International Journal of Kinesiology & Sports Science
ISSN: 2202-946X
www.ijkss.aiac.org.au

Lower limb compression garments do not influence dynamic and static balance performance in young males

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ARTICLE INFO

Article history
Received: June 14, 2021
Accepted: July 28, 2021
Published: July 31, 2021
Volume: 9 Issue: 3

Conflicts of interest: None
Funding: None

ABSTRACT

Background: Some studies show that wearing compression garments (CGs) improves balance performance. However, the overall evidence supporting their use for balance improvement is inconclusive. **Objective:** This study aimed to further explore the effect of CGs on balance. **Method:** Using a cross sectional within subjects repeated measures design fourteen participants (27 ± 3 years) completed three trials for each of four balance tests, under three conditions: compression garment, no garment, and sham. Subjective performance and garment rating scores were also collected following each test condition. A repeated-measures analysis of variance was performed to compare derived variables between conditions for each balance test. **Results:** No significant differences were found across conditions or tests for either balance performance or subjective measures. **Conclusions:** This study demonstrated CGs did not influence dynamic or static balance performance in healthy young males. Further, in contrast to other research this study did not demonstrate an effect of compression garments on dynamic or static balance in healthy young males. However, it remains that CGs may provide benefit in other populations including those with balance and movement deficit disorders.

Key words: Clothing; Motor Control; Motor Learning; Postural Balance; Proprioception; Stability

INTRODUCTION

The ability to maintain balance is a key element for the execution of motor skills, and postural control, in many populations, including those involved in physical activity (Daneshjoo et al., 2020; Gebel et al., 2018). In addition, relationships between balance, sport performance and injury risk have been established (Hrysomallis, 2011). For example, the ability to maintain balance while motionless correlates with several movement skills including superior kicking accuracy (Chew-Bullock et al., 2012), skating speed (Behm et al., 2005), change of direction agility scores (Pau et al., 2015), Tai Chi (Daneshjoo et al., 2020), and single-leg counter-movement jump performance (Gualtieri et al., 2008).

The ability to balance and maintain postural control is a complex motor skill reliant on the integration of mechanisms in the vestibular, somatosensory, and musculoskeletal systems (Riemann & Lephart, 2002; Williams et al., 2016; Woo et al., 2014). Consequently, studies have investigated a variety of strategies that target functions of the central nervous system with the aim of improving balance. One such strategy is the use of compression garments (CGs), which is elastic based clothing that applies a pressure gradient onto the skin which can be fitted onto an individual covering portions or entirely the upper or lower body (Born et al., 2014; Xiong & Tao, 2018). It has been suggested that CGs trigger the activities of mechanoreceptors in the skin and muscles and enhance proprioception (MacRae et al., 2011). This notion is asserted by Cameron et al., (2008) and Lien et al., (2014) who found that athletes wearing CGs improved their awareness, detecting errors in their kicking technique. Similarly, Hasan et al. (2016) found lesser skilled athletes produce greater hip extension and flexion towards a soccer ball in the contact phase, optimising kicking technique. More recently, the wearing of CGs has been shown to optimise landing techniques which may help with reducing lower limb injuries. For instance, Zampporri and Aguinaldo (2018) found female athletes displayed significant reductions in hip valgus when drop landing from a 27cm tall box. This is in-line with the findings of de Britto et al., (2017) who found female participants who wore CG's had reductions in knee flexion and knee valgus when wearing CGs. These findings support the premise that wearing a CG can enhance proprioceptive

Published by Australian International Academic Centre PTY.LTD.

http://dx.doi.org/10.7575/aiac.ijkss.v.9n.3p.44

feedback to the central nervous system and improve motor performance.

To date, research investigating the effect of CGs on the motor performance associated with balance has been limited to the assessment of static balance (balance while motionless) and using a single balance test. While evidence exists demonstrating improved static balance when wearing CGs when eyes were closed (Michael et al., 2014), contrasting studies show no significant change in balance compared to wearing regular training clothes (Bernhardt & Anderson, 2005; Michael et al., 2014; Sperlich et al., 2013). However, relatively few sporting pursuits require balance while motionless, with many sporting and exercise movements requiring dynamic balance and postural control. The use of a single static balance test, commonly used in clinical and patient assessments, may not be analogous to dynamic sporting demands. This is supported by studies where no correlations between static and dynamic balance performance have been found (Riemaan & Schmitz, 2012; Krkelijas, 2017), and suggests that dynamic balance requires a greater simultaneous involvement of neuromuscular and somatosensory control than static balance (Krkleijas, 2017).

Based on the contrasting findings of prior research it appears that the pressure effect from CGs may be more effective in dynamic movement due to the change in joint and limb positions during movement tasks, thus further exploration is needed that uses a more robust experimental design. The aim of this study, therefore, is to comprehensively evaluate the effect of CGs on balance when performing a range of static and dynamic balance tests, where we hypothesize that the CGs will result in improved dynamic and static balance performance, in addition to improved perceived benefits from the participants.

METHODS

Participants and Study Design

A cross sectional within subjects repeated measures design was used to carry out this study which involved fourteen healthy male volunteers with a mean (±SD) age of 27 years ± 3; mass of 81 ± 8.5kg; and height of 175.3 ± 3.6cm. Sample size was determined based on a priori power analysis conducted using G*Power3 (Faul et al., 2007), where 12 or more participants would achieve an alpha of 0.05 and a power of 0.8. All volunteers self-reported as healthy with regular moderate to high intensity recreational exercise or competitive sport (2-5 training sessions per week). Individuals were excluded from participation if they competed above the local level of their chosen sport and/or had any lower limb injuries within six months prior to testing. Prior to participation, all volunteers received an information statement, completed a health screening questionnaire and provided written informed consent. Body Science V8 Compression Longs™ (26% Lycra and 74% polyester) were used for the study and were fitted according to the manufacturer guidelines and referred to as compression garments (CGs). Ethical approval for this investigation was provided by the institutional Human Research Ethics Committee.

Instrumentation

Force Plate

Ground reaction force data (GRF) 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 1000Hz and filtered with a 10Hz low-pass Butterworth filter to remove unwanted noise. A software trigger was used such that data collection began when vertical GRF first exceeded 10 N (Sambaher et al., 2016).

Garment-Skin Interface Pressure

Garment and skin interface pressures (Kikuhime, TT Medi Trade, Søleddet 15, Denmark, DK 4180 Soro) at the mid-thigh and at maximal calf girth were measured during sitting and standing prior to balance testing (Brophy-Williams et al., 2015). Pressure readings were displayed in real time in 1mmHg increments with a typical error of measurement of ± 1mmHg (Brophy-Williams et al., 2015). Pressure was identified at the tenth second of measurement and was repeated for 3 trials, then averaged.

Subjective Survey

Participant subjective data were recorded via a short survey, administered at the completion of the balance tests in each testing condition The survey consisted of questions pertaining to the participant's perception of exertion (RPE) (Borg, 1982), required for the balance tasks, in addition to their perception of the stability, support, comfort, and enjoyment (Hooper et al., 2015), provided by the CGs when performing the balance tasks (Table 1). These questions also explored each participant's perception of the CG's influence on their performance, and if they would prefer to wear CGs rather than regular training shorts when exercising/participating in sports. Data were grouped into key variables (Table 2).

Balance Tests

Vertec Jump

The vertec jump test required participants to perform a two-legged jump at a 45-degree lateral projection angle of a dis-

Table 1. Key perception indicators measured in the subjective survey

Variable	Definition
Restriction	Feeling stiff/restricted during movement
Support	Lower limbs felt reinforced (i.e. musculature feels protected from the testing condition)
Stable	Maintenance of equilibrium when balancing
Comfort	Sense of ease when wearing the CGs
Enjoyment	Feelings of enjoyment/interest of the testing condition
Influence	Participants felt like the testing condition influenced/impacted their performance
Preference	Participants prefer wearing the testing condition rather than the control condition for training environments

Table 2. 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

tance of 70cm, reach a vertical height of at least 50% of their max counter-movement jump (CMJ) height, land on their dominant leg and maintain static balance for 15-20seconds(s) post impact (Wikstrom et al., 2008). Consistent with standardised protocols, trials were discarded and repeated if a participant: 1) lost balance and fell; 2) touched the floor with their contralateral limb; 3) performed a short hop upon landing; 4) swayed excessively with the contralateral limb, trunk and/or arms (Ross & Guskiewicz, 2004; Wikstrom et al., 2008).

Participants were given three practice trials (Gribble et al., 2012) with a one-minute rest between each trial (Valerie et al., 2016). Prior to performing the vertec jump test, each participant's 50% Max jump height was calculated (Gribble et al., 2012; Ross & Guskiewicz, 2004; Wikstrom et al., 2008).

Balance Stabilometer

Participants stood on a stabilometer (Lafayette Instruments, Inc, USA) with a bipedal stance, feet positioned hip to shoulder width apart, eyes looking straight ahead while aiming to keep the platform as horizontal as possible (Davlin, 2004). Within the 20s test trial period, the stabilometer recorded the aggregate duration the participant held the platform within and outside ±5° of the neutral position (horizontal). Participants were given one practice trial (Hosp et al., 2017).

Hurdle Jump

The hurdle jump balance test required participants to perform a forward, double-leg jump over a 15cm high hurdle, travel a horizontal distance of 40% of their standing height, land on their dominant leg on a force platform and hold the static position for 15-20s post impact. Instructions were to clear the hurdle without producing unnecessary or excessive jump height. Consistent with standardised protocols, trials were discarded and repeated if a participant: a) lost balance; b) touched the floor with their contralateral limb; c) performed a short hop upon landing; d) swayed excessively with the contralateral limb, trunk and/or arms.

Single Leg Balance Test (SLB)

The SLB required participants to hold a static single leg position on their dominant leg on the force plate for 20s with their eyes open (EO) for three trials and then eyes closed (EC) for three trials. Trials were discarded and repeated if the participant's opposing leg touched the ground (Sell, 2012).

Testing Protocol

Participants performed and repeated four balance tests that assessed their dynamic and static balance in three conditions: a) compression garment (CG), b) no garment, and c) sham. For the control condition, participants wore their own loose-fitted training shorts. The sham condition involved light application of a 5cm 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 (Gupta et al., 2015). The participants were informed that the tape may stimulate sensory feedback that may assist in their balance performance. Testing conditions were number identified (1 = CG, 2 = control and 3 = sham) and counter-balanced across participants to control for potential order effects.

Each balance test was performed in the following order by every participant for each of the three conditions: 1) vertec jump, 2) balance stabilometer, 3) hurdle jump, and 4) single leg balance (SLB). This order of tests was chosen to minimise potential fatigue related effects from performing repeated single leg tasks and to avoid confounding, randomised order effects between conditions.

All tests were performed barefoot on the participant's dominant leg (Cavanaugh et al., 2015; Krkeljas, 2018), with familiarisation trials completed for each test. Three experimental trials were completed for each balance test with a two-minute rest between each test trial. Failed trials were discarded to maintain consistency with previously published protocols and enable non-confounding comparison between garment conditions. At the completion of all four balance tests within a testing condition, participants rated their perceived exertion levels on a 6-20 Borg scale (Borg, 1982). A 10-minute rest was provided between each test condition to minimise fatigue and allow changing of garments (Doan et al., 2003). Participants completed the survey following the final balance test for each garment condition.

Data Reduction and Calculated Variables

Filtered ground reaction force (GRF) data were collated in Microsoft Excel (Microsoft Corp, Redmond, Washington) and analysed with a custom MATLAB (The Mathworks, Natick, RI, USA) script. Dependent variables included dynamic postural stability index (DPSI) and the time to stabilization (TTS) (x, y, z) for the vertec and hurdle jumps, time on the Stabiliometer (STAB) test, and centre of pressure path length ($COP_{pathlength}$) for the eyes open and eyes closed SLB tests.

Dynamic postural stability index (DPSI) calculates a combined stability index (SI) based on the medio-lateral: (MLSI), anterior-posterior: (APSI) and vertical (VSI) stability (Sell, 2012; 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, 2012; 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 mass (Equation 1) (Sell, 2012; Wikstrom et al., 2005).

DPSI =

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

Where, DPSI = Dynamic postural stability index; GRF, ground reaction force; x, mediolateral; y, anteroposterior; z, vertical (Sell, 2012).

An unbound third-order polynomial (UTOP) was used to calculate TTS in the vertical, AP and ML directions between the time of impact (vertical GRF > 10 N) to 20s post impact (Ross & Guskiewicz, 2004). A 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 15-20s window following ground contact. Time to stabilisation was defined as when the UTOP signal intersected and remained within the stability threshold (Figure 1) (Sell, 2012).

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 mass (Equation 2).

$$f(x) = \sum_{i=1}^{n} \sqrt{\left((Ay_{i+1} - Ay_i)^2 + (Ax_{i+1} - Ax_i)^2 \right)}$$

Where "n" denotes the total number of samples in the trial, i = the successive sample number.

Statistical Analysis

A one-way repeated measures Analysis of Variance (ANOVA) was used to determine differences between conditions (CG, sham, control) for all dependant variables (SPSS Inc., v24, Chicago, IL). Statistical significance was set at $p<0.05$, with Bonferroni correction made. Mauchly's test of sphericity was used 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 and the likelihood of violating numerous statistical assumptions and producing a type 1 error, statistical analysis was confined to descriptive comparisons of means for survey data.

RESULTS

Garment and skin interface pressures at the mid-thigh and at the position of maximal calf girth during sitting and standing measured prior to balance testing are shown in Table 3.

No significant main effect was observed between conditions for any of the vertec jump ($F = 2.420$, $p = .109$), STAB ($F = 3.288$, $p = .060$), hurdle jump ($F = 1.435$, $p = .256$), and SLB EO ($F = 0.624$, $p = .487$) and SLB EC ($F = 0.915$, $p = .377$GG balance tests used (Table 4).

The survey response scores for each condition are presented in Table 5 with an overall preference for not wearing garments expressed at 71% compared to 29%, where participants preferred to wear standard training shorts during the balance tasks as opposed to CGs.

DISCUSSION

This study demonstrated that the use of CGs did not enhance static or dynamic balance compared to control and sham conditions. However, some participants perceived a greater level of stability and support when wearing CGs compared to the other conditions. Despite this perceived support, most participants reported a preference for wearing regular training shorts rather than CGs.

Our results show that CGs did not impact dynamic balance and the ability to stabilize faster in the DPSI and TTS measures for either balance task. Therefore, we conclude that the wearing of full-length CGs did not improve dynamic balance performance. This finding corroborates those of Cavanaugh et al. (2015), who examined the effect of an exter-

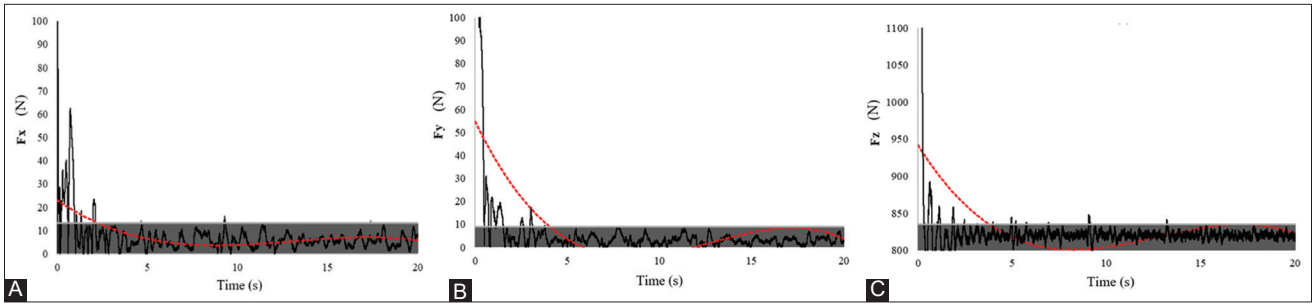

Figure 1. Time to Stabilisation calculated using an unbound third-order polynomial (UTOP) A) in mediolateral (Fx), B) anteroposterior (Fy) and C) vertical (Fz) directions. The vertical axis denotes force in Newtons. Horizontal axis indicates time in seconds. The red dashed line is the respective UTOP 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 15-20s post ground contact. TTS is defined as the time is takes until the UTOP signal intersects the ± 3 SDs stabilisation threshold after landing.

nally applied compression device with jump landing balance performance. They found no COP excursion length differences during an anterior drop-landing, from a platform of 50cm whilst wearing a knee compressive sleeve (NP), KT and training shorts. This is despite some research demonstrating that lower limb aids can improve dynamic balance by lowering DPSI and Vertical Stability Index scores. While ankle braces and CG differ in design, the current findings highlight that sufficient externally applied pressure, whether sensory or mechanically focused on specific regions of the limb (particularly the ankle), can alter balance stabilization performance.

In the current study, CGs did not induce a change in COP pathway in either the eyes open or eyes closed single leg balance (SLB) tests, which is consistent with Maeda et al., (2016). In contrast, Michael et al., (2014) found significant improvements in COP excursion and range when participants had their eyes closed while wearing CGs compared to control and sham conditions. These contrasting findings may be due to differences in the task, as participants in the current study balanced for a maximum of 20 seconds as opposed to the participants in Michael et al., (2014) who held a static SLB position for 60 seconds. This longer duration may have afforded participants greater opportunity to receive, interpret and process tactile feedback and thus, perform better corrective actions. Further comparison between these two studies is limited by the fact that Michael et al., (2014) did not measure CG pressures. It remains, however, that greater somatosensory stimulation may have contributed to the improved eyes closed balance performance in Michael et al., (2014), which was not replicated here.

Analysis of the subjective measures in this study showed that 85% of the participants felt more stable and supported when wearing CGs compared to the other conditions, with four participants noting specifically increased support around the knee. The CGs and applied pressures were therefore adequate to provide many participants with a perceived mechanical support effect. These findings are consistent with a previous study where 93% of participants felt that the CG was supportive during various sprinting and agility tests, despite there being no significant differences in test performance scores (Bernhardt & Anderson, 2005). The more resistive material and garment design used by Bernhardt and Anderson (2005) may explain why there were higher ratings of support in their study. The perceptions of improved stability without a performance change may demonstrate a placebo effect when wearing CGs. Such perception of stability can be beneficial when assisting sport performance and rehabilitation from injury (Morgana et al., 2007), and is thus nontrivial.

Table 3. Mean ± SD compression garment and skin interface applied pressures

	Mid-thigh (mmHg)	Mid-calf (mmHg)
Standing	9 ± 0.5	14 ± 1.6
Sitting	9 ± 0.4	10 ± 1.3

Table 4. Mean ± SD scores and between condition repeated measures ANOVA comparison for all stability measures. Also shown are degrees of freedom (df), *F*-ratio and *p*- values. GG next to the *p*-value indicates data where a Greenhouse-Geisser correction was applied

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, 23.20	3.288	0.060_{GG}
Hurdle jump ⇩	DPSI	0.23 ± 0.75	0.23 ± 0.06	0.24 ± 0.88	1.190, 15.48	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, 18.170	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
SLB EO ⇩	$COP_{pathlength\ (m)}$	0.10 ± 0.03	0.12 ± 0.06	0.10 ± 0.02	1.356, 17.63	0.624	0.487_{GG}
SLB EC ⇩	$COP_{pathlength\ (m)}$	0.17 ± 0.12	0.17 ± 0.06	0.14 ± 0.05	1.281, 16.66	0.915	0.377_{GG}

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

Table 5. Mean ± SD survey response scores for each garment condition

	Restriction	Support	Stable	Comfort	Enjoyment	Influence
NG	4.0 ± 0	4.0 ± 0	4.0 ± 0	3.3 ± 0.9	3.5 ± 0.9	3.5 ± 0.7
Sham	4.0 ± 0	4.0 ± 0	4.0 ± 0	4.6 ± 0.7	5.0 ± 0.7	3.9 ± 0.3
CG	3.6 ± 1	5.3 ± 0.8	5.4 ± 0.8	4.4 ± 1.3	4.4 ± 1.2	3.8 ± 1.3

Survey ratings were scored from 1 (strongly disagree) to 7 (strongly agree).

Despite improved perception of support and stability, participants did not rate the CG to have a beneficial influence on their performance. This may have been due to wearer acceptance and comfort which were rated low, with 10 of the 14 participants reporting a preference for wearing their training shorts instead of the CGs. Additionally, four participants rated the CG to be slightly uncomfortable and unenjoyable to wear. This corroborates previous research where participants who reported CGs to be uncomfortable also perceived hindered performance (Bernhardt & Anderson, 2005). Further, in the same study, participants who felt the garment was comfortable perceived that their performance was enhanced (Bernhardt & Anderson, 2005). This aligns with the findings of Hooper et al. (2015) where experienced golfers and baseball pitchers improved sport-specific skills when wearing upper body CGs. Participants also found garments to be more comfortable and enjoyable than regular training wear. Though the researchers speculate the improvements were attributed to improved proprioception, there is a likelihood that comfort and enjoyment of a CG can influence individual psychological state and alter performance.

A further consideration when interpreting these findings is that participants in the current study only used their dominant leg in single leg balance tasks and can only be applied to dominant leg balance performance. For example, 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 (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, and for greater relevance to sporting populations.

Finally, the absence of improved balance performance demonstrated 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 utilization 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 et al., 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). Hence the findings of Hosp et al. (2017) and Shaw et al., (2008) suggest that external devices may be more effective as compensatory aid to stimulate tactile feedback when sensory awareness is diminished from fatigue.

CONCLUSIONS

The current study used multiple tests and measured both performance and perception to contribute to our understanding of the relationship between compression garments and balance. The findings demonstrated that CGs did not influence dynamic or static balance performance in healthy young males, though participants perceived improved balance stability when wearing the garments. Despite the limited findings it remains possible however, that CGs may prove useful as a compensatory aid to stimulate tactile proprioceptive feedback and provide mechanical support in other populations such as the elderly or the injured. Consequently, the study provides an impetus for further exploration of the potential use of CGs for applications in balance tasks especially where factors such as fatigue may present. Future research should explore the benefit of wearing CGs in more ecologically valid contexts across a broader population based, and under varied conditions.

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