ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2021; 28(**2**): 127-135
ISSN 2299-9590
DOI: 10.23829/TSS.2021.28.2-6

Could socks play an active role in ankle sprain prevention? A preliminary investigation

RUI M. TORRES[1,2], INÊS MESQUITA[2,3]

Abstract

Introduction. Ankle sprain represents about 10% to 30% of all recorded musculoskeletal injuries, and is one of the most prevalent injuries in sports. Thus, any type of intervention based on prevention is extremely important to reduce its incidence. Aim of Study. To compare the immediate effect of three different types of socks, namely standard, compression, and Prevent Sprain Technology (PST) socks, on the dynamic unipodal balance and ankle joint position sense in healthy participants. Material and Methods. Forty-two healthy adults, aged 20.34 ± 1.69 years old, volunteered to participate in the study. Participants were randomly assessed using three different sock models. The main measured outcomes selected for this study were the dynamic balance using the Biodex Balance System®, and the active ankle joint repositioning movement through the Biodex System Pro 4®. We used the Friedman test to compare the variables under study among the three conditions, with Dunn's post-hoc analysis and a significance level of 0.05. Results. In the Biodex Balance System® the participants had a lower Global Instability Index value with the PST socks compared to compression socks (p = 0.031), and standard socks (p = 0.005), but only lower anteroposterior (p = 0.042) and mediolateral (p = 0.026) instability indices when compared to standard socks. Regarding the ankle joint position sense, subjects with PST socks revealed lower absolute errors compared to standard socks (p = 0.007), smaller minimum errors compared to compression socks (p = 0.049), and smaller maximum errors compared to compression socks (p = 0.049) and standard socks (p = 0.008). Analysis of relative errors revealed a significant miss regarding the target joint position at higher inversion angles only with standard socks (which is potentially more dangerous) when compared to PST socks (p = 0.031), which error tends to be at lower inversion angles (which is potentially less dangerous). Conclusions. The PST socks seem to have a global positive influence on the mechanisms underlying the dynamic unipodal balance and active joint position sense, which could be an important tool for ankle sprain prevention.

KEYWORDS: Prevent Sprain Technology socks, compression socks, proprioception, joint position sense, unipodal dynamic balance.

Received: 11 May 2020
Accepted: 16 February 2021

Corresponding author: rui.torres@ipsn.cespu.pt

[1] *North Polytechnic Institute of Health, CESPU, Paredes, Portugal*
[2] *Polytechnic of Porto, Center for Rehabilitation Research (CIR), Porto, Portugal*
[3] *Polytechnic of Porto, School of Health Sciences, Porto, Portugal*

Introduction

Ankle sprain is the most prevalent sports injury [10] and is estimated to represent 10% to 30% of all musculoskeletal injuries [9]. Its mechanism of injury involves a sudden movement of the ankle beyond its normal range of motion, commonly associated with ankle inversion movement, affecting several joint structures [9]. The importance of ankle injury is evident due to its socio-economic impact. Indeed, it is estimated that in the United States alone there are more than 2 million ankle sprains per year, resulting in an annual expenditure of $3.65 billion [20]. At the same time European countries, such as e.g. the Netherlands, face the same challenge, where ankle sprains are associated with costs of around €43 million per year [26], reinforcing the importance of developing prevention strategies.

It is important to recognize the risk factors associated with this injury to implement preventive measures. In addition to intrinsic risk factors, such as postural control deficits [18], a decreased dorsiflexion range of motion [11], and a reduced joint position sense in active and passive inversion movements [15], some authors suggest extrinsic risk factors, such as the non-implementation of a proprioceptive exercise program [27] and not using external supports (orthoses and functional taping) [6]. However, orthoses and functional taping are not always used as preventive methods, because athletes often report them as uncomfortable and refer changes in the technical landing gesture [13]. Thus, even athletes who present some risk of injury do not use any external preventive method. Instead, they use standard or compressive socks as an interface between the foot and footwear. Although during the rehabilitation period they accept orthoses or bandages, athletes often return to wearing only standard socks during practice. Thus, external methods that more closely resemble the characteristics of a sock may be more easily accepted by athletes [13]. However, the effect of socks on postural and ankle stability is not well understood yet. Indeed, there are few studies in this field. In a recent research, a novel ankle-realigning sock immediately improved dynamic postural stability in a subjective ankle instability scale in individuals with chronic ankle instability [16]. Moreover, You et al. [30] found that a circumferential ankle pressure applied above the talocrural joint (to allow unrestricted ankle movement) seems to provide an additional tactile stimulation around the ankle, which reveals improved proprioceptive acuity, active stiffness in the ankle and thus, also postural stability. Nonetheless, Jaakkola et al. [12] found no differences between groups which performed 8 weeks of exercise of static and balance and postural control, leg strength and agility training, using three different types of socks, recommending further investigation examining the effects of wearing socks on motor behavior. In fact, proprioceptive information is essential for the preparation, maintenance, and restoration of stability of both the entire body (postural stability) and the segments (joint stability) [22]. This information coming specifically from receptors in the skin and the skeletal muscle system from the ankle-foot complex allows adjustments to be made in ankle position and proximal joints to successfully perform the complex motor tasks required in sports [23].

Aim of Study

The aim of this study was to compare the immediate effect of three different types of socks available in the market, namely standard, compressive, and Prevent Sprain Technology (PST) socks on the unipodal dynamic balance and the active joint position sense of the ankle in healthy participants.

Material and Methods

Participants

This is a cross-sectional study with a convenience sample. Forty-two healthy higher education students of both sexes, aged between 18 and 25 years, were included in this research. To be included in this study volunteers had to participate in mild or moderate levels of physical activity as assessed through the International Physical Activity Questionnaire (IPAQ), have fewer than four "Yes" responses in the Ankle Instability Instrument to ensure that participants had no functional ankle instability [6], and have an absence of mechanical ankle instability, tested through the anterior drawer test by an expert physiotherapist. All participants with musculoskeletal, neurological, or visual dysfunctions were excluded. At the same time, participants using common medication that directly interfered with postural control or joint position sense were also excluded. Furthermore, any participant considered an outlier regarding the range of motion was excluded, since this characteristic could affect the tasks assessed in the study. The current investigation was approved by the local Ethics Committee (EC-3392) and all the participants provided their informed written consent based on the Declaration of Helsinki.

Instruments

Dynamic balance was assessed using the Biodex Balance System® (model 950-441, United States, Biodex Medical Systems, Inc.). The Biodex Balance System used to assess postural stability consists of a movable balance platform that provides up to 20° of surface tilt over a 360° range of motion. The movable balance platform includes coordinate lines to standardize foot position on the platform and a sensing mat to record the position. The balance assessment and/or training platform measure the degree of inclination on each axis: the sagittal plane (anterior/posterior) Y-axis and the frontal plane (medial/lateral) X-axis, providing an average oscillation score in degrees. This instrument makes it possible to modify the degree of freedom of movement of the surface through twelve levels of instability, programmed according to the degree of difficulty to be used, and to evaluate two types of support, i.e. bipodal and unipodal. It provides valid, reliable, and objective measurements, in which three indices are described: global, anterior/posterior, and medial/lateral instability. Platform reliability was obtained by a calculation having the intraclass correlation coefficient reach (ICC): 0.881, which is in agreement with the Hinman study with a 95% confidence interval and an intraclass correlation coefficient of (ICC): 0.81 [12].

The joint position sense was assessed by the Biodex System Pro 4 ® (United States, Biodex Medical Systems, Inc., Shirley, NY). This instrument facilitates evaluation of the joint position sense and provides valid, reliable, reproducible and objective measurements. The reliability of the joint position sense in the isokinetic dynamometer was obtained by calculating the intraclass correlation coefficient as (ICC): 0.95, similar to the study of Drouin et al. [7], which assessed the same variable with a 95% onfidence interval, and an intraclass correlation coefficient of (ICC): 0.99.

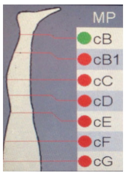
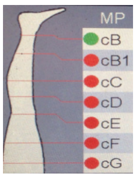
So as to assess the ankle dorsiflexion range of motion, bubble inclinometer (Baseline®, Fabrication Enterprises Inc., White Plains, NY) was used, and means of three measurements were obtained in a weight-bearing lunge [17].

In order to verify if the participants had any functional ankle instability, we used the Ankle Instability Instrument (AII), which is a reliable and valid tool [6]. The AII is organized into three components: severity of initial ankle sprain; history of ankle instability; and instability during daily life activities, and presents a total of nine closed (dichotomous) questions. The AII is confirmed by four affirmative answers, including the first question. This instrument presents ICC values ranging from 0.99 to 1.00 and a Kuder–Richardson coefficient of 0.79, suggesting a good internal consistency [24].

Sock features

Three types of socks were used in this study, all of them being commercially available in January of 2019. Table 1 provides information on the composition of

Table 1. Textile characteristics of socks under study [mean (standard deviation)]

Characteristics					
Textile fibers (composition expressed in the information leaflet for each model)		polyamide	72%	95%	90%
		cotton	26%	–	–
		elastane	2%	5%	10%
Structural properties		anti-slip material	No	No	Yes
		ankle restraint	No	No	Yes
Compression (mmHg)[a]		cB	15.70 (1.93)	13.48 (0.19)	23.34 (0.21)
		cB1	9.96 (2.25)	13.24 (0.30)	16.38 (0.67)
		cC	18.56 (1.66)	12.72 (0.13)	16.02 (1.00)
		cD	27.76 (2.45)	14.38 (0.18)	14.34 (1.00)
Elasticity (cm)[b]		cB	24.24 (0.15)	20.62 (0.13)	19.58 (0,08)
		cB1	25.68 (0.13)	20.18 (0.18)	23.10 (0.10)
		cC	26.26 (0.17)	21.16 (0.13)	25.08 (0.08)
		cD	19.18 (0.11)	23.14 (0.09)	25.56 (0.05)
		Total length[c]	106.24 (0.15)	70.14 (0.09)	81.14 (0.09)

Note: PST – Prevent Sprain Technology; cB – ankle region 1 cm above the malleolus; cB1 – region below the gastrocnemius muscle belly; cC – gastrocnemius muscle belly; cD – region 1 cm inferior to the popliteal fold

[a] MST MK V – device used for the assessment of compression – Swisslastic Ag, St. Gallen, Switzerland); [b] Electric Stretch Tester – device used for the assessment of elasticity – CETME, Italy); [c] overall length of stocking from toe to collar

each socks and the compression and elasticity per sock segment. Five measurements were made for each sock segment, and then the mean and standard deviation of these measurements were calculated. All measurements were made under the same temperature (24°C) and humidity conditions (60%).

Procedures

The study began with a detailed explanation of the procedures, as well as the delivery of informed consent and the International Physical Activity Questionnaire (IPAQ). During the procedures the researchers were always responsible for the same tasks in order to minimize the inter-observer error. A calm environment with controlled temperature was maintained in order to standardize the collection conditions. All assessments of balance and active joint position sense were preceded by a trial with the participant's personal socks to enhance familiarization with the procedures, as well as diminish the learning effect. Before starting the data collection, a bubble inclinometer, placed at 15 cm of the anterior tuberosity of the tibia, was used to evaluate the ankle dorsal flexion range of motion in the participant's dominant limb. With hands resting on a table and the dominant limb in front of the non-dominant, the participant was asked to reach the maximum dorsiflexion range of motion, moving the knee of the dominant limb in the anterior and inferior direction without allowing the heel of that foot to leave the floor. Data on the dorsal flexion range of motion under load was collected since the decrease of ankle dorsal flexion is considered a risk factor for ankle sprain [11]; this made it possible to conclude that the participants had no amplitude deficits, based on reference values, which could influence data collection [16].

Each participant was asked to perform three trials using each sock and the average value was used for the analysis. The order of the tests as well as the type of socks was randomly selected. The data was recorded in the Biodex Balance System using an instability level of 4 (level 1 is the most unstable and level 12 is the most stable); this level was selected to induce a significant instability, but at the same time it was attainable for all the participants. This analysis was based on preparatory procedures, such as positioning of the dominant foot (chosen to kick a ball) on the platform, with the foot in the same position during the three trials with the different socks to ensure that the center of pressure (CoP) remained centered with the visual reference on a display at 50 inches away from the participant at the eye level. This visual reference was only available prior to collection with the different socks and was not available during the trials. In each trial the participant was asked to remain as stable as possible for three sets of 20 seconds on a unipodal support, the support lower limb with 5° of knee flexion, the contralateral lower limb with 45° of knee flexion (measured with a Baseline® Universal Goniometer), hands on the waist, and eyes straight ahead. The recovery time between sets was 40 seconds, in which the participant remained seated on a bench, but

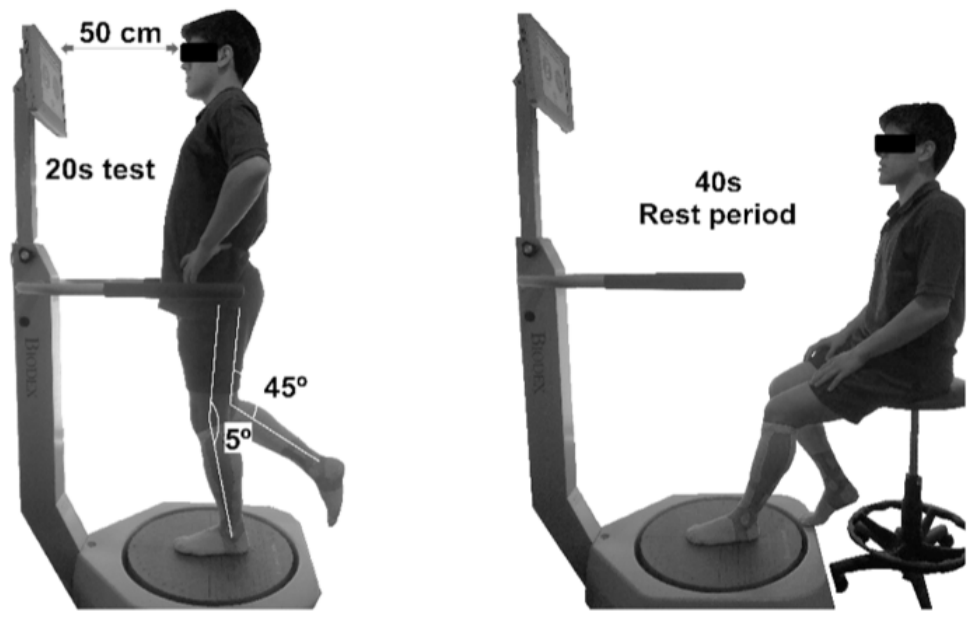


Figure 1. Experimental setup. Participant positioning on the Biodex Balance System – Dynamic Balance Assessment Procedure

with the dominant foot always in the initially defined position. Invalid testing was considered whenever the participant removed their hands from the waist or supported the non-dominant foot on the platform during the trial (Figure 1).

In the evaluation of the Active Joint Position Sense, the participant remained with the test member at 45º of knee flexion, keeping the tibia parallel to the floor and supported on the proximal third. The hip joint remained at 45º of flexion and the trunk supported on the backrest with 30º of inclination in relation to the ground. The ankle remained at 0º (plantar/dorsal flexion) and the test amplitude was defined between 15º of eversion and 30º of inversion. The participant remained blindfolded. The trials consisted of three sets of active joint repositioning, interspersed with 30 seconds of rest. Each set involved an active inversion movement (starting at the 15° eversion – start position) until the dynamometer was locked (at the 15° inversion – target position) and the participant had 5 seconds to memorize this position. Then, the researcher passively positioned the dynamometer again at 15º of eversion and asked the participant to actively assume the target position. When the participant expected to have reached the target position, they pressed a knob/switch that had been previously handed to them (Figure 2).

The order of evaluations was random for both the instrument used (Biodex Balance System or Isokinetic Dynamometer) and socks worn (standard, compression, or PST).

Statistics

The descriptive and inferential statistical analysis of the data was performed using the IBM software Statistical Package for the Social Sciences® (SPSS), version 24.0, which has a 95% confidence level (significance level of 0.05).

Regarding descriptive statistics, the mean value was used as a measure of central tendency and the standard deviation was used as a measure of dispersion. Nonparametric inferential tests were also used, since most variables did not follow normality, which was tested using the Shapiro–Wilk test. To compare the variables under study among the three conditions we used the Friedman test with Dunn's post-hoc analysis.

Results

No participants were excluded, thus the final sample consisted of 42 participants (30 male and 12 female).

Table 2. Sample characterization

	Mean	Standard deviation
Age (years)	20.34	±1.69
Height (cm)	173	±10
Mass (kg)	70.74	±15.49
Ankle dorsal flexion (degrees)	39.92	±4.64
IPAQ (MET – min/week)	4102.36	±3214.01

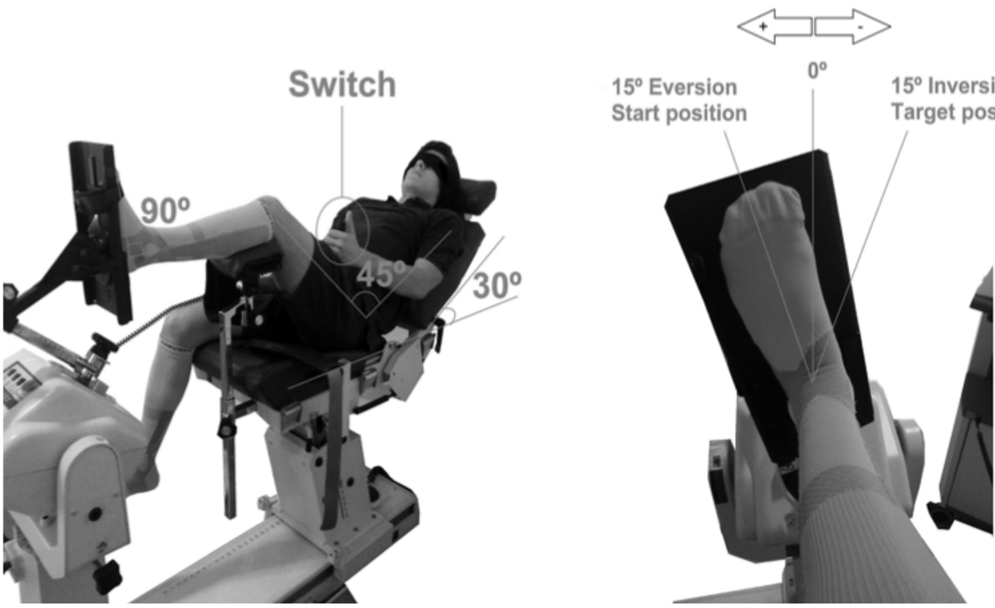


Figure 2. Experimental setup. Participant positioning on the isokinetic dynamometer for assessment of Active Joint Position Sensation Procedure

Table 3. Differences in instability indices and in the ankle joint position sense between different socks [median (interquartile range)]

		Standard (St) Median (IQR)	Compression (Cp) Median (IQR)	Prevent Sprain Technology (PST) Median (IQR)	Friedman test	p-value	Dunn's post-hoc
Instability indices variation (degrees)	global instability indices	2.000 (1.35)	2.100 (0.82)	1.900 (1.03)	11.937	p = 0.003	St > Cp (p = 1.000) **PST < Cp** (p = 0.031)* **PST < St** (p = 0.005)*
	anteroposterior instability indices	1.500 (1.23)	1.500 (0.80)	1.350 (1.03)	6.443	p = 0.040	St = Cp (p = 1.000) PST < Cp (p = 0.305) **PST < St** (p = 0.042)*
	mediolateral instability indices	1.050 (0.90)	1.000 (0.83)	0.850 (0.53)	8.680	p = 0.013	St > Cp (p = 1.000) PST < Cp (p = 0.100) **PST < St** (p = 0.026)*
Ankle joint position sense (degrees)	absolute errors	3.600 (1.80)	3.500 (3.20)	2.700 (1.83)	10.287	p = 0.006	St > Cp (p = 1.000) PST < Cp (p = 0.057) **PST < St** (p = 0.007)*
	minimum errors	1.650 (1.73)	1.350 (2.10)	0.700 (1.30)	7.176	p = 0.028	St > Cp (p = 1.000) **PST < Cp** (p = 0.049)* PST < St (p = 0.087)
	maximum errors	5.950 (4.08)	5.850 (4.50)	4.250 (2.63)	10.267	p = 0.006	St > Cp (p = 1.000) **PST < Cp** (p = 0.049)* **PST < St** (p = 0.008)*
	relative errors	–0.450 (5,83)	0.150 (5.68)	1.200 (3.60)	6.695	p = 0.035	St < Cp (p = 0.380) PST > Cp (p = 0.900) **PST > St** (p = 0.031)*

Note: St – Standard sock; Cp – Compression sock; PST – Prevent Sprain Technology sock
* significant differences between groups

Thirty-nine participants had the dominant right lower limb. Table 2 shows the sample characteristics, namely participants' age, anthropometric data, IPAQ classification and dorsal flexion range of motion.

Table 3 shows the instability indices measured on the Biodex Balance System and the ankle joint position sense with each of tahe sock models: standard, compression, and Prevent Sprain Technology (PST).

The participants had a significantly lower global instability index when they used the PST compared to the compression socks (p = 0.031) and the standard stocks (p = 0.005). They also had significantly lower anteroposterior and mediolateral instability indices compared to the standard stocks (p = 0.042 and p = 0.026, respectively).

The participants also had significantly lower absolute error level with the PST socks compared to the standard socks (p = 0.007). At the same time, when analyzing only the best (minimum error) and worst (maximum error) trials with each sock it was found that the PST allowed smaller minimum errors compared to compression socks (p = 0.049), as well as smaller maximum errors compared to compression (p = 0.049) and standard socks (p = 0.008). Analysis of relative errors revealed that participants assumed the target joint position at higher inversion angles with standard socks (potentially more dangerous) compared to PST socks (p = 0.031), which error was revealed to be at lower inversion angles.

Discussion

The aim of this study was to evaluate the immediate effect of socks on the dynamic balance in the unipodal support and on the active ankle joint position sense in healthy individuals in order to understand if they can bring additional protection to the ankle, i.e., an active protective role. To achieve this goal, three different types of socks available on the market were compared: standard, compression, and PST.

Participants improved their dynamic balance with PST socks, represented by the lowest values in the global index compared to the other socks. Furthermore, the anteroposterior and mediolateral instability indexes were also lower with PST, but only when compared to the standard socks. Additionally, PST socks positively influenced the joint position sense expressed by lower absolute, maximum, and minimum errors compared to the other sock models. The relative error associated with PST socks was recorded at a significantly lower inversion amplitude when compared to the standard sock, which may be indicative of a possible protective factor.

It is necessary to consider some methodological considerations in order to analyze the results. Our sample consisted of healthy and "active" participants classified by IPAQ and we assessed their dominant limb. Thus, the interpretation of the results is dependent on these characteristics of the sample. It is not known what the results would be if the study were conducted in sedentary individuals and/or those with chronic ankle instability.

Furthermore, it is also important to mention that the preparation, maintenance and restoration of stability in both the entire body (postural stability) and the segments (joint stability) are processes underlying the execution of all motor tasks [22]. According to Riemann and Lephart [22], the process of maintaining joint stability during human movements (functional joint stability) is accomplished through a complementary relationship between static and dynamic components. Ligaments, the joint capsule, cartilage, friction and the geometry within the joint comprise the static (passive) components. Thereby, dynamic contributions arising from the feedforward/feedback neuromotor control and the use of taping, bracing or high-top shoes have been described to provide active and passive/mechanical ankle stability, respectively [22]. Thus, we believe that the results of this study, expressed by a lower CoP dispersion with the PST during dynamic balance assessment, could be explained by the ankle restraint provided by the sock model not only in terms of the mechanical support they provide (because of the higher fiber resistance in the ankle area), but also in facilitating the activation of structures responsible for proprioceptive ankle mechanisms. This mechanical support in the ankle structures seems to allow better biomechanical alignment of the ankles, thereby optimizing the functions of the proprioceptive ankle structures [2]. Similarly, active stiffness contributes to ankle and postural stability and is provided by muscle excitation, recruitment and reflex behavior [19]. Although the stability values are better in PST than in compression socks, no significant anteroposterior or mediolateral differences were found when compared with compression socks. Therefore, it may be speculated that ankle pressure could increase stiffness by activating the proprioceptive reflex system. This hypothesis is based on the fact that ankle stiffness is greatly influenced by the reflex response [25]. Furthermore, some studies that compared the effects of visual, vestibular and proprioceptive stimuli on ankle stiffness in healthy individuals concluded that proprioceptive stimulation alone could generate substantial active ankle stiffness to stabilize the standing posture [8].

In the ankle joint position sense assessment, the 15º of unloaded inversion is in accordance with existing studies, which argue that it is this amplitude that leads to a greater risk of ankle sprain [21]. The PST globally presented the lowest values in the evaluated variables (absolute difference, maximum and minimum errors) of measurement in comparison with compression and standard socks. Spanos et al. [25] evaluated the ankle joint position sense, with and without an elastic bandage on the ankle, in a population of 4 women and 16 men, with an average age of 23 years and with a history of grade 1 or 2 sprains. They evaluated the plantar flexion (10º and 30º) and inversion (5º and 20º) movements of the ankle through an electrogoniometer (XM 180) in an unloaded position. The results with the use of anelastic bandage presented a reduction in the dispersion values, i.e., better sensation of the ankle position, compared to the participants who did not use a bandage.

The PST socks have a heterogeneous physical structure (Table 1) compared to compression socks and standard socks. The tensile strength provided by the PST material and the tension bands it presents, limiting inversion/eversion movements, possibly make the ankle limited to a dynamic range of motion. Thus, it is hypothesized that skin contact with PST may enable a tactile sensory input that stimulates cutaneous mechanoreceptors [3]. This input vertically ascends through the dorsal spinal cord to later be projected to the brainstem, cerebellum and cerebral cortex, via the thalamus [3]. At the cortical level the tactile information is processed, organized, and interpreted, resulting in descending commands that adjust the motor behavior [3]. According to Kennedy [14], cutaneous mechanoreceptors are preferentially sensitive to time-space stimuli, such as velocity, acceleration and intensity, thus contributing to a decrease in mechanical oscillations of the ankle joint [28]. According to Cordova [4], this increase in skin information and feedforward mechanisms are responsible for a pre-activation of the peroneus longus, leading to an increased dynamic control of the ankle joint during the movement. Although muscle mechanoreceptors and cutaneous receptors are known to be responsive to pressure, it was impossible to elucidate the relative functional contribution of pressure to different sensory receptors [1].

The PST socks also have an anti-slip surface at their base, which may allow for more continuous afferent stimuli to be sent, possibly improving the proprioceptive response. Therefore, these preliminary results, consistent with those obtained by Kobayashi et al. [16], suggest that dynamic postural stability could be improved by wearing a "special sock".

This study had the following limitations. First, the difficulty in ensuring participant blindness regarding the socks while they wore them. Second, the small sample size compared to studies of similar methodology [29]. Third, muscle recruitment patterns, such as the peroneal and anterior tibial muscles through electromyography, that were not measured in this study, may have contributed to active joint stiffness and may be used for control of stiffness and stability [5]. It is important to evaluate participants with a history of previous ankle sprain injury to understand the level of stability achieved. Future research is required to determine the relative contribution of the selective tensile strength on the active protection of the ankle.

Conclusions

This study concludes that PST socks seem to positively influence global instability index values during dynamic balance evaluation, as well as the active ankle joint position sense. Thus, it seems to indicate that socks may play an active role in ankle sprain protection. However, further studies on PST and other socks should be conducted to provide insight into these mechanisms.

Conflict of Interests

The authors declare no conflict of interest.

References

1. Batavia M, Gianutsos JG, Ling W, Nelson AJ. The effects of circumferential wrist pressure on reproduction accuracy of wrist placement in healthy young and elderly adults. J Gerontol a-Biol. 1999;54(4):M177-M183.
2. Briem K, Eythorsdottir H, Magnusdottir RG, Palmarsson R, Runarsdottir T, Sveinsson T. Effects of kinesio tape compared with nonelastic sports tape and the untaped ankle during a sudden inversion perturbation in male athletes. J Orthop Sports Phys Ther. 2011;41(5):328-335.
3. Bui TV, Stifani N, Panek I, Farah C. Genetically identified spinal interneurons integrating tactile afferents for motor control. J Neurophysiol. 2015;114(6):3050-3063.
4. Cordova ML, Ingersoll CD. Peroneus longus stretch reflex amplitude increases after ankle brace application. Br J Sports Med. 2003;37(3):258-262.
5. De Luca CJ. The use of surface electromyography in biomechanics. J Appl Biomech. 1997;13(2):135-163.
6. Docherty CL, Gansneder BM, Arnold BL, and Hurwitz SR. Development and reliability of the ankle instability instrument. J Athl Train. 2006;41(2):154-158.
7. Drouin JM, Valovich-McLeod TC, Shultz SJ, Gansneder BM, Perrin DH. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. Eur J Appl Physiol. 2004;91(1):22-29.
8. Fitzpatrick RC, Taylor JL, McCloskey DI. Ankle stiffness of standing humans in response to imperceptible perturbation: reflex and task-dependent components. J Physiol. 1992;454:533-547.
9. Fong DT, Hong Y, Chan LK, Yung PS, Chan KM. A systematic review on ankle injury and ankle sprain in sports. Sports Med. 2007;37(1):73-94.
10. Hertel J. Do voluntary strength, proprioception, range of motion, or postural sway predict occurrence of lateral ankle sprain? Commentary. Brit J Sport Med. 2006;40(10):824-828.
11. Hinman MR. Factors affecting reliability of the biodex balance system: a summary of four studies. J Sport Rehabil. 2000;9(3):240-252.
12. Jaakkola T, Linnamo V, Woo MT, Davids K, Piirainen JM, Gråstén A. Effects of training on postural control and agility when wearing socks of different compression levels. Biomed Hum Kinet. 2017;9(1):107-114.
13. James LP, Kelly VG, Beckman EM. Injury risk management plan for volleyball athletes. Sports Med. 2014;44(9):1185-1195.
14. Kennedy PM, Inglis JT. Distribution and behaviour of glabrous cutaneous receptors in the human foot sole. J Physiol. 2002;538(Pt 3):995-1002.
15. Kobayashi T, Tanaka M, Shida M. Intrinsic risk factors of lateral ankle sprain: a systematic review and meta-analysis. Sports Health. 2016;8(2):190-193.
16. Kobayashi T, Watanabe K, Ito T, Tanaka M, Shida M, Katayose M, et al. The effect of novel ankle-realigning socks on dynamic postural stability in individuals with chronic ankle instability. Int J Sports Phys Ther. 2019;14(2):264-272.
17. Konor MM, Morton S, Eckerson JM, Grindstaff TL. Reliability of three measures of ankle dorsiflexion range of motion. Int J Sports Phys Ther. 2012;7(3):279-287.
18. Martin RL, Davenport TE, Paulseth S, Wukich DK, Godges JJ; Orthopaedic Section American Physical Therapy Association. Ankle stability and movement coordination impairments: ankle ligament sprains. J Orthop Sports Phys Ther. 2013;43(9):A1-A40.
19. Nielsen J, Sinkjaer T, Toft E, Kagamihara Y. Segmental reflexes and ankle joint stiffness during co-contraction

of antagonistic ankle muscles in man. Exp Brain Res. 1994;102(2):350-358.
20. Osborne MD, Rizzo TD, Jr. Prevention and treatment of ankle sprain in athletes. Sports Med. 2003;33(15):1145--1150.
21. Refshauge KM, Kilbreath SL, Raymond J. The effect of recurrent ankle inversion sprain and taping on proprioception at the ankle. Med Sci Sport Exer. 2000; 32(1):10-15.
22. Riemann BL, Lephart SM. The sensorimotor system, part II: the role of proprioception in motor control and functional joint stability. J Athl Train. 2002;37(1):80-84.
23. Sasagawa S, Ushiyama J, Masani K, Kouzaki M, Kanehisa H. Balance control under different passive contributions of the ankle extensors: quiet standing on inclined surfaces. Exp Brain Res. 2009;196(4):537-544.
24. Silva DCF, Vilas-Boas JP, Mesquita CC, Maia J, Santos R, Peixoto TAT, et al. Cross-cultural adaptation and measurement properties of the Portuguese version of the Ankle Instability Instrument. Trends Sport Sci. 2018; 4(25):187-194.
25. Spanos S, Brunswic M, Billis E. The effect of taping on the proprioception of the ankle in a non-weight bearing position, amongst injured athletes. The Foot. 2008;18(1):25-33.
26. Verhagen EA, van Tulder M, van der Beek AJ, Bouter LM, van Mechelen W. An economic evaluation of a proprioceptive balance board training programme for the prevention of ankle sprains in volleyball. Br J Sports Med. 2005;39(2):111-115.
27. Wedderkopp N, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball. A prospective intervention study. Scand J Med Sci Sports. 1999;9(1):41-47.
28. Wheat JS, Haddad JM, Fedirchuk K, Davids K. Effects of textured socks on balance control during single-leg standing in healthy adults. Procedia Engineer. 2014;72:120-125.
29. Wilczynski J. Postural stability in goalkeepers of the Polish national junior handball team. J Hum Kinet. 2018;631:61-170.
30. You SH, Granata KP, Bunker LK. Effects of circumferential ankle pressure on ankle proprioception, stiffness, and postural stability: a preliminary investigation. J Orthop Sports Phys Ther. 2004;34(8):449-460.