



Position of compression garment around the knee affects healthy adults' knee joint position sense acuity



Li Yin Zhang^{a,1}, János Négyesi^{a,*,1}, Takeshi Okuyama^b, Mami Tanaka^b,
Tibor Hortobágyi^c, Ryoichi Nagatomi^{a,d}

^a Department of Medicine and Science in Sports and Exercise, Tohoku University Graduate School of Medicine, Sendai, Japan

^b Department of Robotics, Tohoku University Graduate School of Biomedical Engineering, Sendai, Japan

^c Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, the Netherlands

^d Division of Biomedical Engineering for Health & Welfare, Tohoku University Graduate School of Biomedical Engineering, Sendai, Japan

ABSTRACT

Athletes use compression garments (CGs) to improve sport performance, accelerate rehabilitation from knee injuries or to enhance joint position sense (JPS). The position of CGs around the knee may affect knee JPS but the data is inconsistent. The purpose of the present study was to determine the effects of CG position on healthy adults' knee joint position sense acuity. In a counterbalanced, single-blinded study, 16 healthy young adults (8 female, age: 25.5 y) performed an active knee joint position-matching task with and without (CON) a below-knee (BK), above-knee (AK), or whole-knee (WK) CG in a randomized order on the dominant (CompDom) or the non-dominant leg (CompNon-Dom). We also determined the magnitude of tissue compression by measuring anatomical thigh and calf cross sectional area (CSA) in standing using magnetic resonance imaging (MRI). Subjects had less absolute repositioning error (magnitude of error) in BK compared with CON condition. On the other hand, the analysis of the direction of error (constant error) revealed that in each condition subjects tended to underestimate the target position (AK, BK and CON: 75%; WK: 94%). In WK condition there was a significantly larger negative error (-2.7 ± 3.4) as compared with CON (-1.6 ± 3.7) condition. There also was less variable error, in WK compared to BK and CON conditions, indicating less variability in their position sense using a WK CG, regardless of the underestimation. CG reduced thigh CSA by 4.5 cm² or 3% and calf CSA by $\Delta 1.3$ cm² or 1%. The position of CG relative to the knee modifies knee JPS. The findings helps us better understand how the application of a WK CG may support athletic activities.

1. Introduction

Athletes often use elastic bandages and compression garments (CGs) with the assumption that the mechanical support and tissue compression under CGs facilitate recovery from or even prevent injuries (Fousekis et al., 2017). Practitioners also speculate that CGs enhance joint position sense (JPS) (Ghai, Driller, & Masters, 2018; Van Tiggelen, Coorevits, & Witvrouw, 2008) by reducing muscle fatigue (Miyamoto, Hirata, Mitsukawa, Yanai, & Kawakami, 2011; Van Tiggelen et al., 2008) and/or by stretching the skin, a mechanical effect that might be expected to distort position sense (Collins & Prochazka, 1996), i.e., proprioceptive acuity (Ghai, Driller, & Ghai, 2017; Van Tiggelen et al., 2008). However, paralleling the inconsistencies of these physiological mechanisms, the results are also contradictory concerning how and if at all tissue compression under CGs affects knee JPS, the perceived sense of knee joint

Abbreviations: AK, above-knee compression garment; ANOVA, Analysis of variance; BK, below-knee compression garment; CG, compression garment; CON, without compression garment; CSA, cross-sectional area; JPS, joint position sense; MRI, magnetic resonance imaging; SD, standard deviation; WK, whole knee compression garment

* Corresponding author.

E-mail address: negyesi@dc.tohoku.ac.jp (J. Négyesi).

¹ These authors contributed equally to this work.

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position, and joint movement per se (Friden, Roberts, Ageberg, Walden, & Zatterstrom, 2001).

While some authors claim that if CGs improve joint function, such beneficial effects are independent of tissue pressure created by the garment (Beliard et al., 2015), others suggest that the benefits of CGs on muscle performance and/or proprioception are related to the magnitude of tissue compression (Ali, Creasy, & Edge, 2011; Kemmler et al., 2009). For instance, it was shown that CGs and sleeves could improve performance through proprioception-mediated effects related to an increase in afferent input from skin, muscle and joint receptors due to the pressure and contact afforded by the garments (Robbins, Waked, & Rappel, 1995). Afferent signals from tactile and muscle receptors set joint position and the cutaneous component of the afferent signal contributes to the neuromuscular control of the limb covered by the garment (Cameron, Adams, & Maher, 2008). It is possible that the conflicting data between studies, concerning the proprioceptive effects of CGs on performance, may be related to the barrage of afferent input caused by the CG. CGs may in fact cause a sensory conflict and the abundance of afferent input becomes unhelpful, producing interference and ultimately reducing performance (Newcomer, Laskowski, Yu, Johnson, & An, 2001; Perla, Frank, & Fick, 1995). It is therefore important to determine if the placement of the CG differentially affect neuromuscular control and knee JPS.

Previous studies applied whole knee bracing (Birmingham, Inglis, Kramer, & Vandervoort, 2000; Bottoni, Heinrich, Kofler, Hasler, & Nachbauer, 2015; Tiggelen, Coorevits, & Witvrouw, 2008; Van Tiggelen et al., 2008) or used a below-knee CG (Ghai et al., 2018) to determine its influence on knee JPS. The limited JPS data are inconsistent concerning the effects of garment position along the leg. It is thought that a below-knee compared with over the knee garment would minimize interference with knee range of motion and mobility of the knee (Lien et al., 2014). However, there is also evidence (Birmingham et al., 2000; Bottoni et al., 2015; Tiggelen et al., 2008; Van Tiggelen et al., 2008) that proprioception is enhanced when the garment is on the knee joint most probably due to skin stretching which in turn augments the sense of movement (Collins & Prochazka, 1996). In our recent study (Negyesi, Mobark, Zhang, Hortobagyi, & Nagatomi, 2018), an above-knee CG failed to reduce passive target-matching errors. Indeed, JPS was actually more accurate without the garment. One reason could be that the target-matching task was performed in a passive manner in this particular study. Active instead of passive repositioning could increase sensory input through the fusimotor drive and muscle receptor activation (Cholewicki, Shah, & McGill, 2006). In addition, active compared with passive repositioning evaluates afferent input in a more functional way due to general attenuation and selective gating of kinesthetic awareness during voluntary movements (Kaminski & Perrin, 1996). Compared with passive testing paradigms (Kaminski & Perrin, 1996), in active testing conditions muscle spindles appear to play a role in the conscious perception of limb movement by detecting changes in muscle length (McCloskey, 1978). Therefore, active compared to passive repositioning of the joint seems to be a more functional assessment of proprioception. Nevertheless, the methodological heterogeneity between studies makes it difficult to determine if CGs enhance JPS. Therefore, the purpose of the present study was therefore to determine if the position of a CG around the knee affects healthy adults' knee JPS measured by an active repositioning task. Based on the contradictory results of studies showing different effects of CG on proprioception according to the position of the CG around the knee, we hypothesized that active target-matching errors of the knee joint would be more accurate when the CG is positioned below the knee. Moreover, we aimed to determine the magnitude of soft tissue compression produced by the above- and below-knee CGs using magnetic resonance imaging (MRI) with the expectation that the pressure produced by the garments reduces the cross-sectional area (CSA) of the thigh and calf.

Although it was shown that knee joint position sense is not more accurate in the non-preferred left limb under non-weight-bearing, partial weight-bearing and full weight-bearing conditions (Bullock-Saxton, Wong, & Hogan, 2001), strongly right-side dominant participants consistently sense movements more accurately using the left joints on both the upper- and lower limbs (Galamb et al., 2018; Han, Anson, Waddington, & Adams, 2013). To support these previous findings, we aimed to determine if subjects performed target-matching task more accurately with their non-dominant left leg. Concerning the effects of leg dominance on proprioception we expected that proprioception tends to be worse in dominant as compared to non-dominant leg and below-knee CG improves proprioception. Along these lines, we hypothesized that CG has a preferential effect on proprioception so that the leg with poorer proprioception, i.e., dominant vs. non-dominant, would benefit most from wearing the garment (Chu, Kane, Arnold, & Gansnedder, 2002; McNair & Heine, 1999; Newcomer et al., 2001; Perla et al., 1995). However, it is unclear if such benefits would vary with the position of the CG, i.e., above, below or on the knee. In the present study, subjects therefore wore the CGs on their right dominant or the left non-dominant lower limb to detect if the position of the CG may affect the dominant- and non-dominant leg's position sense differently.

2. Materials and methods

2.1. Participants

Sample size calculations (G*Power 3.1.7 (Faul, Erdfelder, Lang, & Buchner, 2007)) were based on a previous study (Van Tiggelen et al., 2008) which determined the effects of bracing on active JPS in healthy adults' knee joint. Power analysis for repeated measures analysis of variance (ANOVA) indicated a total sample size of 12, assuming type I error of 0.05 and power of 0.80.

Based on the power analysis, 16 strongly right-side dominant healthy adults were enrolled in the study (age = 25.5 ± 2.57 y, range 22–30 y; height = 1.67 ± 0.1 m; mass = 60.96 ± 16.32 kg; 8 female). Handedness was determined using the Edinburgh Handedness Inventory (Oldfield, 1971). Leg dominance was determined by one- or two-foot item skill tests such as kicking a ball or stepping up on a chair (van Melick, Meddeler, Hoogbeem, Nijhuis-van der Sanden, & van Cingel, 2017). Laterality index for both handedness and footedness were calculated by summing the number of tasks performed with the right limb (R) and the number of tasks performed with the left limb (L) as follows: $(R - L)/(R + L)$ (Negyesi et al., 2018). Laterality index was 0.89 ± 0.18 for handedness and 0.78 ± 0.24 for footedness, showing that participants were strongly right-side dominant. Participants had no history

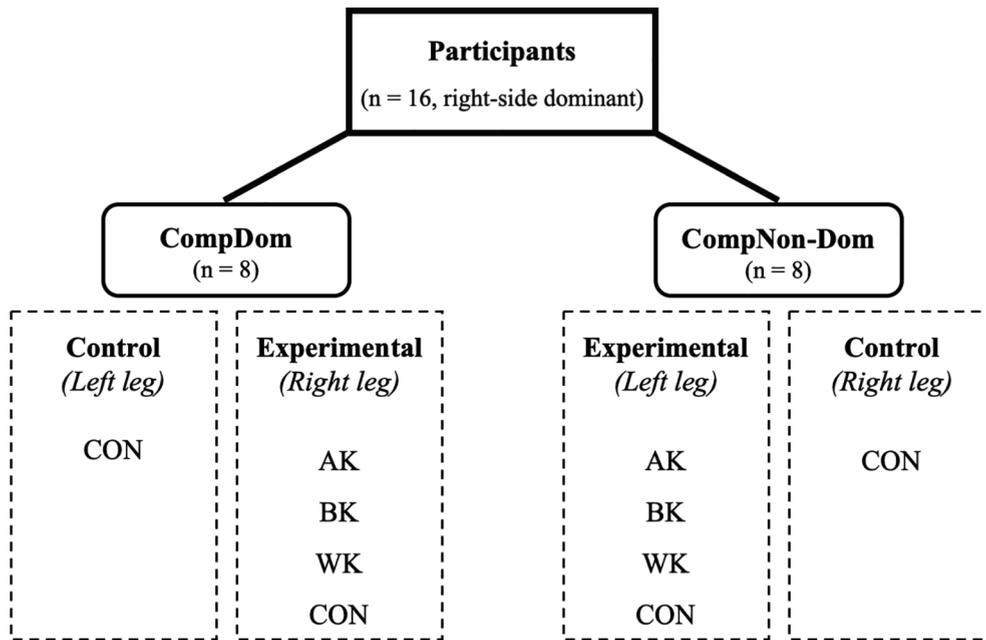


Fig. 1. Experimental design. Participants were randomly allocated in equal numbers to wear the compression garments on the dominant (*CompDom*) or non-dominant leg (*CompNon-Dom*). *AK*: above-knee compression garment; *BK*: below-knee compression garment; *WK*: whole-knee compression garment; *CON*: without compression garment.

of or presented with neurological or orthopedic disorders. After giving both verbal and written explanation of the experimental protocol, all participants gave written informed consent in accordance with the Declaration of Helsinki. The study was carried out in accordance with the recommendations of Tohoku University Medical Ethical Committee.

2.2. Compression garment

A standard unisex compression sleeve (D&M Co., Tokyo, Japan) was worn by the participants. The compression garment extended between the proximal two-thirds and the distal two-thirds of the femoral shaft in *AK* garment position; between the superior aspect of the tibial tuberosity and the proximal two-thirds of the tibial shaft in *BK* garment position; and between the distal two-thirds of the femoral shaft and the superior aspect of the tibial tuberosity in *WK* garment position. Participants wore the same best fitting *CG* of the three available sizes for each garment position.

2.3. Experimental design

Participants were randomly allocated in equal numbers to wear the compression garments on the dominant (*CompDom*), or on the non-dominant leg (*CompNon-Dom*). Each group and with each leg, participants performed an active target-matching task with and without (*CON*) wearing an above-knee (*AK*), below-knee (*BK*), or whole-knee (*WK*) *CG* in a randomized order (Fig. 1).

2.4. Procedures

2.4.1. Active Target-matching task

The application and position of the *CG* (*AK*, *BK*, *WK*, *CON*) were randomized. Position sense was measured on an isokinetic dynamometer (HUMAC NORM, Computer Sports Medicine Inc., Stoughton, MA). Participants were blindfolded to eliminate visual cues. Participants sat on the dynamometer seat in an upright position. One leg hanged freely over the edge of the dynamometer seat and the other leg was attached to the dynamometer's lever arm. The center of the knee joint was aligned with the dynamometer's head and the hip angle was kept constant (90° of hip flexion) during the measurement.

We measured limb proprioception by an active limb positioning protocol. After one familiarization trial, we collected data in a random order at seven targets, 30, 35, 40, 45, 50, 55 and 60° of knee flexion, to reduce learning effects. The initial starting position was 90° of knee flexion. Participants were instructed to focus on the position of the leg. The dynamometer was programmed to move the participant's leg attached to the lever arm passively at 4°/s toward the target angle, which was then held for 5 s before the dynamometer's lever arm with the subject's leg attached to it, returned to the initial starting position. Following a 5 s interval the participant attempted to actively reposition the leg at the same joint angle. The participant was required to hold the leg at the perceived target angle for 4 s and then return it to the starting position. Participants received no feedback about their performance

through the measurement. Each target angle was repeated twice. To maintain attentional alert, after every 5 trials participants counted backwards by seven, starting from a two-digit number selected at random by the investigator.

2.4.2. MRI measurement

On the day after the proprioception measurement, participants underwent an *MRI* (G-Scan Brio, ESAOTE, Genova, Italy) measurement in standing position to determine the effects of the *CG* on thigh and calf cross sectional area (*CSA*). The details of the *MRI* set up and data acquisition is described in our previous study (Negyesi et al., 2018). Briefly, participants lay in the scanner and were moved from a supine to a standing position. The acquisition time was about 40 ± 5 min, including preparation, positioning and scanning with and without wearing the *CG* only on the experimental leg.

For *AK* garment position, thigh *CSA* was measured at ~ 15 cm above the upper edge of the patella guided by the contour of the rectus femoris muscle. For *BK* garment position, calf *CSA* was measured where the circumference was the greatest without the *CG*. The images were digitized to determine *CSA* by the ImageJ software (Schneider, Rasband, & Eliceiri, 2012) as described previously (Gomez-Perez et al., 2016).

2.5. Data analyses

JPS was evaluated using three types of error: 1) absolute error, i.e. the measure of the magnitude of the error, without directional bias; 2) constant error, i.e. the measure of the deviation from the target with directional bias and 3) variable error, i.e. the measure of the consistency in performance, determined as the standard deviation from the mean of the relative errors. Although most of the previous studies have measured only absolute repositioning error (Angyan, Antal, & Angyan, 2007; Bjorklund, Crenshaw, Djupsjobacka, & Johansson, 2003), evaluating variable and constant errors might provide a different information on the integrity of the sensorimotor system by reflecting how accurately the target is represented in the nervous system (Rossetti, Meckler, & Prablanc, 1994; Vafadar, Cote, & Archambault, 2015).

In the present study, any deviation from the target position, discounting direction, was defined as the absolute position error:

$$E_{\text{absolute}} = |X_{\text{participant}} - X_{\text{target}}| \quad (1)$$

For constant error, the difference between reproduced and actual target angle was used, considering the direction of the error:

$$E_{\text{constant}} = (X_{\text{participant}} - X_{\text{target}}) \quad (2)$$

The variable error was calculated as the overall standard deviation (*SD*) of constant error from 14 trials, irrespective of the target range:

$$E_{\text{variable}} = \sqrt{\sum (X_{\text{participant}} - E_{\text{constant}})^2} \quad (3)$$

2.6. Statistical analyses

We report the data as mean \pm *SD*. The analyses were performed using SPSS Statistics Package (version 22.0, SPSS Inc., Chicago, IL). To statistically investigate the difference between conditions of *CG* position (*AK*, *BK*, *WK*, *CON*) in each type (absolute, constant and variable) of repositioning error (the dependent measure), one-way analyses of variance (ANOVAs) were used, with a level of significance set at $p < 0.05$. Furthermore, to detect if repositioning errors differ between the experimental (*Experimental_CON*) and control (*Control_CON*) leg in the absence of *CG*, paired samples t-tests were performed. Also, t-tests were used to detect the effects of *CGs* on thigh and calf *CSA*. Cohen's effect size, *d*, was also computed as appropriate.

To detect if the effect of the *CG* position was consistent for the dominant right and non-dominant left leg, a group (*CompDom/CompNon-Dom*) \times *CG* position (*AK*, *BK*, *WK*, *CON*) analyses of variance (*rANOVAs*) with repeated measures on *CG* position was conducted in each type of error, with a Bonferroni correction for multiple comparisons resulting in a significance level set at $p < 0.05$. Additionally, effect sizes of the independent variables were expressed using partial eta squared (η_p^2) (Peat, Barton, & Elliott, 2008). Results were interpreted by 95% confidence intervals.

3. Results

The main aim of the present study was to determine the effects of *CG* position on healthy adults' knee *JPS* acuity, measured by three types of repositioning errors. Table 1 shows the descriptive data for proprioceptive target matching. We found evidence for less absolute target-matching errors when *CG* was placed below the knee. Statistical analysis, performed by ANOVA revealed a significant main effect of *CG* position ($F_{3,12} = 4.8$, $p = 0.021$, $\eta_p^2 = 0.54$), with the post-hoc analysis showing a significantly smaller error in *BK* position compared with the *CON* condition ($p = 0.026$, Fig. 2A). The analysis of the direction of error (constant error) showed significantly larger underestimation in *WK* compared to *CON* condition ($p = 0.029$, Fig. 2B). The results also indicated that subjects tended to mostly underestimate the target position in each condition (*AK*, *BK* and *CON*: 75%; *WK*: 94%). Finally, variable position errors also showed a *CG* position main effect ($F_{3,12} = 9.6$, $p = 0.002$, $\eta_p^2 = 0.71$). Post-hoc testing using Bonferroni correction revealed that subjects tended to perform the active target-matching task with significantly lower variability in *WK* position compared to *BK* ($p = 0.023$) and *CON* ($p = 0.004$) conditions (Fig. 2C).

Table 1
Effects of garment position on absolute, constant and variable errors for the right dominant (*CompDom*) and left non-dominant (*CompNon-Dom*) groups.

	<i>CompDom</i>	<i>CompNon-Dom</i>
Absolute error		
AK	5.4 (1.6)	4.4 (1.1)
BK	4.2 (1.3)	4.3 (0.7)
WK	4.8 (1.5)	3.5 (1.0)
CON	5.4 (0.5)	5.0 (0.9)
Constant error		
AK	-4.3 (5.1)	-2.6 (3.5)
BK	-2.0 (3.4)	-1.0 (1.6)
WK	-4.0 (4.4)	-1.4 (1.4)
CON	-3.1 (4.6)	-0.2 (1.6)
Variable error		
AK	4.4 (0.9)	4.9 (1.2)
BK	4.1 (0.9)	5.2 (1.2)
WK	3.9 (0.7)	4.1 (1.2)
CON	4.9 (1.3)	6.3 (1.0)

Values are mean (*SD*) of position sense errors in degrees. AK: above-knee compression garment; BK: below-knee compression garment; WK: whole-knee compression garment; CON: without compression garment

Furthermore, we failed to find differences between subjects' dominant and non-dominant leg in the absence of the CG, as shown by non-significant pairwise comparisons of *Experimental_CON* and *Control_CON* for all types of repositioning errors (all $p > 0.05$) (Fig. 3). Exploratory *rANOVAs* failed to detect modulation of the effect of placement of CG on target-matching behaviour by leg dominance, that is, interactions between CG position and groups were not significant, regardless of type of the error (all $p > 0.05$).

Evidentially, the *MRI* data revealed that the garment reduced thigh CSA by $\Delta 4.5 \text{ cm}^2$ or 3% (CON: $144.4 \pm 16.8 \text{ cm}^2$, AK: $139.9 \pm 17.2 \text{ cm}^2$, $p < 0.001$, Cohen's $d = 0.27$) and calf CSA by $\Delta 1.3 \text{ cm}^2$ or 1% (CON: $95.5 \pm 10.2 \text{ cm}^2$, BK: $94.1 \pm 10.2 \text{ cm}^2$, $p = 0.016$, $d = 0.13$).

4. Discussion

The aim of the present study was to determine the effects of CG position on healthy adults' active knee *JPS* and to measure the magnitude of soft tissue compression produced by the garment using *MRI*. In agreement with our hypotheses, we found that subjects had less absolute repositioning error in BK compared with CON condition. On the other hand, results also indicated that subjects constantly produced less *JPS* errors in the absence of the CG, but tended to perform the active target-matching task with significantly lower variability when the CG was applied on the knee joint. Furthermore, CG reduced thigh CSA by 4.5 cm^2 or 3% and calf CSA by 1.3 cm^2 or 1%. However, contrary to our hypothesis, no differences occurred in target-matching behaviour between the dominant and non-dominant leg, and CG position did not interact with leg dominance.

Unlike most previous studies, we evaluated not only the absolute but also the constant and variable errors, making it possible to detect the direction and the variability of the errors, respectively. Mean absolute position sense data showed that the compression by the BK garment used in our study seems to enhance healthy adults' knee joint proprioceptive acuity compared with CON condition (BK: $4.2 \pm 1.0^\circ$ vs. CON: $5.2 \pm 0.8^\circ$). Although subjects tended to underestimate the target positions in each CG conditions, *JPS* data considering the direction of the errors (constant error) showed that subjects constantly produced less *JPS* errors in the absence of the garment (CON: $-1.6 \pm 3.7^\circ$) compared with the condition when CG compressed the whole knee joint (WK: $-2.7 \pm 3.4^\circ$). On the other hand, variability error was significantly less in WK ($4.0 \pm 0.9^\circ$) compared with BK ($4.6 \pm 1.2^\circ$) and CON ($5.6 \pm 1.4^\circ$) conditions.

Although a recent study (Mizuno, Arai, Todoko, Yamada, & Goto, 2017) investigated if exercise performance and muscle damage are affected by a CG wearing at different areas of the lower limb (above-knee, whole leg, below-knee), the present study is the first to report on the effects of the position of a CG on active knee joint position sense. While often studied (Birmingham et al., 2000; Bottoni et al., 2015; Tiggelen et al., 2008; Van Tiggelen et al., 2008), practitioners suspected that knee bracing would limit ROM and athletes started to place CGs above or below the knee with the expectation to improve proprioception without affecting range of motion. The results of the present study are in line with this expectation and with a previous study (Ghai et al., 2018) showing that the position of the CG does affect absolute *JPS* errors so that below-knee CG vs. the absence of CG improves *JPS*. This favorable effect may be related to an increase in Golgi tendon organ activation and feedback from proprioceptors to muscle (Ghai et al., 2018; Herrington, Simmonds, & Hatcher, 2005; Van Tiggelen et al., 2008). If there is true deformation of the muscle due to compression applied by the CG, such a mechanical effect could excite Golgi tendon organs which in turn inhibit the synergistic agonist motoneuron via disynaptic connections through the Ib inhibitory interneurons and excite the motoneurons in the antagonist muscle via di- or trisynaptic connections. The absolute force threshold for tendon organs may be as little as 4 mg (Binder, Kroin, Moore, & Stuart, 1977). Therefore, high compression forces due to CGs could conceptually interfere with limb movement if used for active *JPS* measurements. Thus, it is possible that subjects may use a constant motor control strategy without the application of a CG, which resulted in less

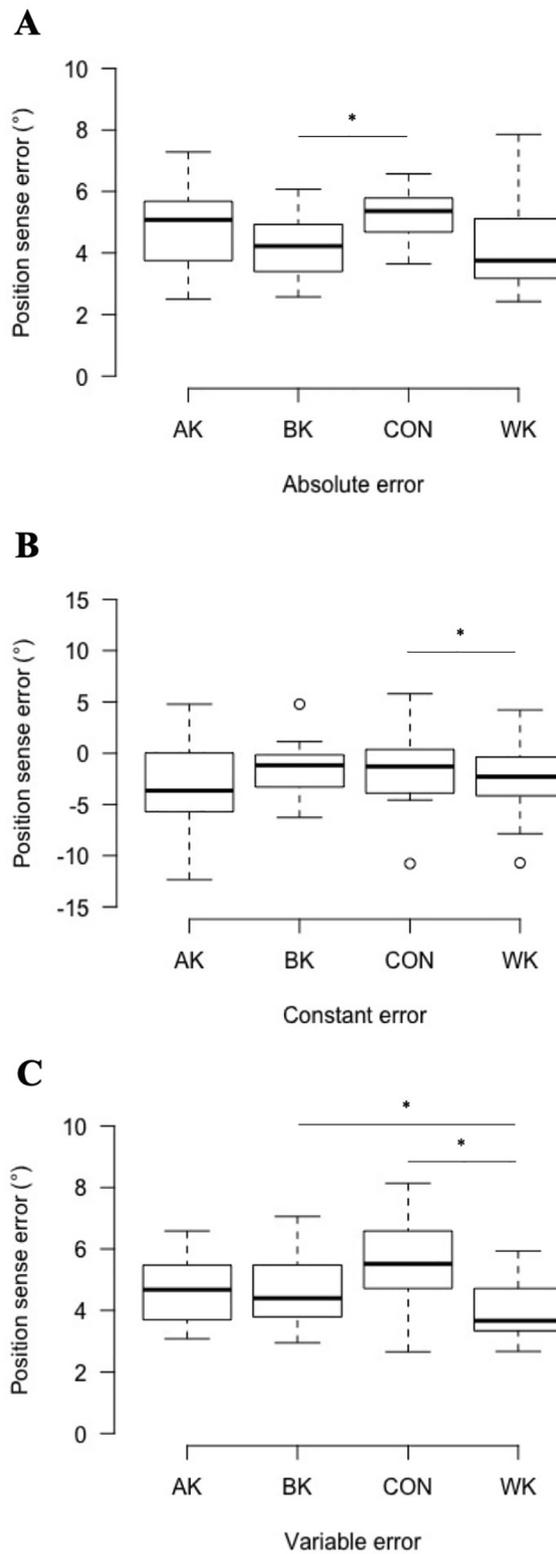


Fig. 2. Overall active repositioning errors in the knee joint. Comparison of absolute (Panel A), constant (Panel B) and variable (Panel C) errors between each garment position (AK: above-knee compression garment; BK: below-knee compression garment; WK: whole-knee compression garment, CON: without compression garment) considering all seven target angles. * $p \leq 0.05$. Vertical bars denote + 1SD.

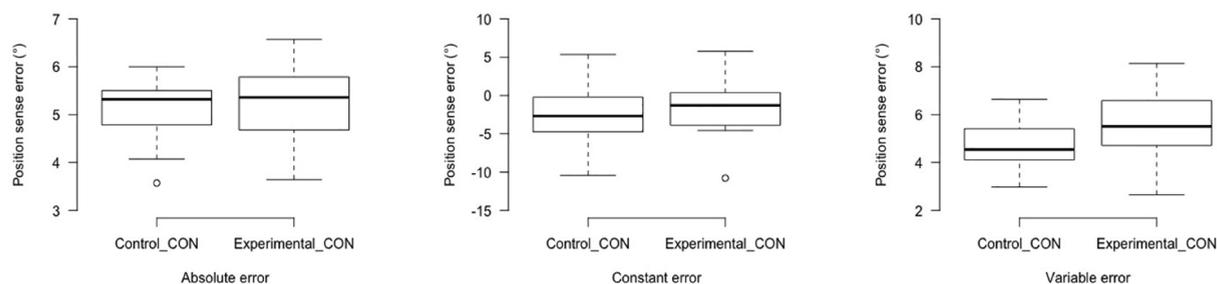


Fig. 3. Target-matching behaviour of the experimental and control leg in the absence of the compression garment, regardless of group. Comparison of absolute (Panel A), constant (Panel B) and variable (Panel C) errors between each garment position. Vertical bars denote + 1SD.

variability in *JPS* errors. In the present study, we found small but significant reductions in *CSA* of the thigh and calf ($\Delta 4.5 \text{ cm}^2$ or 3%, $\Delta 1.3 \text{ cm}^2$ or 1%, respectively) due to the compression produced by the CGs that might have been just sufficient to induce negative effects on knee *JPS*. This idea is supported by the results, showing that subjects constantly produced less *JPS* errors in the absence of the garment.

In a target-matching task, any error in *JPS* derives from two possible sources: 1) not sensing the start or 2) not sensing the target position of the limb due to the incorrect sensing of the movement threshold and/or the magnitude of movement. In the present study, no feedback was given to the subjects about their performance, it is therefore possible that the process was slow for the subject to learn the correct sensing of limb positioning and needed many more trials to reduce the error effect. Thus, it was important to determine if CG placement may affect the variability of active target-matching behaviour as variability may contribute to the central organization of voluntary movement (Latash, Scholz, & Schoner, 2002). Variability in movements is essential for flexibility and stability (Mathiassen, Moller, & Forsman, 2003). However, when increased beyond its optimal level, the neuromuscular system gets noisier and less adaptable (Stergiou, Harbourne, & Cavanaugh, 2006). On the other hand, when it is reduced below its optimal value, the individual cannot have all the beneficial effects of redundancy in the motor system (Madeleine, Mathiassen, & Arendt-Nielsen, 2008). Therefore, each condition leads to an increased chance of injury. It is possible that compression produced by the CG may induce a fatigue effect through blood flow restriction transiently bringing about the state of deafferentation. Poor or a lack of feedback due to compression-induced deafferentation effect could increase variability under the conditions of the present study. This is in line with our data, showing that subjects tended to perform the active target-matching task with significantly lower variable error in *WK* position compared to *BK* and *CON* conditions, suggesting that the compression, applied by the CG when it was placed on the knee, had favorable effects on the variability of target-matching errors compared to the *CON* condition (in the absence of the garment), without inducing deafferentation through the compression of the muscle. Although the differences were minimal (1 to 2°), this outcome may help us better understand how the application of a whole-knee CG can decrease the risk of musculoskeletal injuries during sport activities.

In addition to the position of the garment, pressure is also an important factor contributing to the inconsistencies (MacRae, Cotter, & Laing, 2011) between studies that make it difficult to determine whether CGs could improve proprioceptive acuity (Birmingham et al., 1998; Ghai et al., 2018; Herrington et al., 2005). Our results indicate that the pressure level by the above-knee and the below-knee CG was sufficient to significantly modify thigh and calf *CSA* compression, respectively, which in turn influenced knee joint active repositioning behaviour.

Some of the outcomes of the present study were not in line with the expectations. First, in line with our recent study (Negyesi et al., 2018), we found that above-knee CGs failed to improve proprioceptive acuity of the knee joint. We discussed that a lack of improvement in *JPS* may be due to an ineffective modulation of Ia afferents by the CG when the knee joint was moved passively during the repositioning task. We therefore used in the present study an active repositioning task that may be more appropriate for functional assessment of afferent paths (Kaminski & Perrin, 1996). However, just like in our previous study, we have to interpret that the compression applied by the above-knee CGs may have been insufficient to afford significant physiological changes regardless of a compression effect and garment position per se. Second, we found no differences between *CompDom* and *CompNon-Dom* groups in any CG conditions, which is not in line with previous studies showing that strongly right-side dominant participants consistently sense movements more accurately using the left joints on both the upper- and lower limbs (Galamb et al., 2018; Han et al., 2013). One of the possible reasons for this finding is that instead of using a crossover study design, participants were allocated to *CompDom* or *CompNon-Dom* groups in the present study. Between-subject differences in target matching can influence our results, however, the present study design is most likely being used to prevent memory effect, an executive control factor that is responsible for target-matching accuracy (Butler et al., 2004).

The present study has some limitations. First, active vs. passive repositioning is functionally a more relevant method to assess the afferent paths. However, when the leg is moved and held in the target angle, the effects of gravity are presumably counteracted by the dynamometer but when the subject actively moves and holds the target angle the muscle force is required to maintain leg position vary with joint angle. Thus, the quadriceps muscle activity associated with target position is quite different in the active movement compared with when the dynamometer moves and holds limb position in the target, which in turn may also contribute to the observed position sense errors. A different target angle can produce a different moment effect, which may proportionally influence the activity of the quadriceps muscle. Second, the research by Collins et al. (Collins, Refshauge, Todd, & Gandevia, 2005) showed that

stretching the skin over the anterior aspect of the thigh and patella contribute, along with muscle spindles, to knee position sense. In the present study, the CGs compressed the skin all around the thigh or calf and would, altering the output of many cutaneous receptors instead of only cutaneous receptors in a particular region of the skin. Thus, it is difficult to predict if only the CG had an effect on *JPS*. Finally, although we recorded the average forces under the garments, it was performed only after the experiment in our laboratory. Because errors were measured when the subject actively repositioned the leg, muscle contractions of the quadriceps may affect the measured pressure under the garment, therefore we strongly encourage researchers to consider detecting undergarment force during the repositioning task.

Future studies need to resolve the inconsistencies reported previously (Ghai et al., 2018; Herrington et al., 2005; Van Tiggelen et al., 2008) and separate compression and placebo effects (Mothes, Leukel, Seelig, & Fuchs, 2017) by detecting the physiological mechanisms underlying the effect of compression on target-matching behaviour. Also, it is difficult to assess the changes in proprioception after applying a CG if target-matching accuracy is already good before the investigated condition. Therefore, there is a need to use a more challenging task to avoid ceiling effects. Results from a previous study (Marini, Ferrantino, & Zenzeri, 2018) suggested a preference for proprioceptive identification of joint position rather than kinesthetic movement reproduction, so kinesthetic movement reproduction, that implies knowledge of the starting position and movement's range for accuracy, seems to be physiologically more challenging. Finally, unlike most of the previous studies, we elucidated not only the absolute but also the constant and variable errors. Giving the direction of errors at each angle and overall constant and variable error measures across all target angles is very important to detect *JPS*. For example, if a subject consistently undershoots all angles by about 5° they would have a -5° overall constant error and near zero variable error. In contrast, if a subject overshoots some target angles and undershoots others, they would have a near 0° constant error and a very large variable error, indicating very poor *JPS*. Good position sense is indicated by low constant and variable errors. Therefore, we strongly encourage researchers to analyze not only absolute but also constant and variable errors to clearly detect target-matching behaviour.

5. Conclusions

The results of the present study showed less knee *JPS* errors when a CG was applied below the knee (absolute error), regardless of leg dominance. However results indicated that subjects produced constantly less *JPS* in the absence of the CG, but tended to perform the active target-matching task with significantly lower variability when the CG was applied on the knee joint. This finding may help us better understand how the application of a whole-knee CG can decrease the risk of musculoskeletal injuries during sport activities.

Data Availability Statement

All relevant data are within the paper and its Supporting Information files.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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