adequately stimulate mechanoreceptor feedback for balance improvement to occur. There is a belief that CGs with neoprene or rubber characteristics may be better to suited to achieve improved performance outcomes due to increased applied pressure. Several studies are reported to have used these garment types (Cameron, Adam, & Rogers, 2008; Doan et al., 2003; Pearce, Kidgell, Grikepelis, & Carlson, 2009; Sperlich et al., 2013). Of these investigations, only Sperlich et al. (2013) reported improved movement patterns when participants wore a pair of medium and high-grade CG shorts and calf sleeve. The medium grade pair applied mean pressures of 20 mmHg on the calf and thigh, while the high grade applied 40 mmHg on the calf and thigh (Sperlich et al., 2013). Mean CG pressures applied in the current study were 13 ± 1.64 mmHg on the calf and 9.28 mmHg ± 0.45 on the thigh. To date, there is insufficient research with stated garment pressures to conclude whether or not a relationship exists between the magnitude of CG pressure and performance improvement, especially in relation to balance.

Failure to demonstrate improved balance performance in the current study may be due to the degree of difficulty presented by each balance test. That is, participants may not have been sufficiently challenged to necessitate referral to and utilisation of increased mechanoreceptor feedback. In support of this notion, improvements in balance performance have been demonstrated following fatigue inducing interventions when participants wore KT tape (Hosp et al., 2017) and a soft-rigid brace (Shaw, Gribble & Frye, 2008), compared to no device control conditions. Further, the effects of fatigue have been found to reduce participant proprioception, the ability to differentiate movement speeds and consequently lead to poorer movement patterns (Hooper et al., 2014).

The findings of both Hosp et al. (2017) and Shaw, Gribble and Frye (2008) suggest that these external devices may be more effective when sensory awareness is diminished from fatigue. Similarly, external devices such as CGs may be more effective when sensory awareness is diminished due to injury (Donath & Faude, 2016; Jung, Kim, & Park, 2013) or in the elderly who experience sensory degradation from the effects of aging (Woo et al., 2014). The idea that CGs may be more effective at improving balance when the task is more demanding, there is increased system fatigue, or the population has initial balance performance deficiency (the aged, injured, or diseased) is under-explored in the literature and warrants further investigation.

5.7 Limitations and future recommendations

There are several limitations affecting the current study that need to be considered. First, the recruited population consisted of healthy young men who regularly participated in a diverse range of sports and exercise activities. This included: soccer, rugby league, combat sports, basketball and general health and fitness activity such as jogging, swimming and weight training. According to Hrysomallis (2011), athletes develop static and dynamic balance specific to their sport. Therefore, the findings of the current study are limited to this sample population and not generalizable to the broader population.

The diversity in sporting / exercise background may have decreased the homogeneity of the cohort, generated inconsistency in their ability to perform the balance tasks, which could have confounded the findings. This may have had an impact on the data collected in the current study as the balance tests may not have been compatible with the participant's sporting background. Future research should select or group participants of specific sporting backgrounds for data homogeneity. Moreover, a larger participant sample and the inclusion of an increased number of participants including both sexes, the elderly, various sport and exercise backgrounds and those that are injured would allow for greater analysis of comparisons and increase the generalisability of the research.

Second, the laboratory-based tests administered in the current study are relatively low in ecological validity. Adjustment to the research design to include balance capacities required in activities of daily living, sport, and exercise performance would allow for a more valid and applicable assessment of the effects of CGs on balance (Ghai, 2016; Hooper et al., 2015; Maeda et al., 2016). Further, the inclusion of a fatiguing protocol to assess whether CGs provide a beneficial balance effect when there is elevated systemic stress would improve the empirical assessment of wearing CGs on balance. Furthermore, implementing dual-tasks in the experimental design would also improve the ecological validity as full conscious attention on balance is not entirely allocated during most tasks of daily living, and many sporting and exercise contexts (Masters & Maxwell, 2008).

Previous research has shown participants to be more efficient in their movement by displaying lower levels of adductor muscle activity when wearing CGs during an unanticipated cutting manoeuvre (Chaudhari, Jamison, McNally, Pan, & Schmitt, 2014) and rectus femoris muscle activity during fatigue-induced leg presses (Fu, Liu, Zhang, Xiong, & Wei, 2012), compared to no garment conditions. On that basis, comprehensive assessment of balance performance should include measures of motion and also include determinants of efficiency. Therefore, the concurrent collection of muscle activation data via electromyography and movement kinetics and kinematics will further our understanding of the effect CG applied pressures have on neuromuscular control and motor output.

It is common for studies to measure the immediate effects of CGs. As a result, it is unknown whether garment pressure gradients reduce after repetitive wear and whether this has an impact on performance (MacRae, Laing, & Partsch, 2016). In addition, it remains unknown whether balance enhancing effects from wearing CGs are related to user familiarity and regular, ongoing use. That is, there may be a learning effect associated with receiving and using the mechanoreceptor and proprioceptive feedback believed to be supplied by CGs. Therefore, the execution of studies examining the effects of medium to long term use of CGs are recommended.

Lastly, participants in the current study only used their dominant leg in single leg balance tasks. Thus, the findings can only be generalised to dominant leg balance performance. Previous research has found altered kinetics and kinematics when participants wore prophylactic devices and tested their non-dominant legs, in comparison to their dominant leg performance (de Britto et al., 2016; Maeda et al., 2016). Therefore, future research should consider assessing the effect of wearing CGs on balance performance bi-laterally to comprehensively determine their efficacy in enhancing dynamic and static balance.

CHAPTER 6. CONCLUSION

A thorough search of the relevant literature suggests this was the first study to investigate the effects of full leg-length CGs across a range of dynamic and static balance tests. The findings demonstrated that CGs did not enhance or hinder static or dynamic balance performance compared to a no garment and sham condition. When surveyed, a majority of participants reported favourable perceptions of stability and support when wearing CGs, however most indicated a preference for wearing regular training clothes than CGs. The results of this study provide further evidence to consumers that, contrary to manufacturer claims, the wearing CGs are unlikely to improve balance performance, thus enabling more informed purchase decisions. Future studies examining the effects of CGs on balance performance in more demanding and applied contexts, in the presence of fatigue, and in populations with balance performance deficiencies (the aged, injured, or diseased) are necessitated.

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CHAPTER 8. APPENDICES

Appendix A: Invitation to Participants

WESTERN SYDNEY
UNIVERSITY

School of Science and Health

Sporting accessories and skill acquisition

Invitation for participants

Dear potential participant,

We, the researchers listed below, would like to extend an invitation for you to participate in a research project we are undertaking titled *"The effectiveness of compression garments on various balance protocols".*

Participation in this study will involve initially passing a pre-health screening questionnaire. Then performing tasks would involve jumping and landing, single leg standing, standing on a balance stabilometer and multi-directional reaching with your leg. These tests will be repeated in three conditions. There will be a recovery period in between performances in order to repeat the tasks sustainably.

If you are a current male over the age of 18, playing a recreational sport that involves and averaging three to ten hours a week of practice, you are acceptable for the study. However, if you currently/or have previously played at a higher-grade/division other than a recreational level within the past five years, you will be excluded from the study as the researchers are targeting a specific athletic ability. Further, to control for previous experience influences, those who have worn compression garments fortnightly within the past year will be excluded. Finally, if you have had an ankle sprain, patellar or Achilles tendon pain, shin soreness, torn muscle or anterior cruciate ligament tear within this past six months, you will be excluded from the study for safety concerns.

Testing will be performed indoors in a laboratory at the Campbelltown Campus of Western Sydney University. It is anticipated that your involvement in this investigation will require 2 hours of your time. Please contact either of the researchers listed below for further information or to register your interest in participating.

Thank you for your consideration,

Mr Nathan Washington

Researchers:

- Mr Nathan Washington, Western Sydney University (Email: n.washington@westernsydney.edu.au)
- Dr. Kylie Steel, Western Sydney University (Ph: +61 2 4736 0589; Email: k.steel@westernsydney.edu.au)
- Dr. Peter Clothier, Western Sydney University (Ph: +61 2 4736 0589; Email: p.clothier@westernsydney.edu.au

Appendix B: Pre-exercise health screen

WESTERN SYDNEY
UNIVERSITY

School of Science and Health

The effectiveness of compression garments on various balance protocols

Pre-Exercise Health Screening

The information provided in the answers of this health screen is required by the researchers to assess your suitability for participation in the research project titled "The effectiveness of compression garments on dynamic balance". If you do not understand a question please do not hesitate to contact either of the researchers who are listed on the information for participation sheet.

PLEASE ANSWER ALL QUESTIONS HONESTLY

Date of Birth: / /	**Sex:** Male / Female
Height:	**Weight:**

Researchers Only

Subject code: __________

Group:

Have you previously worn compression garments regularly within the past year?

No Yes

If yes, briefly describe how often you have worn them.

____

Section 1 – Signs and Symptoms

1. Has your doctor ever told you that you have a heart condition or have you ever suffered a stroke? (Please Circle)

   No Yes

2. Do you ever experience unexplained pains in your chest at rest or during physical activity/exercise?

   No Yes

3. Do you ever feel faint or have spells of dizziness during physical activity/exercise that causes you to lose balance?

   No Yes

4. Do you have any diagnosed muscle, bone or joint problems that you have been told could be made worse by participating in physical activity/exercise?

   No Yes

   If yes, provide details. If no, leave blank.

____

____

____

5. Do you have any other medical condition(s) that may make it dangerous for you to participate in physical activity/exercise?

   No Yes

If yes, provide details. If no, leave blank.

____

____

____

Section 2 – Risk Factors

1. Do you have a family history of heart disease (e.g.: stroke, heart attack)? That is has your father, mother, brother, sister had a stroke/heart attack?

No Yes

If you answered YES to the previous question, what is/are the gender(s) and age(s) of the relative(s) with heart disease?

Male > 55 Male < 55
Female > 65 Female < 65

2. Do you smoke cigarettes on a daily or weekly basis, or have you quit smoking in the last? 6 months?

No Yes

If you answered YES to the previous question, how many cigarettes do you currently or did smoke per day / week?

Please provide details below.

____

____

____

3. Which statement best describes your current physical activity / exercise level?

Sedentary Light
Moderate Vigorous

4. Have you participated (within the past five years) in a higher grade/division other than recreational level?

No Yes

5. Are you currently or have participated in any sports at recreational club level?

No Yes

If yes, provide details of sporting club

____

6. How many training sessions do you usually do each week?

____

7. How many minutes of exercise / physical activity do you usually do each week?

____

8. How long have you been continuously participating in the above activity?

__________ years __________ months __________ weeks

9. Have you spent time in hospital (including day admission) for any medical condition/illness/injury during the last 12 months?

No Yes

If yes, please provide details below. If no, leave blank.

____

____

____

12. Are you pregnant or have you given birth within the last 12 months?

No Yes

If yes, please provide details below. If no, leave blank.

____

____

____

13. Do you have any muscle, bone or joint pain or soreness that is made worse by particular types of activity?

No Yes

If yes, please provide details below. If no, leave blank.

____

____

____

14. Have you previously sustained any leg injury (sprains, broken bones, muscle damage etc.)?

No Yes

If yes, please provide details below. If no, leave blank.

____

____

____

15. Does this injury still cause pain or influence your performance during exercise/sport?

No Yes

If yes, please provide details below. If no, leave blank.

____

____

____

16. Do you currently have any injury or illness that you believe may exclude you from participation in this study?

No Yes

If yes, please give details

____

____

____

17. I believe that to the best of my knowledge, all of the information I have supplied within this survey is correct.

No Yes

Declaration:

I, ____ have completed all questions honestly and to the best of my knowledge. I will inform one of the researchers if there are any changes in my health or injury status which may impact on my ability to participate in the study "The influence of compression garments on balance performance".

Participant signature: ___________________________________

Participant name: __________________________________

Date: _____________________

Appendix C: Consent form

WESTERN SYDNEY
UNIVERSITY

Consent Form – General

Project Title: The effectiveness of compression garments on various balance protocols

I hereby consent to participate in the above-named research project.

I acknowledge that:

- I have read the participant information sheet (or where appropriate, have had it read to me) and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s
- The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

I consent to:

☐ *Participating in human movement tasks specific to the research*

I consent for my data and information provided to be used in this project and other related projects for an extended period of time.

I understand that my involvement is confidential and that the information gained during the study may be published and stored for other research use but no information about me will be used in any way that reveals my identity.

I understand that I can withdraw from the study at any time without affecting my relationship with the researcher/s, and any organisations involved, now or in the future.

Signed:

Name:

Date:

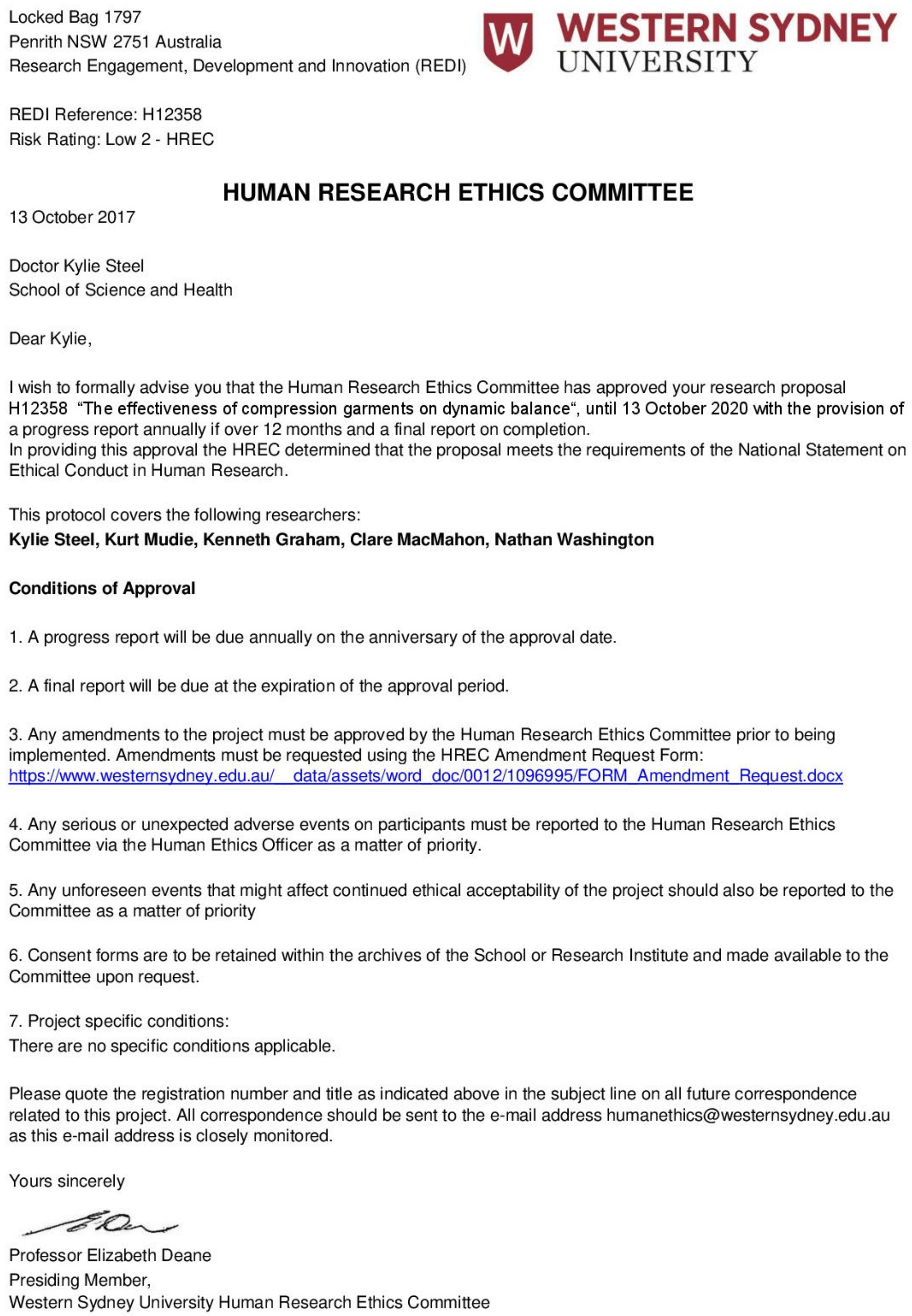
This study has been approved by the Human Research Ethics Committee at Western Sydney University. The ethics reference number is: H12358

What if I have a complaint?

If you have any complaints or reservations about the ethical conduct of this research, you may contact the Ethics Committee through Research Engagement, Development and Innovation (REDI) on Tel +61 2 4736 0229 or email humanethics@westernsydney.edu.au.

Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix D: Ethical approval



Locked Bag 1797
Penrith NSW 2751 Australia
Research Engagement, Development and Innovation (REDI)

WESTERN SYDNEY
UNIVERSITY

REDI Reference: H12358
Risk Rating: Low 2 - HREC

HUMAN RESEARCH ETHICS COMMITTEE

13 October 2017

Doctor Kylie Steel
School of Science and Health

Dear Kylie,

I wish to formally advise you that the Human Research Ethics Committee has approved your research proposal H12358 "The effectiveness of compression garments on dynamic balance", until 13 October 2020 with the provision of a progress report annually if over 12 months and a final report on completion.
In providing this approval the HREC determined that the proposal meets the requirements of the National Statement on Ethical Conduct in Human Research.

This protocol covers the following researchers:
Kylie Steel, Kurt Mudie, Kenneth Graham, Clare MacMahon, Nathan Washington

Conditions of Approval

1. A progress report will be due annually on the anniversary of the approval date.

2. A final report will be due at the expiration of the approval period.

3. Any amendments to the project must be approved by the Human Research Ethics Committee prior to being implemented. Amendments must be requested using the HREC Amendment Request Form:
https://www.westernsydney.edu.au/__data/assets/word_doc/0012/1096995/FORM_Amendment_Request.docx

4. Any serious or unexpected adverse events on participants must be reported to the Human Research Ethics Committee via the Human Ethics Officer as a matter of priority.

5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the Committee as a matter of priority

6. Consent forms are to be retained within the archives of the School or Research Institute and made available to the Committee upon request.

7. Project specific conditions:
There are no specific conditions applicable.

Please quote the registration number and title as indicated above in the subject line on all future correspondence related to this project. All correspondence should be sent to the e-mail address humanethics@westernsydney.edu.au as this e-mail address is closely monitored.

Yours sincerely

Professor Elizabeth Deane
Presiding Member,
Western Sydney University Human Research Ethics Committee

Appendix E: Subjective measures questionnaire

12/13/2018 Qualtrics Survey Software

Garment (a) exp survey

Please select an answer that best describes your perceived level of exertion of the task.

- ○ 6 -
- ○ 7 - Very very light
- ○ 8
- ○ 9 - Very light
- ○ 10
- ○ 11 - Fairly light
- ○ 12
- ○ 13 - Somewhat hard
- ○ 14
- ○ 15 - Hard
- ○ 16
- ○ 17 - Very hard
- ○ 18
- ○ 19 - Very Very hard
- ○ 20

Did you feel any restriction in your movement when wearing this condition?

Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
○	○	○	○	○	○	○

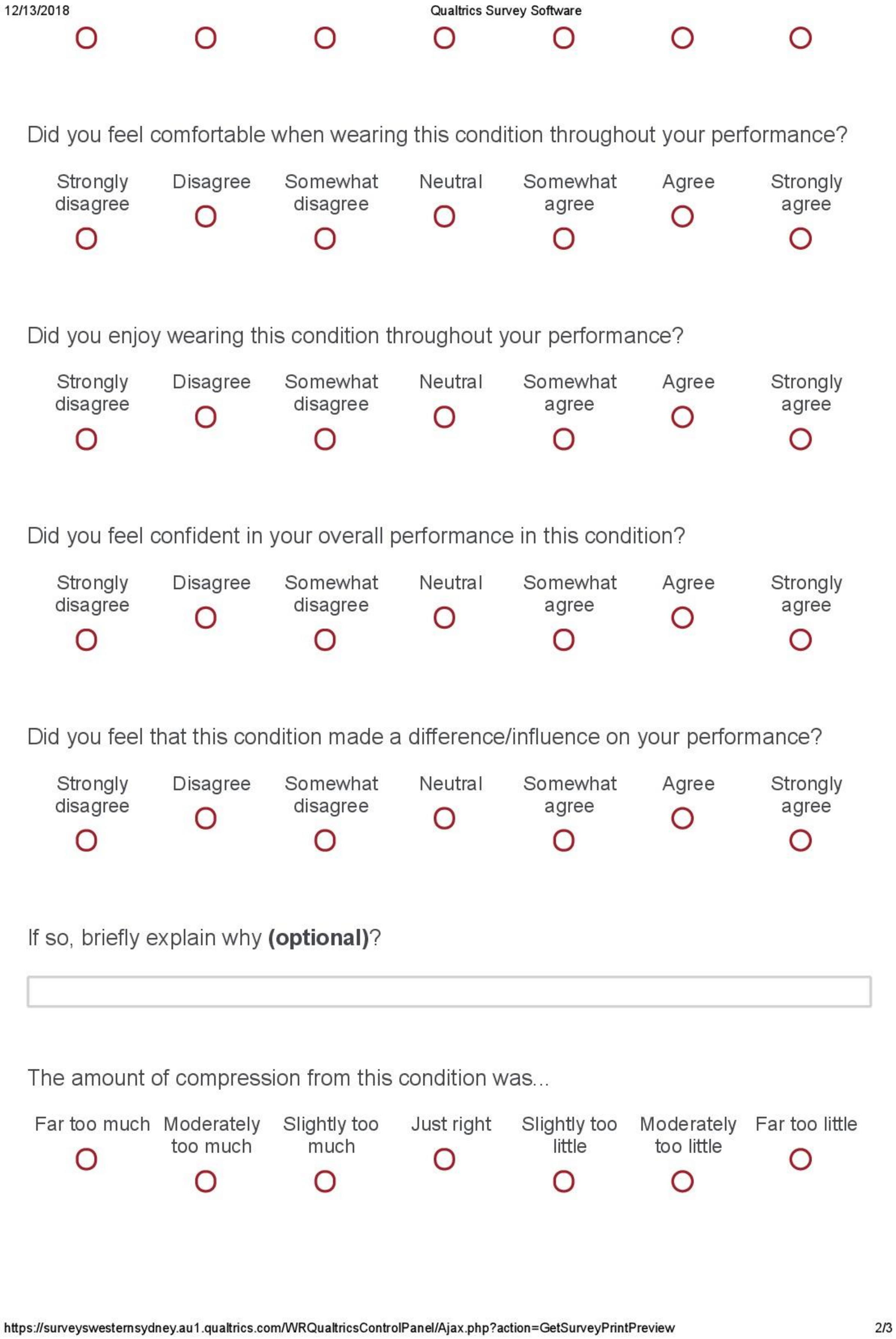
Did you feel that this condition provided support to your limbs?

Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
○	○	○	○	○	○	○

Did you feel stable in your movements when wearing this condition?

Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

https://surveyswesternsydney.au1.qualtrics.com/WRQualtricsControlPanel/Ajax.php?action=GetSurveyPrintPreview 1/3



○	○	○	○	○	○	○

Did you feel comfortable when wearing this condition throughout your performance?

Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
○	○	○	○	○	○	○

Did you enjoy wearing this condition throughout your performance?

Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
○	○	○	○	○	○	○

Did you feel confident in your overall performance in this condition?

Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
○	○	○	○	○	○	○

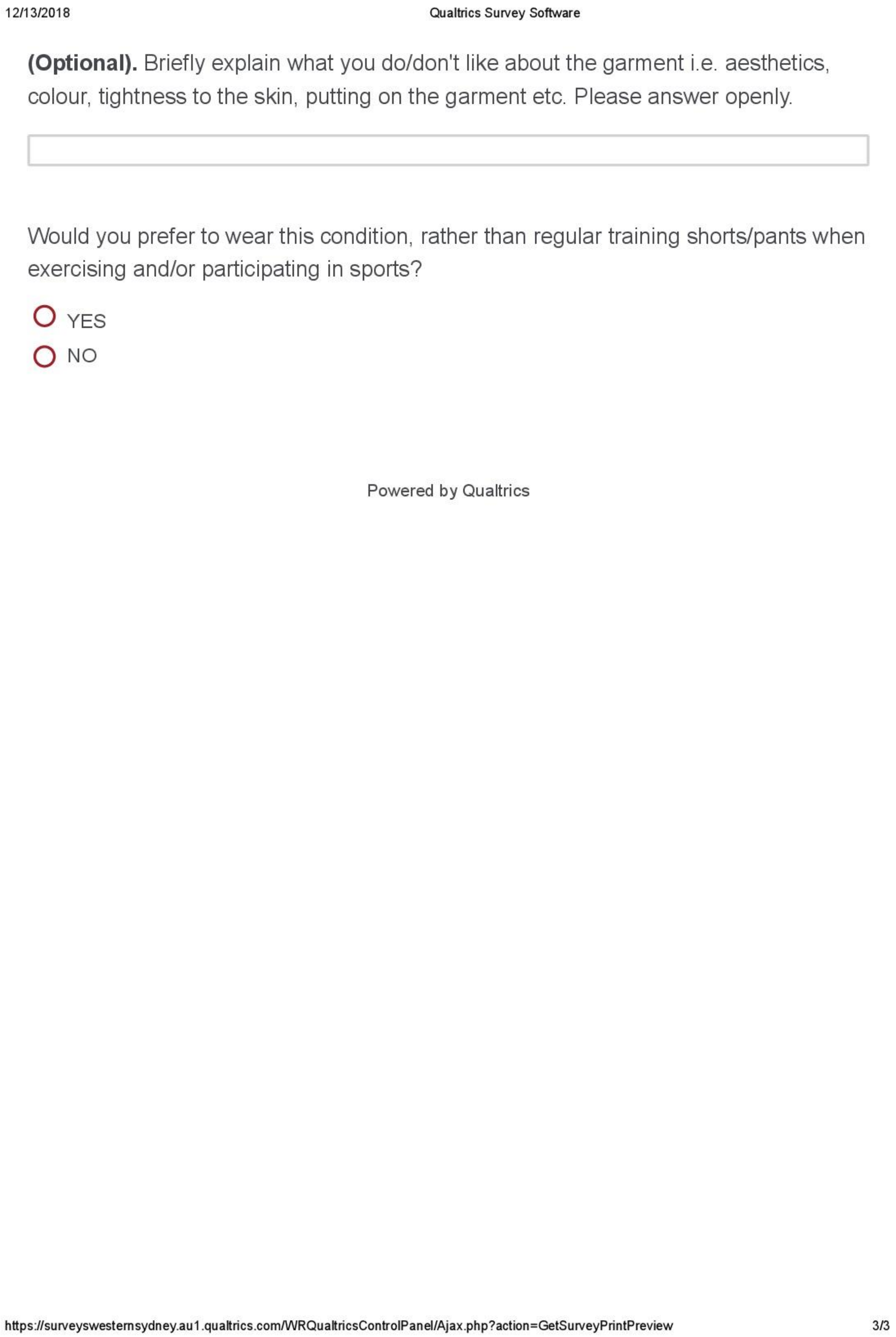
Did you feel that this condition made a difference/influence on your performance?

Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
○	○	○	○	○	○	○

If so, briefly explain why **(optional)**?

The amount of compression from this condition was...

Far too much	Moderately too much	Slightly too much	Just right	Slightly too little	Moderately too little	Far too little
○	○	○	○	○	○	○



12/13/2018 Qualtrics Survey Software

(Optional). Briefly explain what you do/don't like about the garment i.e. aesthetics, colour, tightness to the skin, putting on the garment etc. Please answer openly.

Would you prefer to wear this condition, rather than regular training shorts/pants when exercising and/or participating in sports?

○ YES
○ NO

Powered by Qualtrics

https://surveyswesternsydney.au1.qualtrics.com/WRQualtricsControlPanel/Ajax.php?action=GetSurveyPrintPreview 3/3

Appendix F: MATLAB scripts

COP LENGTH

```
%% Import data from text file.
% Script for importing data from the following text file:
%
%    E:\NATHAN\SAMPLE FOR STATIC BALANCE.txt
%
% To extend the code to different selected data or a different text file,
% generate a function instead of a script.

% Auto-generated by MATLAB on 2019/01/29 10:37:28

%% Initialize variables.
filename = 'E:\DATA COLLECTION\.txt';
delimiter = '\t';
startRow = 20;

%% Format for each line of text:
%   column1: double (%f)
%   column2: double (%f)
%   column3: double (%f)
%   column4: double (%f)
%   column5: double (%f)
%   column6: double (%f)
%   column7: double (%f)
%   column8: double (%f)
%   column9: double (%f)
% For more information, see the TEXTSCAN documentation.
formatSpec = '%f%f%f%f%f%f%f%f%f%[^\n\r]';

%% Open the text file.
fileID = fopen(filename,'r');

%% Read columns of data according to the format.
% This call is based on the structure of the file used to generate this
% code. If an error occurs for a different file, try regenerating the code
% from the Import Tool.
dataArray = textscan(fileID, formatSpec, 'Delimiter', delimiter, 'TextType', 'string', 'EmptyValue', NaN,
'HeaderLines' ,startRow-1, 'ReturnOnError', false, 'EndOfLine', '\r\n');

%% Close the text file.
fclose(fileID);

%% Post processing for unimportable data.
% No unimportable data rules were applied during the import, so no post
% processing code is included. To generate code which works for
% unimportable data, select unimportable cells in a file and regenerate the
% script.

%% Allocate imported array to column variable names
abstimes = dataArray{:, 1};
Fx = dataArray{:, 2};
Fy = dataArray{:, 3};
Fz = dataArray{:, 4};
Mx = dataArray{:, 5};
My = dataArray{:, 6};
```

```
Mz = dataArray{:, 7};
Ax = dataArray{:, 8};
Ay = dataArray{:, 9};

%% Clear temporary variables
clearvars filename delimiter startRow formatSpec fileID dataArray ans;

%% Convert Fz
Fz1 = Fz - mean(Fz(1:20));
% Peak magnitude of force across x, y and z planes
Fz_pk = max(Fz1) - mean(Fz1(1:20),1);
Fz_pk_time = abstimes(Fz1==max(Fz1));
BW = mean(Fz1(15000:16000));

%% Identify GNDcontact
tolerance = mean(Fz(1:20),1)+10;
I = Fz>tolerance;
tGND = abstimes(find(I,1));
B = Fz>BW;
tBW = abstimes(find(B,1));
%%COPmeasures
Ax1 = -Mx./Fz1;
OutAx = filloutliers(Ax1,'clip');
Ay1 = My./Fz1;
OutAy = filloutliers(Ay1,'clip');
axfilt = lowpass(OutAx,10,1000);
ayfilt = lowpass(OutAy,10,1000);
%Linear length
Ax2 = axfilt(1:5000);
Ay2 = ayfilt(1:5000);

Ax0 = Ax2 - mean(Ax2);
Ay0 = Ay2 - mean(Ay2);

COPlength = sqrt(((sum(abs(diff(Ax0)))).^2)+(sum(abs(diff(Ay0)))).^2);
afilt = table(axfilt,ayfilt);

%%Graphs
figure(1)
subplot(3,1,1)
plot(OutAx)
subplot(3,1,2)
plot(OutAy)
subplot(3,1,3)
plot(Fz)

figure(2)
subplot(2,1,1)
plot(Fx,Fy)
hold on
xlabel('Fx')
ylabel('Fy')
hold off
subplot(2,1,2)
plot(Ax0,Ay0)
hold on
xlabel('Ax0')
ylabel('Ay0')
hold off
```

ALL DYNAMIC VARIABLES AND RMS TTS

```
%% Calculation of Time-to-stabilisation of force data
%Author: Cassandra Thompson, PhD Student Western Sydney University
%email: c.thompson2@westernsydney.edu.au

%% Initialize variables.
filename = 'G:\DATA COLLECTION\.txt';
delimiter = '\t';
startRow = 20;

samprate = 1000;
BW =  %Newtons
baseline = 0; %Newtons

%% Format string for each line of text:
%   column1: double (%f)
%   column2: double (%f)
%   column3: double (%f)
%   column4: double (%f)
% For more information, see the TEXTSCAN documentation.
formatSpec = '%f%f%f%f%[^\n\r]';

%% Open the text file.
fileID = fopen(filename,'r');

%% Read columns of data according to format string.
% This call is based on the structure of the file used to generate this
% code. If an error occurs for a different file, try regenerating the code
% from the Import Tool.
dataArray = textscan(fileID, formatSpec, 'Delimiter', delimiter, 'EmptyValue' ,NaN,'HeaderLines' ,startRow-1,
'ReturnOnError', false);

%% Close the text file.
fclose(fileID);

%% Post processing for unimportable data.
% No unimportable data rules were applied during the import, so no post
% processing code is included. To generate code which works for
% unimportable data, select unimportable cells in a file and regenerate the
% script.

%% Allocate imported array to column variable names
abstimes = dataArray{:, 1};
Fx = dataArray{:, 2};
Fy = dataArray{:, 3};
Fz = dataArray{:, 4};

%% Clear temporary variables
clearvars filename delimiter startRow formatSpec fileID dataArray ans;



%% Convert Fx and Fz to RMS

```

```
FxNorm = Fx - mean(Fx(1:20),1);
FxRMS = rms(FxNorm,500);
FyNorm = Fy - mean(Fy(1:20),1);
FyRMS = rms(FyNorm,500);
FzRMS = Fz - mean(Fz(1:20),1);

%% Identify Coefficient of Variation
%Calculate mean and SD
FxMean = mean(FxRMS(15000:20000),1);
FyMean = mean(FyRMS(15000:20000),1);
FzMean = mean(FzRMS(15000:20000),1);
FxSD = std(FxRMS(15000:20000));
FySD = std(FyRMS(15000:20000));
FzSD = std(FzRMS(15000:20000));
%Calculate Coefficient of variation
FxCoV = FxSD/FxMean
FyCoV = FySD/FyMean
FzCoV = FzSD/FzMean

RMSfigure  = plot(FxRMS)
hold on
plot(FyRMS)
hold off

%% Identify GNDcontact

tolerance = mean(FzRMS(1:20),1)+10;
I = FzRMS>tolerance;
tGND = abstimes(find(I,1));

%% Dynamic postural stability index
DPSI = sqrt((sum((0-FxRMS).^2)+sum((0-FyRMS).^2)+sum((BW-FzRMS).^2))/length(Fz))/BW;

%% TTS - Identify thresholds

%%Calculate MedioLateral Force TTS
%Caluclate threshold limits of Mean Force +- 3SD
UpperFxThresh = FxMean+(FxSD.*3);
LowerFxThresh = FxMean-(FxSD.*3);
tolerance = 500;

%Create a logical array of force data, where: force above and or below threshold limit = 0,
%and force between threshold limits = 1
FxLogic = zeros(size(FxRMS));
FxLogic2 = +((FxRMS > LowerFxThresh) & (FxRMS < UpperFxThresh));
for iiFx = 500:numel(FxRMS)
    if FxRMS(iiFx)>UpperFxThresh
        FxLogic(iiFx) = 0;
    elseif FxRMS(iiFx)<LowerFxThresh
        FxLogic(iiFx) = 0;
    else LowerFxThresh<FxRMS(iiFx)<UpperFxThresh
        FxLogic(iiFx) = 1;
    end
end

%Count Number of consecutuve ones
out = zeros(size(FxLogic));
FxOut = strfind([0,FxLogic(:)'],[0 1]);
```

```
out(FxOut) = strfind([FxLogic(:)',0],[1 0]) - FxOut + 1;

%Force time-to-stabilsation is when force reaches threshold and remains
%within the limits for 0.5seconds
FxTTS = abstimes(out>=500) - tGND

%%Calculate Anteroposterior Force TTS
UpperFyThresh = FyMean+(FySD.*3);
LowerFyThresh = FyMean-(FySD.*3);
tolerance = 500;
FyLogic = zeros(size(FyRMS));
for iiFy = 500:numel(FyRMS)
    if FyRMS(iiFy)>UpperFyThresh
        FyLogic(iiFy) = 0;
    elseif FxRMS(iiFy)<LowerFyThresh
        FyLogic(iiFy) = 0;
    else
        FyLogic(iiFy) = 1;
    end
end

outFy = double(diff([~FyLogic(1);FyLogic(:)]) == 1);
v = accumarray(cumsum(outFy).*FyLogic(:)+1,1);
outFy(outFy == 1) = v(2:end);

FyTTS = abstimes(outFy>=500) - tGND

%%Calculate Vertical Force TTS
UpperFzThresh = FzMean+(FzSD.*3);
LowerFzThresh = FzMean-(FzSD.*3);
tolerance = 500;
FzLogic = zeros(size(Fz));
for iiFz = 500:numel(Fz)
    if Fz(iiFz)>UpperFzThresh
        FzLogic(iiFz) = 0;
    elseif FxRMS(iiFz)<LowerFzThresh
        FzLogic(iiFz) = 0;
    else
        FzLogic(iiFz) = 1;
    end
end

outFz = double(diff([~FzLogic(1);FzLogic(:)]) == 1);
v = accumarray(cumsum(outFz).*FzLogic(:)+1,1);
outFz(outFz == 1) = v(2:end);

FzTTS = abstimes(outFz>=500) - tGND
```

UTOPTTS

```
%% Import data from text file.
% Script for importing data from the following text file:
%
%    G:\csthomp2017\JH_S2_2909317\JH_ 001.txt
%
% To extend the code to different selected data or a different text file,
% generate a function instead of a script.
```

```
% Auto-generated by MATLAB on 2018/05/15 17:29:47

%% Initialize variables.

filename = 'E:\DATA COLLECTION\.txt';
delimiter = '\t';
startRow = 20;

%% Format string for each line of text:
%   column1: double (%f)
%   column2: double (%f)
%   column3: double (%f)
%   column4: double (%f)
%   column5: double (%f)
%   column6: double (%f)
% For more information, see the TEXTSCAN documentation.
formatSpec = '%f%f%f%f%f%f%[^\n\r]';

%% Open the text file.
fileID = fopen(filename,'r');

%% Read columns of data according to format string.
% This call is based on the structure of the file used to generate this
% code. If an error occurs for a different file, try regenerating the code
% from the Import Tool.
dataArray = textscan(fileID, formatSpec, 'Delimiter', delimiter, 'EmptyValue' ,NaN,'HeaderLines' ,startRow-1,
'ReturnOnError', false);

%% Close the text file.
fclose(fileID);

%% Post processing for unimportable data.
% No unimportable data rules were applied during the import, so no post
% processing code is included. To generate code which works for
% unimportable data, select unimportable cells in a file and regenerate the
% script.

%% Allocate imported array to column variable names
abstimes1 = dataArray{:, 1};
Fx1 = dataArray{:, 2};
Fy1 = dataArray{:, 3};
Fz1 = dataArray{:, 4};
Ax = dataArray{:, 5};
Ay = dataArray{:, 6};


%% Clear temporary variables
clearvars filename delimiter startRow formatSpec fileID dataArray ans;

%% Convert Fx and Fz to RMS
FxNorm = Fx1 - mean(Fx1(1:20),1);
FxRMS = rms(FxNorm,500);
FyNorm = Fy1 - mean(Fy1(1:20),1);
FyRMS = rms(FyNorm,500);
FzRMS = Fz1 - mean(Fz1(1:20),1);
% Peak magnitude of force across x, y and z planes
Fx_pk = max(FxRMS) - mean(FxRMS(1:20),1);
Fy_pk = max(FyRMS) - mean(FyRMS(1:20),1);
```

```
Fz_pk = max(Fz1) - mean(Fz1(1:20),1);
Fz_pk_time = abstimes1(Fz1==max(Fz1));
Fx_pk_time = abstimes1(FxRMS==max(FxRMS));
Fy_pk_time = abstimes1(FyRMS==max(FyRMS));
% RFD x, y, z planes


% Periods from Peak:end
FxP2end = FxRMS(Fx_pk_time*1000:end);
FxT2end = (abstimes1(Fx_pk_time*1000:end));
FyP2end = FyRMS(Fy_pk_time*1000:end);
FyT2end = (abstimes1(Fy_pk_time*1000:end));
FzP2end = FzRMS(Fz_pk_time*1000:end);
FzT2end = (abstimes1(Fz_pk_time*1000:end));
% Third-orderpolynomials
Fxpoly = polyfit(FxT2end,FxP2end,3);
FxP2 = polyval(Fxpoly,FxT2end);
Fypoly = polyfit(FyT2end,FyP2end,3);
FyP2 = polyval(Fypoly,FyT2end);
Fzpoly = polyfit(FzT2end,FzP2end,3);
FzP2 = polyval(Fzpoly,FzT2end);

plot(FxP2end)
hold on
plot(FxP2)
hold off

%% Identify GNDcontact

tolerance = mean(FzRMS(1:20),1)+10;
I = FzRMS>tolerance;
tGND = abstimes1(find(I,1));

%% Identify Coefficient of Variation
%Calculate mean and SD
FxMean = mean(FxRMS(15000:20000),1);
FyMean = mean(FyRMS(15000:20000),1);
FzMean = mean(FzRMS(15000:20000),1);
AxMean = mean(Ax(tGND*1000:5000),1);
AyMean = mean(Ay(tGND*1000:5000),1);
FxSD = std(FxRMS(15000:20000));
FySD = std(FyRMS(15000:20000));
FzSD = std(FzRMS(15000:20000));
AxSD = std(Ax(tGND*1000:5000),1);
AySD = std(Ay(tGND*1000:5000),1);
%Calculate Coefficient of variation
FxCoV = FxSD/FxMean;
FyCoV = FySD/FyMean;
FzCoV = FzSD/FzMean;
AxCoV = AxSD/AxMean;
AyCoV = AySD/AyMean;

%% TTS - Identify thresholds

%%Calculate MedioLateral Force TTS
%Caluclate threshold limits of Mean Force +- 3SD
UpperFxThresh = FxMean+(FxSD.*3);
LowerFxThresh = FxMean-(FxSD.*3);
UpperFyThresh = FyMean+(FySD.*3);
```

```
LowerFyThresh = FyMean-(FySD.*3);
UpperFzThresh = FzMean+(FzSD.*3);
LowerFzThresh = FzMean-(FzSD.*3);


%Force time-to-stabilsation is when force reaches threshold
FxTTS = (abstimes1(FxP2 < UpperFxThresh)) + Fx_pk_time - tGND;
%%Calculate Anteroposterior Force TTS
FyTTS = (abstimes1(FyP2 < UpperFyThresh)) + Fy_pk_time - tGND;
FzTTS = (abstimes1(FzP2 < UpperFzThresh)) + Fz_pk_time - tGND;

Fz_pk_time = abstimes1(Fz1==max(Fz1));
Fx_pk_time = abstimes1(FxRMS==max(FxRMS));
Fy_pk_time = abstimes1(FyRMS==max(FyRMS));

figure(1)
subplot(3,1,1)
plot(FxP2end)
hold on
plot(FxP2)
ylabel('Fx')
hold off
subplot(3,1,2)
plot(FyP2end)
hold on
plot(FyP2)
ylabel('Fy')
hold off
subplot(3,1,3)
plot(FzP2end)
hold on
plot(FzP2)
ylabel('Fz')
hold off

figure(2)
subplot(2,1,1)
plot(Fx1,Fy1)
hold on
xlabel('Fx')
ylabel('Fy')
hold off
subplot(2,1,2)
plot(Ax,Ay)
hold on
xlabel('Ax')
ylabel('Ay')
hold off

figure(3)
subplot(2,1,1)
binscatter(Fx1,Fy1)
hold on
colormap(gca,'parula')
xlabel('Fx')
ylabel('Fy')
hold off
subplot(2,1,2)
binscatter(Ax,Ay)
```

```
hold on
colormap(gca,'parula')
xlabel('Ax')
ylabel('Ay')
hold off
```

Appendix G: YBT mean scores

Part.	YBTantCG	YBTantNG	YBTantSH	YBTleftCG	YBTleftNG	YBTleftSH	YBTrightCG	YBTrightNG	YBTrightSH
1	65	62	62	118	117	116	111	110	112
2	75	75	76	130	125	128	128	129	131
3	76	74	73	127	132	131	129	130	131
4	68	64	62	122	120	118	119	120	121
5	65	62	66	116	114	119	126	124	122
6	70	74	73	129	130	130	124	123	125
7	62	59	58	117	112	109	104	100	97
8	80	78	79	115	116	116	135	135	136
9	80	77	77	123	123	119	126	129	130
10	73	68	67	130	129	130	136	135	136
11	65	61	62	114	113	120	125	122	127
12	59	60	64	115	113	111	120	118	121
13	68	66	66	120	118	119	123	120	120
14	67	70	69	126	125	127	130	128	132
Means ±	69.48 ± 6.22	67.81 ± 6.49	68.11 ± 6.23	121.55 ± 5.78	120.49 ± 6.58	120.96 ± 6.90	124.06 ± 8.26	123.07 ± 9.25	124.34 ± 9.93

YBT (Y-Balance Test) performance is expressed in centimetres (cm); Part, participant; CG, compression garments; NG, no garment; SH, sham condition; ant, anterior reach direction, left, reach posteromedial reach direction; right, posterolateral reach direction.

Appendix H: Stabilometer mean score

Participant.	STABcentCG	STABcentNG	STABcentSH
1	6.46	6.03	7.74
2	7.25	6.33	6.58
3	7.25	6.58	6.33
4	6.46	7.74	6.03
5	15.57	14.45	17.18
6	6.46	7.74	6.03
7	5.30	5.22	5.19
8	14.61	12.63	8.41
9	11.69	13.20	10.97
10	7.54	5.97	5.03
11	12.62	15.40	12.31
12	13.06	12.69	9.14
13	5.65	7.61	6.14
14	10.75	12.70	10.36
Mean ±	9.33 ± 3.43	9.59 ± 3.52	8.39 ± 3.266

Stabilometer (STAB) performance is expressed in seconds (s). CG, compression garments; NG, no garment; SH, sham condition; Cent, time spent in the 0-5° horizontal inclination range.

Appendix I: Individual participant survey scores

PAR T.	RES CG	RES NG	RES SH	SUP CG	SUP NG	SUP SH	STA CG	STA NG	STA SH	COM CG	COM NG	COM SH	ENJ CG	ENJ NG	ENJ SH	CON CG	CON NG	CON SH	INF CG	INF NG	INF SH
1	2	4	4	5	4	4	5	4	4	6	4	3	5	5	3	4	6	3	4	4	4
2	3	4	4	6	4	4	5	4	4	5	4	4	4	4	4	4	4	4	3	3	3
3	3	4	4	5	4	4	5	4	4	5	5	3	5	5	3	4	4	4	3	3	3
4	3	4	4	5	4	4	6	4	4	4	4	4	3	4	4	4	4	4	4	4	4
5	3	4	4	5	4	4	5	4	4	5	5	3	5	5	3	5	5	4	5	4	4
6	3	4	4	6	4	4	6	4	4	6	4	4	6	4	4	6	4	4	6	4	4
7	4	4	4	6	4	4	6	4	4	3	4	4	3	5	5	4	4	4	3	4	4
8	4	4	4	5	4	4	5	4	3	5	5	3	4	5	3	4	4	4	3	4	3
9	4	4	4	4	4	4	4	4	4	2	6	3	4	5	3	4	5	4	2	4	2
10	4	4	4	4	4	4	4	4	4	3	5	5	3	5	5	3	4	4	3	4	4
11	3	4	4	6	4	4	6	4	4	5	4	2	6	6	4	6	6	4	5	4	4
12	5	4	4	5	4	4	6	4	4	2	4	2	2	5	2	4	4	4	2	4	2
13	3	4	4	7	4	4	7	4	4	6	4	2	6	6	2	5	4	4	6	4	4
14	6	4	4	5	4	4	5	4	4	5	6	4	5	6	4	6	4	4	4	4	4

Numbers expressed as 1, strongly disagree; 2, disagree; 3 somewhat disagree; 4, neutral; 5, somewhat agree; 6, agree and 7, strongly agree. Part, Participant no; CG, compression garment; NG, no garment; SH, sham; RES, Restriction; SUP, Support; STA, Stability; COM, comfortable; ENJ, Enjoyment; CON, Confidence; INF, Influence.

Appendix J: RPE scores between conditions

Participant.	Compression garment	No garment	Sham
1	7	7	7
2	7	7	7
3	7	7	7
4	7	7	7
5	7	7	7
6	7	7	7
7	7	7	7
8	7	7	7
9	7	7	7
10	7	7	7
11	7	7	7
12	7	7	7
13	7	7	7
14	7	7	7

Rated of perceived effort, RPE scores; 6 demonstrates no exertion and 20 is maximal exertion.

Appendix K: Preference and comments referring to CG

Participant No:	Would you prefer to wear compression garments instead of training shorts for training/participation in sports (1 = yes, 2 = no)	Further comments on the wearing of CGs.
1	1	I liked how it felt around my knees, felt stable. I didn't like the process of putting them on.
2	2	Putting them on was a pain.
3	2	
4	2	
5	2	
6	1	It feels more stable and less vibration when landing, feels springy like my muscles are warm and ready to go.
7	1	Felt comfortable, felt like it was giving a bit of support to the legs as in a little more stability.
8	2	Putting it on would be cumbersome having to do all the time
9	2	
10	2	
11	2	I felt like the garments gave me support around my knees. it almost felt like an extra thin layer of muscle was supporting my overall strength in my legs. I would prefer to wear the garment at night during winter soccer training as opposed to summer day time training.
12	2	
13	2	I like knee support, I felt restricted when contracting hamstrings
14	1	No comment on garment. Compression was noticeable but comfortable. There are always hard to get on. Style is of no concern to me

Appendix L: ICC pilot study

Background

Compression garment (CG) skin interface pressure has been measured and reported in numerous published investigations. However, many of these studies fail to report their intra-tester reliability. Intra-tester reliability could vary greatly depending on individual experience and skill level and thus, limits the accuracy and credibility of reported CG pressure values. Therefore, the purpose of this pilot study was to measure the intra-tester reliability of measuring sport CG applied pressure.

Method

Six participants volunteered for this reliability study (Table 1.1). All participants wore Body Science V8 longs™ CGs that were sized based on the manufacturer guidelines. Kikuhime pressure sensors were applied to the mid-thigh and maximal girth of the calf, while participants stood in the anatomical position. Skin-garment interface pressures were measured three times, over three consecutive days. All data was analysed using SPSS (IBM Statistics Package 24).

Table 1.1. Participant characteristics

Age	Height (cm)	Weight (kg)	Thigh circ. (cm)	Calf circ. (cm)
27 ± 2.19	172 ± 3.78	82 ± 8.03	55.11 ± 3.26	38.61 ± 1.68

Results

Table 1.2 Raw data measurements

Participants	Day 1		Day 2		Day 3	
	Thigh (mmHg)	Calf (mmHg)	Thigh (mmHg)	Calf (mmHg)	Thigh (mmHg)	Calf (mmHg)
1	9	13	9	12	10	12
2	9	17	9	17	9	16
3	9	15	10	15	9	15
4	10	13	9	13	9	12
5	9	15	9	14	9	14
6	10	13	10	13	10	12

Low intra-individual variability was observed for repeated-measure thigh [mean ± SD, 9.33 ± 0.29; CI %, 3.09%] and calf pressure [mean ± SD, 13.94 ± 0.48; CI %, 3.45%], between days. For both sites on the lower-limb, Intra-class Correlation Coefficient values were high across the six participants [mean ICC = 0.956] and between days [ICC = 0.878].

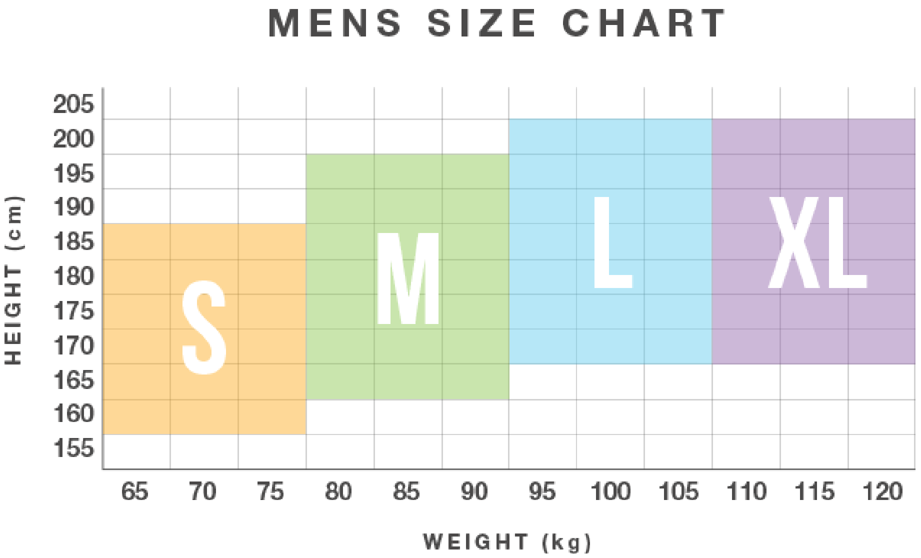
Conclusion

The findings of this pilot study indicate that the tester can reliably record skin-garment interface pressures when using the Kikuhime pressure measuring device. This demonstrates an appropriate level of measurement skill is present to produce reliable and valid CG pressure recordings for the current investigation. Our data aligns with previous research (Brophy-Williams, Driller, Halson, Fell & Shing, 2014) and supports the notion that this device can be used accurately.

Reference list

Brophy-Williams, N., Driller, M. W., Halson, S. L., Fell, J. W., & Shing, C. M. (2014). Evaluating the Kikuhime pressure monitor for use with sports compression clothing. *Sports Engineering*, *17*(1), 55-60.

Appendix M: Garment sizing chart



Body Science sizing chart, accessed from: https://shop.bodyscience.com.au/apparel-accessories/compression/v8-athlete-men-s-compression-longs.html

Appendix N: Individual participant mean skin-garment interface pressures

Part.	**DOB**	**Height**	**Weight**	**Thigh circ. (cm)**	**Calf circ. (cm)**	**Sta. thigh (mmHg)**	**Sit thigh (mmHg)**	**Sta. calf (mmHg)**	**Sit calf (mmHg)**
1	27	170	72	54	38	9	9	13	10
2	30	180	97	60	41	9	9	15	11
3	23	171.9	84.35	57	40.5	9	9	17	13
4	27	172.4	82.7	57.2	38.2	9	9	14	11
5	29	174.3	74.5	50.5	38	10	9	16	12
6	27	168	82	52	36	9	10	13	12
7	27	179.3	97.3	55	39	10	9	14	10
8	29	178	85	53	40	9	9	13	10
9	26	178	77	52.2	40	9	9	15	9
10	38	175	79	56	37	9	9	13	8
11	29	176.9	68.5	51.5	36	10	9	11	9
12	29	179	87	47	37.5	10	10	11	10
13	21	173	70	52	40	9	9	14	10
14	28	178	84.2	55	41	9	10	15	11
Mean	27.85714	175.2714	81.46786	53.74286	38.72857	9.28	9.21	13.85	10.42
±	3.681171	3.624604	8.52089	3.162891	1.671368	0.45	0.41	1.64	1.29

Part, participant; DOB, date of birth; circ, circumference; Sta., represents measurement taken in an anatomical standing position; Sit, represents pressure measurements taken in a sitting position.