Compression enhances lower-limb somatosensation in individuals with poor somatosensation, but impairs performance in individuals wth good somatosensation

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Title:

Compression enhances lower-limb somatosensation in individuals with poor somatosensation, but impairs performance in individuals with good somatosensation.

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Abstract

While research suggests that somatosensation contributes to elite athletic performance, little is known regarding the capacity of ergogenic aids (e.g., compression) to enhance somatosensation. This study assessed the effects of compression socks on functional ankle somatosensory ability, and whether any effects depended on baseline somatosensation or ankle instability. Forty-two participants performed somatosensation testing using the active movement extent discrimination analysis (AMEDA) device, whereby the accuracy that participants could identify repeated ankle inversion movements of different extents were measured. Participants performed the AMEDA test on their ‘stabilising’ and ‘kicking’ legs, with (compression; COMP) and without (barefoot control; CON) compression socks. AMEDA scores were also compared against ankle instability using the Cumberland Ankle Instability Tool (CAIT). There were no condition ($\mathrm{P} = 0.417$) or testing-leg ($\mathrm{P} = 0.507$) effects for mean AMEDA scores. When participants were ranked into tertiles based on barefoot AMEDA scores, COMP reduced ankle somatosensation in the high tertile ($P \leq 0.003$), and increased ankle somatosensation in the low tertile ($P = 0.023$, stabilising). Compression had no effect ($P > 0.05$) on AMEDA scores when participants were split into ‘low’ and ‘high’ CAIT groups. Wearing compression may amplify sensory input in a way that enhances somatosensation for individuals with poor somatosensation, but overloads input and impairs somatosensation of those with good somatosensation. Screening of barefoot ankle somatosensation may be used to identify individuals who might benefit from using compression to improve ankle somatosensation, such as individuals returning to weight-bearing activity following injury, and/or individuals with diminished somatosensation (e.g., elderly).

Key words: Neuromuscular control, ankle injury, proprioception, injury prevention

Introduction

Somatosensation is the process of incorporating both proprioceptive and tactile information arising from mechanoreceptors in our skin, muscles, and joints to provide feedback to the central nervous system regarding body position and movements in space [1]. The ability to process this information is more important for skilful tasks than normal activities [2], suggesting that somatosensation may contribute to elite athletic performance. Somatosensory sensitivity has been positively correlated with the level of elite athletic competition achieved (i.e., national ranking), which suggests athletes may have superior somatosensory ability compared with non-athletic controls. In addition, training of the somatosensory system may yield meaningful improvements in somatosensory and sensorimotor function [3], which in turn may aid athletic performance.

To date, limited research has directly investigated if compression garments can enhance somatosensation. By applying external pressure to cutaneous surfaces and joint receptors, compression garments are hypothesised to increase mechanoreceptor stimulation and subsequent afferent feedback [4]. In support of this, the wearing of compression socks [5] and arm sleeves [6] has been reported to reduce Hoffmann-reflex (H-reflex; a corticospinal neurological examination) [7] amplitude following electrical stimulation to the sciatic and median nerves, respectively. These findings indicate that compression garments can alter spinal cord excitability, which may be the result of changes in pre-synaptic Ia afferent transmission, and/or post-synaptic motor-neuron excitability [5,6]. As such, and considering tactile and muscle afferent feedback is most important to somatosensory sensitivity [8], enhanced cutaneous input via compression may allow better muscle activation and motor control [9].

In support of the hypothesis that compression can enhance somatosensation, the use of compression garments has been reported to improve performance during tasks or conditions that include a large somatosensory component. For example, compression garments have been reported to enhance hip [10], knee [11], and elbow [12] joint position sense, leg swing in participants with low neuromuscular control [13], and postural control/balance [14]. Performance benefits have also been reported whilst wearing compression garments, including kicking performance [4], baseball pitching and golf shot accuracy [15], submaximal running economy [16], and jump performance [10]; these were improvements in which a compression-induced increase in somatosensation was hypothesised to be at least partly responsible. In further support of the hypothesis that compression can enhance somatosensation, Barss et al [6] reported an improvement in reaching accuracy when participants wore compression sleeves, highlighting possible adaptations in sensorimotor control. It was hypothesised that compression may "filter" irrelevant mechanoreceptor information, thereby allowing for optimal task-related sensory information to enhance somatosensation [6]. However, compression garments may not enhance somatosensation in all instances. There is data to suggest that individuals with superior somatosensory judgement may experience a reduction in their ability to judge joint position sense when wearing compression garments [13] or braces [17,18], potentially as a result of additional and counterproductive afferent feedback or 'noise' [18]. Currently, there is no research to directly compare the effects of compression garments on somatosensory sensitivity in individuals with varying levels of baseline somatosensation.

For activities requiring upright movement/locomotion, the plantar surface of the foot and the ankle joint provide critical tactile afferent feedback regarding the body's centre of mass, as well as changing underfoot surface characteristics [19,20]. Improved feedback from this surface (e.g., via compression) may improve foot and ankle positioning, offset the detrimental effects of fatigue on technique and joint sense, and ultimately improve movement efficiency and prevent injury [21]. However, research investigating the effects of compression garments on ankle somatosensation is limited, particularly for ecologically valid movement patterns designed to replicate functional movements. As such, the aim of this study was to assess the effects of commercially available sports compression socks on somatosensory ability at the ankle joint, specifically inversion/eversion movement. Considering ankle instability impairs sensory discrimination [22] and active joint position sense [23], this study also aims to compare the effects of compression socks on ankle somatosensation in individuals with and without chronic ankle instability [24]. Somatosensation was assessed using the active movement extent discrimination apparatus (AMEDA), designed to replicate functional movement (i.e., active, weight-bearing and steady-paced movements, without constraints to non-tested limbs) [25]. It was hypothesised that compression socks would improve somatosensation (as assessed by the AMEDA), as compared with a barefoot control, consistent with previously-reported beneficial effects of compression on joint position sense and postural control/balance [10-1214]. In addition, we hypothesise that compression would improve ankle somatosensation to a greater extent in individuals with poor baseline somatosensation and chronic ankle instability, as compared with individuals with good baseline somatosensation and without symptoms of chronic ankle instability, consistent with previous suggestions [6,18].

Materials and Methods

Participants

Forty-two recreationally active participants (21 male and 21 female; age, 27 ± 4 y; height, 176.4 ± 10.5 cm; body mass, 73.8 ± 14.5 kg; physical activity levels, 247 ± 106 min of moderate-to-vigorous exercise per week) completed the study. Both males and females were included in the study as previous research has reported no sex differences in AMEDA-assessed ankle somatosensation [26]. Written informed consent was obtained prior to participation. During the initial screening process, participants were asked the question; 'Which leg would you kick a ball with?' The answer to this question was defined as the 'kicking leg', and the contralateral leg as the 'stabilising leg'. This has previously been reported as an effective method to determine leg dominance (i.e., preferred leg to kick a ball) during postural control [27,28]. Participants were also asked to complete the Cumberland Ankle Instability Tool (CAIT) questionnaire to assess subjective ratings of ankle instability, and were subsequently matched according to 'low' (0-27) and 'high' (28-30) CAIT scores [24] for each foot (Table 1). All procedures were approved by the Australian Institute of Sport's Human Research Ethics Committee (Approval Number 20160803).

Overview

The study followed a within-subject cross-over design, in which participants completed somatosensation testing on both feet, with (compression socks; COMP) and without (barefoot control; CON). All four trials were completed on the same day in a randomised and counter-balanced fashion, and, as such, participants reported to the laboratory for a single day of testing only (Fig. 1). Participants were asked to refrain from strenuous exercise (>24 h) and caffeine (>12 h) prior to the testing session, which was verified by a 24-h training and dietary recall.

Somatosensation Testing

Somatosensation testing was performed using active movement extent discrimination analysis (AMEDA). The AMEDA device is a custom-made apparatus developed to test joint position sense [21] and is a method of testing somatosensory ability at the ankle in a normal unconstrained stance (Fig. 2), without visual or vestibular sensory input. The AMEDA device consists of a footplate on a platform that can be tilted by the participant to five possible positions, resulting in ankle inversion movements between 10.5 and 14.5 degrees from the horizontal. The participant is familiarised with the five movement ranges in an introductory sequence where the different positions are set in order from smallest (position 1) to largest (position 5), and the sequence is repeated 3 times (~5 min total). Participants are then asked to identify, by moving the platform from the horizontal start position, which position number has been set. This is repeated for 50 trials, each time returning to the start position (i.e., each position is presented 10 times in a randomised sequence). Each 50-repetition trial took ~10 min, and as such the entire study duration (including familiarisation and set-up time between conditions) was ~60 min. To prevent slipping whilst inverting/everting the ankle and wearing a compression sock, a segment of grip tape (Anti-Slip Grit Strip, Croc Grip, Australia) was placed on the middle line of the footplate. This tape was in place for both the CON and COMP conditions. Assessment of ankle somatosensation via the AMEDA has previously been shown to have good test-retest reliability (ICC = 0.80) [29] when testing the same ankle multiple times. To assess the effects of compression on somatosensation in individuals with varying levels of baseline somatosensation, participants were split into tertiles (lower third, 0.5-0.65; middle third, 0.65-0.70; higher third, 0.70-1.00) based on the CON score for each foot. Participant allocation into tertiles (and CAIT groups) are reported in Table 1.

Intervention

Somatosensation testing was performed under two conditions (CON and COMP) for both the kicking and stabilising leg. The barefoot control (CON) condition required participants to perform the AMEDA somatosensation testing without shoes or socks, and the COMP condition required participants to wear a sports compression sock (2XU Elite Compression Sock, Melbourne, Australia) on the leg being tested only. The compression socks were fitted to manufacturer guidelines, which took into account foot size and calf girth. Although not directly measured in the current study, these compression socks have previously been reported to elicit compression of ~23 mmHg and ~20 mmHg at the calf and ankle, respectively [30].

Cumberland Ankle Instability Tool (CAIT)

The CAIT is a valid and reliable questionnaire for discriminating and measuring the severity of functional ankle instability [24]. It is a 9-item questionnaire in which participants are asked to rate ankle pain and instability during different movements (i.e., walking/jogging/running, making sharp turns, walking down stairs, standing on one leg, hopping, and rolling an ankle), for both feet. Each question has a range of 3-5 possible responses, representing an increasing level of difficulty for the activity concerned. Scores are assigned based on the rank of the chosen response and summated to generate a total score out of 30, with a low score indicating more severe functional ankle instability [24].

Statistical Analyses

The number of correctly identified settings were recorded for each trial. Following this, a response matrix was constructed and an area under the response curve (AUC) determined to calculate how accurately the participants were able to identify the correct setting, giving a number between 0.5 (random chance) and 1.0 (perfect ability to discriminate), as previously described [31]. Mean scores obtained from the AMEDA (with 95%

confidence intervals) were calculated for each of the conditions. Comparisons of AMEDA scores were analysed using a linear mixed model and IBM SPSS Statistics V19 (IBM Corporation, USA), with fixed effects for condition (CON vs COMP), testing leg (kicking vs stabilising), and interaction (condition x testing leg). In addition, AMEDA scores were split and aligned with 'low' (0-27) and 'high' (28-30) CAIT scores[24]. This data was analysed using a liner mixed model with fixed effects for condition (CON vs COMP), CAIT score (low vs high), and interaction (condition x CAIT score). Considering athletic expertise has been implicated as a determinant of AMEDA somatosensory scores [31], additional analyses were performed on scores split into tertiles (lower third, 0.5-0.65; middle third, 0.65-0.70; higher third, 0.70-1.00) based on the CON score (performed separately for each leg; Table 1). For this analysis, individual *t-tests* were performed to compare CON vs COMP for each tertile, on each leg, and multiple pairwise comparisons were corrected to the false discovery rate [32]. The level of significance was set at $P < 0.05$. Data are presented as mean ± 95% confidence intervals, unless otherwise stated.

Results

Kicking vs. Stabilising

There were no condition ($P = 0.417$), testing leg ($P = 0.507$), or interaction ($P = 0.551$) effects for mean AMEDA scores (Fig. 3).

CAIT Scores

There were no condition effects for the kicking ($P = 0.307$) or stabilising ($P = 0.873$) legs when comparing AMEDA scores based on ankle instability (CAIT Questionnaire Scores). There was a significant effect of CAIT score for the kicking leg ($P \leq 0.001$), but not the stabilising leg ($P = 0.724$). Specifically, AMEDA scores were higher for the high CAIT group as compared with the low CAIT group (7.6 ± 1.8%). There were no interaction effects for the kicking ($P = 0.332$) or stabilising ($P = 0.917$) legs (Fig. 4).

Tertiles

For the kicking leg, there was a significant condition effect for the higher tertile ($P \leq 0.001$), but not the lower ($P = 0.319$) or middle ($P = 0.894$) tertiles (Fig. 5a). Specifically, COMP reduced (6.7 ± 2.8%) the AMEDA score for the higher tertile, as compared with CON. For the stabilising leg, there were significant condition effects for the lower ($P = 0.023$) and higher ($P = 0.003$) tertiles, but not the middle tertile ($P = 0.550$). Specifically, COMP increased (6.5 ± 5.3 %) the AMEDA score for the lower tertile and reduced (5.1 ± 2.4%) the AMEDA score for the higher tertile, as compared with CON (Fig. 5b).

Discussion

Wearing compression socks during a weight-bearing ankle inversion/eversion task had no effect on mean ankle somatosensation scores derived from the AMEDA apparatus. However, when participants were split into tertiles based on their control somatosensation scores, sports compression socks improved ankle somatosensation in individuals with poor baseline somatosensation, and conversely reduced ankle somatosensation scores in individuals with good baseline somatosensation. These effects were most evident for the stabilising leg. In addition, participants in the high CAIT group (i.e., low severity of symptoms associated with chronic ankle instability) had better ankle somatosensation scores in the kicking leg only.

This study provides the novel observation that compression socks improved the discrimination of ankle inversion/eversion movement in individuals with poor baseline ankle somatosensation. This finding was evident in the stabilising leg only, which plays an important role in the generation and maintenance of athletic stability during tasks like kicking [33]. It has been hypothesised that compression may aid the performance of tasks requiring a large degree of stability (e.g., kicking, shooting, passing etc.), which is consistent with improvement in backward leg swing discrimination in Australian footballers with comparatively low baseline joint position sense when wearing compression shorts [13]. Other studies have also reported an improvement in joint position sense when wearing an elastic support or a brace over multiple joints of the body [17,34].

It is possible compression may tighten the skin around the ankle joint, which results in relatively more skin stretch during the inversion/eversion task; this in turn may increase cutaneous stimulation and afferent signals to the somatosensory centres [34]. Kinesiology taping has previously been used in an attempt to elicit a similar somatosensory response; however, data to support its benefit for improving somatosensory sensitivity at the ankle joint is lacking [35]. A potential reason for this is apparent inter-study differences in taping procedures and/or the smaller level of tactile feedback and cutaneous sense as compared with compression garments [35]. Compression-induced increases in skin stretch may be interpreted in the nervous system as a greater discharge of the appropriate mechanoreceptors, which could alter excitability at multiple levels of the nervous system [6]. In support of this, plantar cutaneous electrical stimulation has been reported to alter the excitability of the soleus stretch and H-reflexes, most notably in the heel [36]. Similarly, compression garments worn across the elbow joint have been reported to reduce *flexor carpi radialis* H-reflex amplitude [6], most likely due to an increase in presynaptic inhibition of the 1a afferents [37]. Considering this resulted in an increase in reaching performance, it is possible that compression acts to filter irrelevant mechanoreceptor information, thereby allowing the nervous system to obtain 'enhanced' sensory information related to somatosensation [6] and to aid in subsequent motor output. Compression may also stimulate deeper skin and muscle afferent receptors, consistent with an increase in intramuscular pressure when wearing a knee brace [38].

Another important finding was that participants with a superior accuracy of judgment without compression socks experienced a reduction in their ability to judge ankle inversion/eversion when wearing compression socks. This is consistent with previous reports [13,17,18], which have proposed a number of mechanisms to explain this occurrence. Most are related to compression adding additional and counterproductive afferent feedback or 'noise' in individuals with an otherwise already good somatosensory sensitivity. For example, it has been suggested there is a 'physiologic normal value' for somatosensation that has an upper limit, and any additional afferent stimulation may be unhelpful and confusing to the control systems [18]. In this instance, individuals with superior neuromuscular control may already be receiving sufficient feedback from internal sources, and compression may provide excessive information that cannot be adequately processed. However, it is unknown if such consequences are only short term, and future research is warranted to investigate whether this response can be minimised or improved with repeated and/or longer duration exposures.

A novel component of this study was the additional assessment of the effect of compression on ankle somatosensation relative to functional ankle instability. Functional ankle instability is characterised by episodes of recurrent ankle sprains [39], which can lead to a wide spectrum of disabilities (e.g., osteoarthritis and articular degeneration at the ankle) [40]. In addition, ankle instability is often associated with perceptions of a weak, more painful, and less functional ankle than pre-injury [41], which may ultimately contribute to ankle injury recurrence rates (in excess of 70% in some sports) [42]. As such, the current study aimed to investigate whether compression garments could enhance somatosensation in individuals with ankle instability, thereby reducing their risk of ankle injury or re-injury. We made the observation that participants with mild symptoms associated with chronic ankle instability (i.e., larger CAIT score) performed better in the ankle inversion/eversion task (kicking leg only) suggesting that ankle joint stability is important for ankle somatosensation. In support of this, functional ankle instability is related to a reduction in the ability to control ankle muscle forces [39], as well as the inhibition of the *peroneus longus* and *tibialis anterior* muscles during drop jumps [43]. When individuals were grouped based on ankle stability, compression had no effect on ankle control during the inversion/eversion task. Although contrary to the data reporting alterations in neural excitability when wearing compression [6] and nylon stockings [44], the severity of underlying pathology in functional ankle instability (e.g., impaired sensory discrimination, osteoarthritis, and/or articular degeneration at the ankle) may have masked any potential benefit of compression on these processes. Furthermore, individuals with chronic ankle instability have been reported to improve repeat-AMEDA testing at a slower rate than stable-ankle controls, suggesting chronic ankle instability affects learning strategies in somatosensory control [29].

A number of limitations with the current study must be acknowledged. Exercise-induced muscle damage (EIMD) has been reported to alter knee joint position sense up to 3 days post exercise [45], and markers of EIMD muscle damage can last over 7 days post exercise [46]. Considering participants were asked to avoid strenuous exercise for 24 h before the AMEDA testing protocol, the authors cannot discount that participants may have performed damaging exercise in the preceding days, which may have influenced the somatosensory scores. However, no participant reported acute muscle soreness in the pre-activity screening questionnaire, and as such the authors are confident that any potential effect of EIMD on somatosensory scores was minimal. Another limitation of the current study is the lack of a ‘regular’ sock (i.e., without compression) and/or footwear control condition. The rationale to exclude such conditions was based on prior reports that ankle movement discrimination is impaired with shoes and socks in netball [47] and football [20] athletes, as compared with a barefoot control. Considering most people use regular socks and shoes/boots during exercise and/or sport, the inclusion of these comparator conditions in future research would provide a more robust assessment of the effects of compression on ankle somatosensation.

Perspective:

Results from this study suggest that wearing compression socks may amplify sensory input in a way that enhances somatosensation for individuals with poor somatosensation, but overload input and impair somatosensation of those with good somatosensation (as measured with a barefoot control). As such, screening of barefoot ankle somatosensation may be used to identify individuals who might benefit from using compression to improve ankle somatosensory ability. This may have important practical applications for athletes/individuals returning to weight-bearing activity following injury (absent of chronic ankle instability), and/or individuals with diminished somatosensory sensitivity (e.g., elderly). However, any positive effect may not be long lasting and/or may only exist while compression is worn [13]. As such, research investigating whether repeated compression sock use can aid somatosensory sensitivity training is warranted.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Tables:

Table 1: Participant sub-group allocations according to the Cumberland Ankle Instability Tool (CAIT) and active movement extent discrimination analysis (AMEDA) scores.

Kicking Leg					
	CAIT sub-group		AMEDA tertile sub-group		
	Low (*n* = 22)	High (*n* = 20)	Lower (*n* = 12)	Middle (*n* = 17)	Higher (*n* = 13)
Age (y)	27 ± 5	28 ± 4	27 ± 4	27 ± 5	28 ± 4
Height (cm)	174.6 ± 11.6	178.9 ± 8.9	174.9 ± 13.8	178.6 ± 8.7	176.0 ± 9.6
Mass (kg)	71.0 ± 15.8	76.3 ± 12.4	70.1 ± 15.6	74.0 ± 13.3	76.3 ± 14.8
Stabilising Leg					
	CAIT sub-group		Tertile sub-group		
	Low (*n* = 21)	High (*n* = 21)	Lower (*n* = 13)	Middle (*n* = 14)	Higher (*n* = 15)
Age (y)	27 ± 5	27 ± 4	26 ± 5	28 ± 5	28 ± 4
Height (cm)	175.9 ± 11.3	177.5 ± 9.7	177.0 ± 12.4	174.1 ± 6.5	179.0 ± 12.3
Mass (kg)	72.9 ± 16.1	74.3 ± 12.5	68.2 ± 12.2	72.2 ± 13.5	79.5 ± 15.6

Figure Captions:

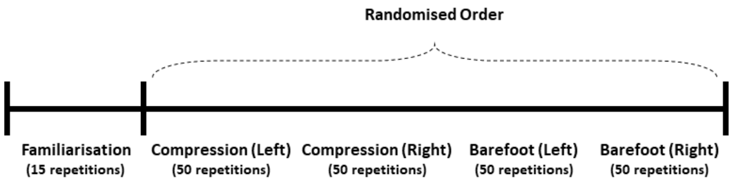

Fig. 1 Experimental overview

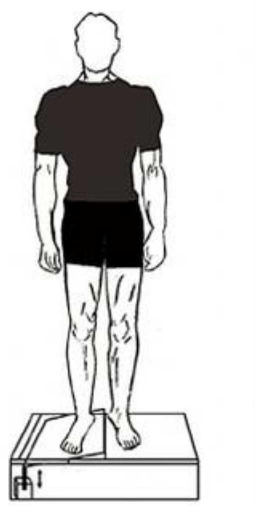

Fig. 2 Active movement extent discrimination apparatus (AMEDA) for testing ankle inversion/eversion somatosensory ability (picture replicated with permission from Han et. al. [31])

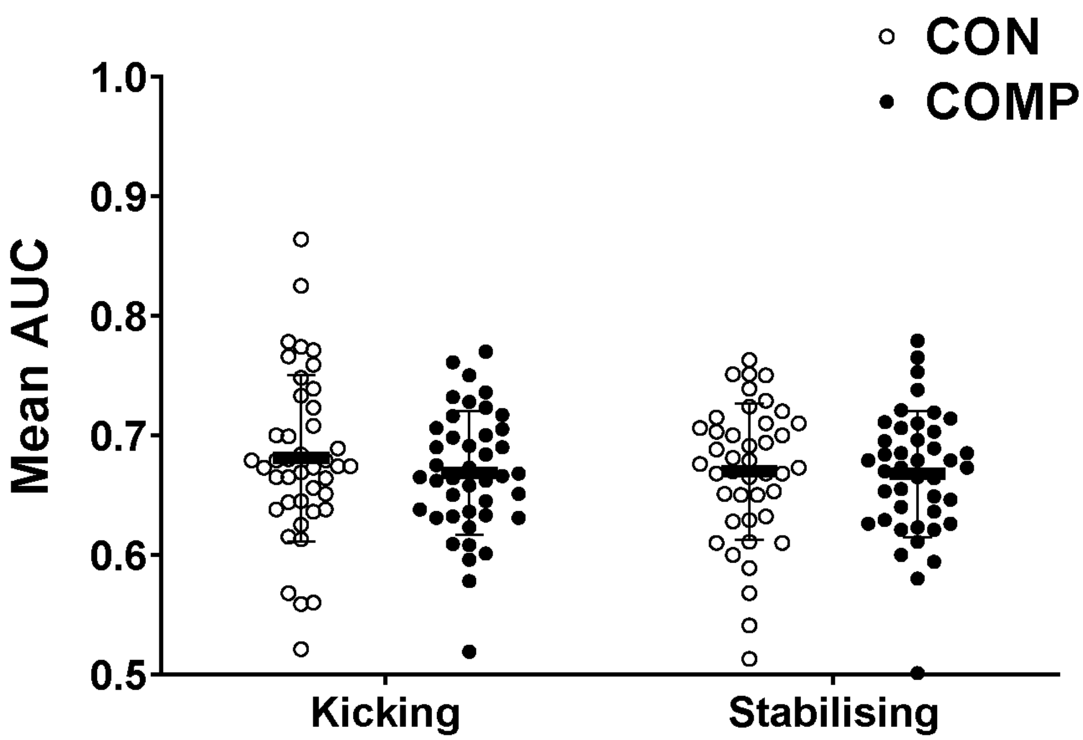

Fig. 3 Ankle proprioception scores (mean ± SD) for barefoot control (CON) and compression sock (COMP) conditions in the kicking and stabilising legs ($N = 42$). AUC, area under the curve. Data are presented as mean ± SD

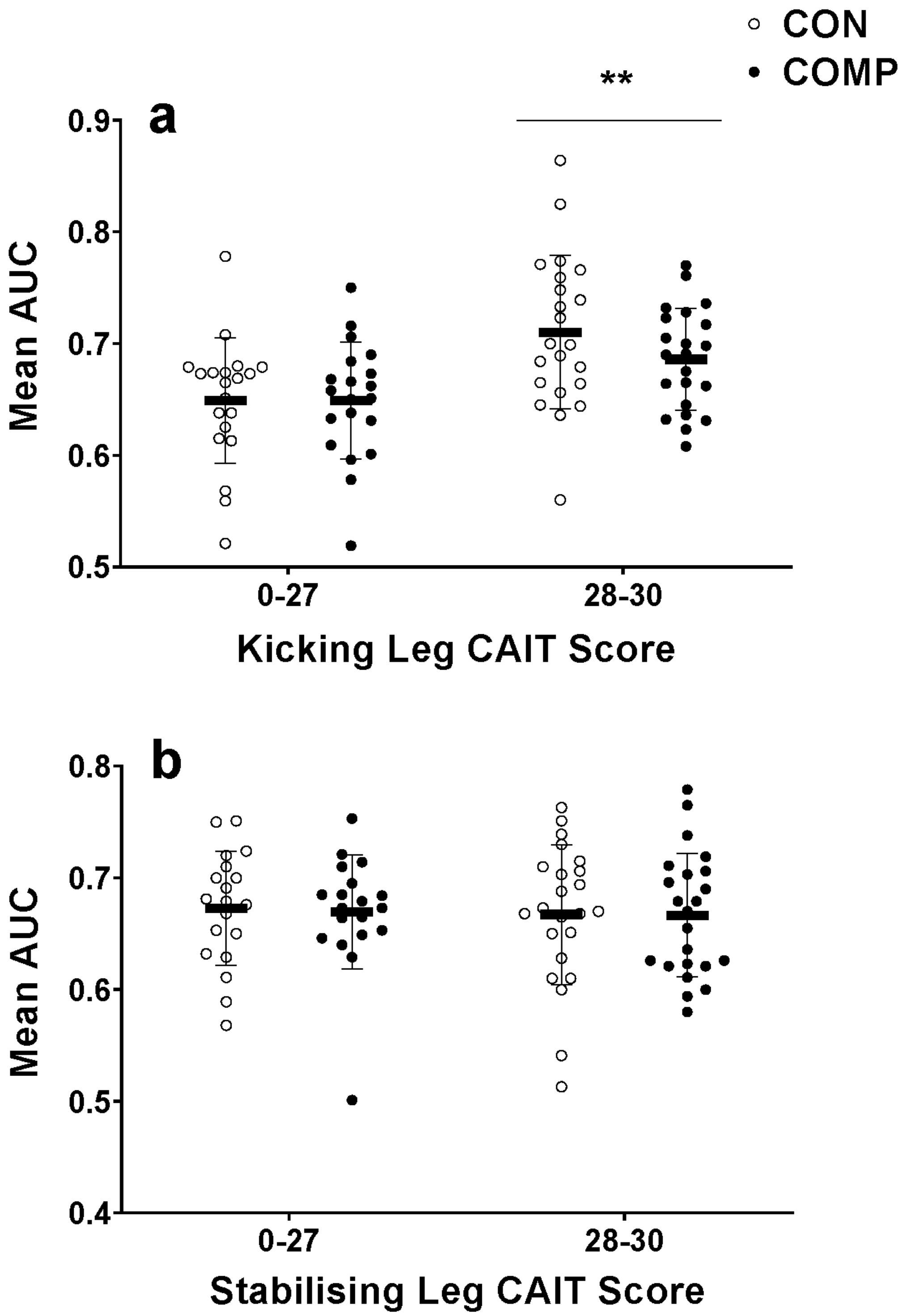

Fig. 4 Mean proprioception scores from the ankle for the kicking (a) and stabilising (b) leg, based on ankle instability scores from the CAIT Questionnaire. Scores have been split into segments equal or higher than (kicking, *n* = 20; stabilising, *n* = 21), and lower than (kicking, *n* = 22; stabilising, *n* = 21), a CAIT score of 28. ** significantly higher than 0-27; Data are presented as mean ± SD

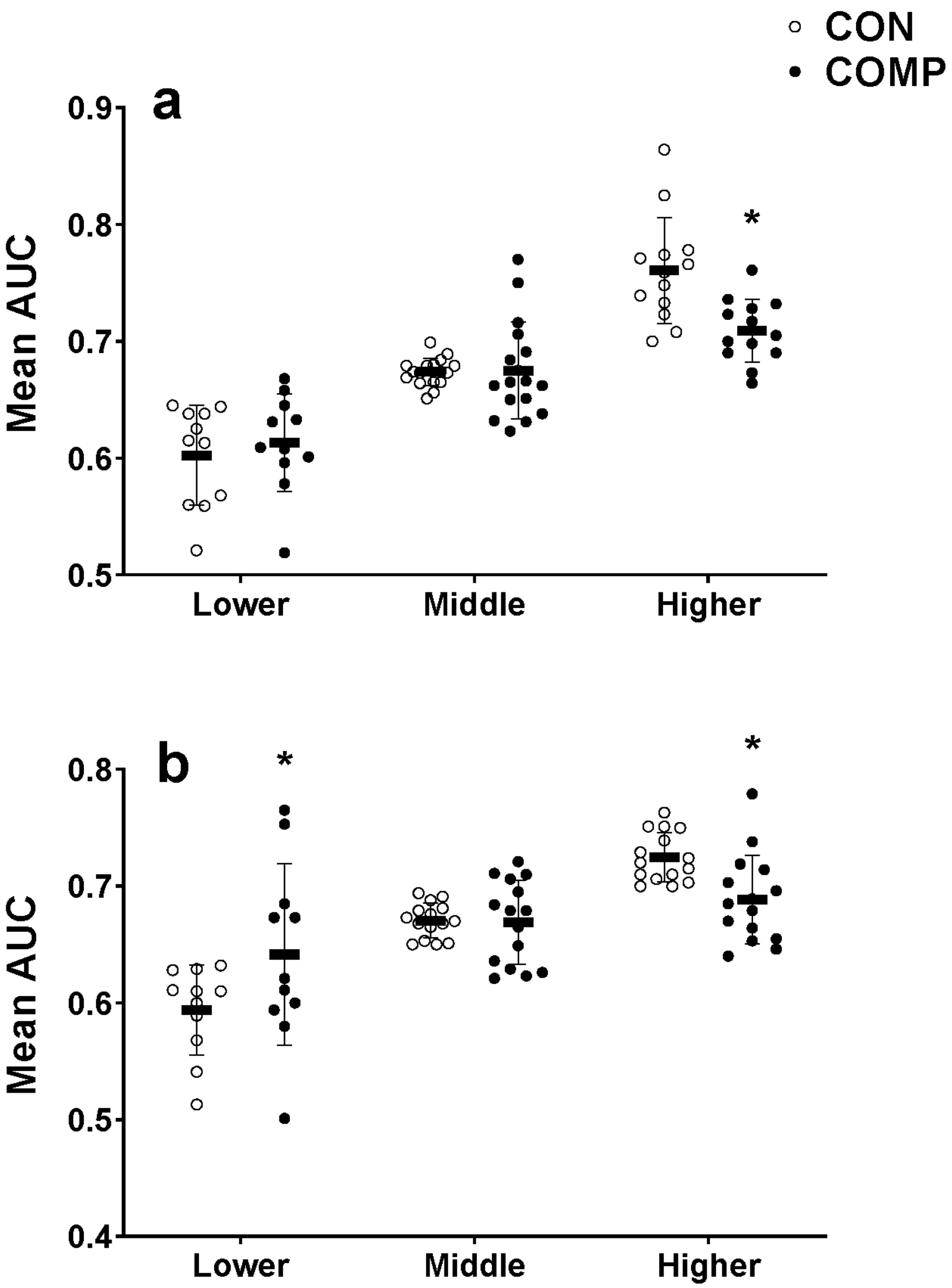

Fig. 5 Ankle proprioception scores (mean ± SD) for the kicking (a) and stabilising (b) legs, for barefoot control (CON) and compression sock (COMP) conditions. Scores have been split into a lower tertile (0.50 - 0.65; kicking, *n* = 12; stabilising, *n* = 13), middle tertile (0.65 - 0.70; kicking, *n* = 17; stabilising, *n* = 14), and a higher tertile (0.70 – 1.00; kicking, *n* = 13; stabilising, *n* = 15). AUC, area under the curve; * significantly different as compared with CON