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Sensory and Tactile Comfort Assessment of Sub-Clinical and Clinical Compression Socks on Individuals with Ankle Instability

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Abstract: This study aims to quantify wearers' perceived sensory/tactile comfort responses to clinical and sub-clinical compression socks before, during, and after several activities (postural stability tasks, donning, and doffing). Through purposive sampling, the researchers recruited 20 participants (11 male and 9 female) aged 21.5 ± 2 years. Among all participants, 40% had chronic ankle instability, 30% were copers, and 30% were healthy control groups. Sensory/tactile and movement comfort were assessed using a comfort 8-item questionnaire in a wear trial. The findings exhibit that the tested clinical socks are more comfortable than subclinical socks regardless of the participant types. The strongest positive correlation was between material appearance and hand feel (r = 0.84, ** $p < 0.01$) and between 'no red marks' and non-itchiness (r = 0.72, ** $p < 0.01$). Additionally, no statistically significant differences in comparisons of comfort assessment measures were reported. However, due to the consistency of the trends in differences, the researchers suggest that these findings warrant additional research using a more robust sampling technique. According to the findings of this study, a higher-pressure level compression sock may be preferable for patients with ankle stability issues, as there is no significant evidence for a comforting outcome.

Keywords: compression socks; comfort scale; postural stability; ankle instability; sensory/tactile comfort

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1. Introduction

Ankle injuries are common in sports that cause 10% to 30% of all sporting injuries and 40% to 56% of injuries in particular sports (e.g., volleyball, soccer, cheerleading, gymnastics, softball, and floorball) [1]. Sprains make up approximately 80% of all ankle injuries [1], and lateral ankle sprains (LAS) account for more than 80% of sprains [2]. LAS is one of the most prevalent types of injury experienced in athletics, military operations, and recreational activities [3–6]. According to several studies, research indicates that 30% of first-time LAS patients experience chronic ankle instability (CAI) [7,8]. Defined as a recurring episode of *giving way* to the ankle's lateral side, CAI often results in persistent (chronic) discomfort and pain [9]. Conversely, "coper" is a term used to define people who cope with instability issues caused by an initial LAS [10]. To heal from these types of ankle injuries, recreational and professional athletes can wear compressive socks to enhance performance or expedite recovery following training or competitions [11,12]. However, the research related to these comfort issues of compression socks is limited, and this topic requires a further investigation of different pressure levels of compression socks and participant responses to comfort assessments when undertaking postural stability activities.

1.1. Compression Socks

Compression socks are high elasticity/recovery compression garments that exert pressure on the lower portion of the leg intended for compression therapy [13]. A sock gently pushes on the users' legs and ankles in compression therapy, boosting blood circulation from the legs to the heart. These socks may also mitigate the issues of muscle soreness, fatigue, and lower limb pressure [12,14,15]. Compression socks are available in various lengths (mid-calf to gull tights) with varying pressure levels measured in millimeters of mercury (mmHg). The European Committee for Standardization designates three categories of clinical/subclinical grade compression socks based on pressure ranges: mild (between 15 and 21 mmHg), moderate (between 20 and 30 mmHg), and firm (between 30 and 40 mmHg) [16,17]. The ability to control one's body position in space for movement and balance is postural stability [18]. Different studies reported that a long-standing period leads to an individual's discomfort [19,20]. So, standing postural stability tasks might relate to the wearer's perceived comfort. In one study on postural control and agility, Jaakkola et al. [21] used three different pressure levels of compression socks: clinical (compression level 20–40 mmHg), sub-clinical (compression level < 20 mmHg), and regular socks without compression. The results indicate no variations in performance between the three socks for performing tasks (i.e., static, and dynamic balance, postural control, agility). Additionally, the findings showed that when combined with a training program, sub-clinical level compression socks can improve motor behavior in physically active persons [21]. Despite being an effective therapy for injury prevention or recovery, users are not always eager to wear compression socks due to the difficulty of donning (putting them on), doffing (taking them off), and perceived discomfort after prolonged use [22]. Because the skin in contact with the compression sock is susceptible to irritation, compression socks' comfort features are crucial for patient compliance and for any rehabilitation benefits, thus warranting more research on the comfort assessment of compression socks.

1.2. Comfort Assessment

Comfort is one of compression socks' fundamental necessities for patients with foot- and ankle-related injuries. As compliance (properly wearing compression garments) plays an essential role in patients' treatments, such as leg ulcer therapy [23], caregivers and therapists are concerned about a product's comfort assessment and its impact on use. Ayala et al. [24] suggested comfortability (49.4%) as one of the main reasons for non-compliant use of socks, among others (e.g., too challenging to put on, itching, sweating, ineffective, unattractive, and other unidentified causes). Donning difficulty and user discomfort are often directly attributed to the sock's friction against the skin. Increased friction between the compression socks and the skin makes it more challenging to wear them [25]. In addition, fabric characteristics impact users' comforts, such as the feeling on users' skin or irritations, e.g., discomfort wearing wool and nylon socks due to their higher friction coefficients compared to cotton and silk [26]. As compression socks come into close contact with the skin, heat transmission occurs through the socks via conduction. Several parameters are associated with this conduction, such as thermal conductivity, air permeation, and thermal effusivity [27]. Changes in thermal perceptions can lead to discomfort assessments or affect user compliance. Fabric surface features, fiber qualities, and moisture at the skin–textile interface play a significant role in defining compression socks' tactile and sensory comfort [25]. In one study, Gupta et al. [28] investigated the use of elastic knitted fabric to produce compression garments that significantly increase the wearers' comfort levels. In a related study on a similar comfort assessment, the researchers showed that rib-structured compression socks were better than single jersey compression socks in terms of easiness and enhanced comfort [27]. However, whether wearing different pressure levels of compression socks affects the comfort of the wearer or not remains unclear and needs further investigation, especially when undertaking postural stability activities.

1.3. Wear Trials

Wear trials are the most effective assessment of any clothing material's performance, comfort, usage, and adaptability. Different studies investigated a wide range of wear trials to measure the comfort of compression socks. For example, in 2015, Carpentier et al. [29] conducted an experiment with 20 females between 68 and 85 years of age who were not suffering from a severe disability. The participants randomly donned, wore for three hours, and doffed five pairs of compression socks (15–20 mmHg) and answered a questionnaire about difficulties and discomfort. The results indicated that the sock's foot and heel insertions and removal were challenging, despite their increased comfort when worn [29]. Treseler et al. [30] conducted a comfort assessment of two types of socks (regular and compression). Nineteen female participants participated in this assessment after two 5 km performance run activities took place over the duration of one week. After each session, participants completed a subjective questionnaire assessing the comfort and likeability of the socks they wore during the session. Participants scored socks on a scale of 1 to 5 on their comfort level, performance benefits, ability to decrease muscular pain and stiffness, and future use in training and competition [30]. However, in these wear trials, the comfort parameters mentioned above were insufficiently comprehensive and specific to accurately reflect wear comfort in human comfort responses, which led to more investigation.

This study aims to quantify the wearers' perceived sensory/tactile comfort responses to compression socks of different pressure levels during activities (postural stability tasks, donning, and doffing). The findings of this wear trial will provide insights into the treatment or regular usage of compression socks for people with ankle stability issues to improve their ankle condition.

2. Materials and Methods

2.1. Samples

Wear trials used two types of compression socks, sourced from Elite® (China) and publicly available, classified as clinical (CL) and subclinical (SC). Clinical compression socks have a compression level of >20 mmHg and provide relief from varicose veins, deep vein thrombosis, and post-sclerotherapy. Conversely, subclinical compression socks have a compression level of between 15 and 20 mmHg, which indicates that the amount of compression will not fall below 15 mmHg and not exceed 20 mmHg. This pressure level slightly alleviates severe swelling, achy muscles, and varicose veins [31]. One prior study used similar target pressure levels in a study to improve motor performance during agility and postural stability tasks [21]. Both compression socks are knee-high and suitable for runners, joggers, athletes, hikers, or office workers, regardless of gender. They provide leg and foot support, reduce swelling, boost endurance, and reduce fatigue. There is no variation in compression socks design, and the fabric contents are 85% nylon, 10% polyester, and 5% copper fiber (Figure 1).

2.2. Participants

Mississippi State University's Institutional Review Board (IRB) approved participant involvement and followed the code of Ethics for Research Involving Human Subjects. Before the study, participants completed written consent forms and were thoroughly informed about the procedures for the wear trials, testing methods, and physical activity readiness questionnaire (PAR-Q) to confirm ongoing diseases. After these procedures, the researchers recruited 20 participants (11 male and 9 female) (age: 21.5 ± 2 (range 19–30) years; height: 169.6 ± 9.2 (range 154.94–187.96) cm; weight: 72.1 ± 16.5 (range 48.97–101.13) kg) through purposive sampling from the university community. Participants were grouped into controls (CON)—healthy individuals (seven participants) with no history of any ankle sprains or injuries, coper (COP)—history of ankle sprains and chronic ankle instability and with a score of 22 and above on the Ankle Joint Functional Assessment Tool (AJFAT; seven participants), and (CAI)—history and recurrence of ankle sprains and with a score less than 22 on the AJFAT (six participants). Among all participants, 40% had chronic ankle instability (CAI), 30% were copers (COP), and 30% were healthy control (CON) groups. Additionally, 40% of participants' right legs, 35% of participants' left legs, and both legs of one participant were injured.

Figure 1. An example of the clinical (left) and sub-clinical (right) compression sock used in the study.

2.3. *Comfort Assessment during Different Standing Postural Stability Tasks*

Researchers utilized a comfort scale from 0 to 10, with 0 being the worst and 10 being the best. To minimize recall bias, participants completed a series of comfort questionnaires using scales for material and hand feel before wearing the samples, itchiness, red marks after wearing the samples, comfort during postural stability tasks, comfort during donning, and comfort during doffing. Wear trials occurred in a controlled air-conditioned lab with the temperature maintained at 22 ± 2 °C. All participants were tested for standing balance activity, which included a static standing on both legs, followed by the modified clinical test of sensory integration on balance (mCTSIB), and finally, a limit of stability (LOS) test, initially in a barefoot condition and when wearing both sub-clinical and clinical compression socks (without shoes) presented in a counter-balanced assignment, with five-minute rests between sock types. Static standing involves standing on a stable surface with eyes open; the mCTSIB is a series of four postural stability tasks (eyes open, stable surface, eyes closed on a stable surface, eyes open on an unstable surface, and eyes closed on the unstable surface), and the LOS consisted of standing and leaning in both forward and backward directions as well as to the right and left directions, without losing balance. These tests were chosen based on previous postural stability assessments commonly used in clinical settings [32,33]. All testing procedures were completed on the same day, and it took about one hour and 15 min to complete the procedure.

This investigation used two primary dimensions, sensory/tactile and movement, for comfort responses related to compression socks. Sensory/tactile means our sensation of touch that transmits to our brains via various sensory receptors in our skin. Sensory/tactile comfort includes the softness/coarseness and smoothness/hairiness of the fabric sensed by our receptors. Tickle, or mild sensory discomfort, results from a stimulation due to the hairiness of the fabric, whereas a particular type of pain nerve can cause a prickle sensation. Additionally, fabric allergies may cause skin irritation and itchiness due to the protruding fibers in the fabric. Overall, tickle, prickle, and itch are unpleasant (discomfort) sensations for the users [34,35]. Researchers measured comfort during movement, including several tasks (i.e., postural stability task, donning, doffing, overall comfort, and adoption). Postural stability, donning, and doffing may influence the convenience and perceived comfort of the compression socks before, during, and after these activities. Therefore, those criteria might be barriers to the overall perceived comfort of the users.

2.4. Data Analysis

All data were prepared and analyzed using the Statistical Package for Social Sciences (SPSS V28.0, Chicago, IL, USA). Descriptive statistics included means and standard deviations of the eight normalized comfort scores for two socks provided by twenty individuals. Spearman's correlation test quantified the links between the subjective comfort measures. One-way analysis of variance (ANOVA) determined any difference in comfort assessment between groups.

3. Results

3.1. Sensory/Tactile Comfort

Table 1 presents the means of two types of socks, including the measures for materials and hand feel before wearing, and non-itchiness and no red marks after wearing, based on comfort. The comfort scale, ranging from 0 to 10, represents 0 as the worst and 10 as the best. In general, the mean score of clinical socks (materials appearance 7.1 ± 1.8, hand feel 7.3 ± 1.6, non-itchiness 8.3 ± 3.1, and no red marks 8.2 ± 3.3) higher than subclinical socks (materials appearance 6.7 ± 2.3, hand feel 6.9 ± 2.1, non-itchiness 8.3 ± 2.4, and no red marks 7.8 ± 3). In terms of participants, as shown in Table 2, the comfort means of chronic ankle instability (CAI) subjects were the lowest in both materials, 6.5 ± 3.0, and hand feels, 6.9 ± 2.6, than the other two subjects, whereas the comfort means of copers (COP) was the highest in both non-itchiness, 8.5 ± 2.5, and no red marks, 8.9 ± 2.4, categories.

Table 1. Means scores of sensory/tactile comforts based on sock types.

	Before Wearing		After Wearing	
Sock Types	**Materials**	**Hand Feel**	**Non-Itchiness**	**No Red Marks**
SC	6.65 (2.32)	6.85 (2.13)	8.25 (2.45)	7.80 (3.02)
CL	7.15 (1.84)	7.35 (1.63)	8.35 (3.10)	8.25 (3.27)

Note: All data are expressed as mean (SD).

Table 2. Means scores of sensory/tactile comforts based on participant types.

	Before Wearing		After Wearing	
Participant Types	**Materials**	**Hand Feel**	**Non-Itchiness**	**No Red Marks**
COP	7 (1.67)	6.94 (1.81)	8.44 (2.5)	8.88 (2.45)
CAI	6.5 (3.06)	6.92 (2.61)	8 (3.84)	6.92 (4.01)
CON	7.17 (1.4)	7.5 (1.09)	8.42 (1.88)	8 (2.8)

Note: All data are expressed as mean (SD).

Assumption testing indicated a normal distribution and no violation of linearity assumption for the four comfort variables. Spearman's correlations identified the intercorrelations of the variables. Table 3 shows that the correlation coefficients (n = 40, df = 38) between the sensory/tactile comfort variables before and after wearing the compression socks were significantly correlated. The strongest positive correlation, which would be considered a considerable effect size, was between the material appearance and hand feel (r = 0.84, ** $p < 0.01$) and between the absence of red marks and non-itchiness (r = 0.72, ** $p < 0.01$). This correlation means that participants who gave the best comfort score for material appearance were highly likely to score high on hand feel. However, materials were also positively correlated with the scores of non-itchiness (r = 0.51) and no red marks (r = 0.55).

Table 3. Spearman's correlation matrix of sensory/tactile comfort.

	Material	**Hand Feel**	**Non-Itchiness**	**No Red Marks**
Material				
Hand feel	0.84 **			
Non-itchiness	0.51 **	0.38 *		
No red marks	0.55 **	0.45 **	0.72 **	

** $p < 0.01$. * $p < 0.05$.

3.2. Comfort Comparison between Sock Types

One-way ANOVA was used to investigate the differences in comfort assessment between clinical and sub-clinical compression socks. In terms of comfort of the material and hand feel before wearing, there were no significance between groups, F (1, 38) = 0.57, $p = 0.455$, and F (1, 38) = 0.69, $p = 0.410$, respectively. Similarly, the results indicated no significant difference in comfort after wearing both socks and doing several activities (postural activity, donning, and doffing). Overall, there was no statistically significant difference among all categories of comfort assessment of compression socks. See Table 4.

Table 4. One-way ANOVA summary table comparing comfort assessment between compression sock types (clinical vs. subclinical).

		Df	**SS**	**MS**	**F**	***p***
Before wearing	Material	1	2.5	2.5	0.57	0.455
	Hand feel	1	2.5	2.5	0.69	0.410
After wearing	Non-itchiness	1	0.1	0.1	0.01	0.910
	No red marks	1	2.03	2.03	0.20	0.654
Activities	Postural activity tasks	1	4.9	4.9	2.70	0.109
	Donning	1	2.03	2.03	0.44	0.510
	Doffing	1	5.63	5.63	2.28	0.139
Overall comfort	Comfort adoption	1	0.9	0.9	0.63	0.434

3.3. Comfort Comparison between Participant Types

A one-way ANOVA was used to investigate the differences in comfort evaluation between healthy controls (CON), copers (COP), and chronic ankle instability (CAI) individuals. There was no significant difference between participant groups in terms of material comfort and hand feel before wearing, with F (2, 37) = 0.326, $p = 0.724$ and F (2, 37) = 0.37, $p = 0.692$, respectively. Table 5 indicates no significant differences in comfort ratings given by the participants after wearing both socks and participating in various activities (postural activity, donning, and doffing). Overall, results indicate no statistically significant differences in compression sock comfort across all participant categories; see Table 5.

Table 5. One-way ANOVA summary table comparing comfort assessment between participant groups (control, copers, and chronic ankle instability).

		Df	SS	MS	F	*p*
Before wearing	Material	2	2.9	1.47	0.32	0.724
	Hand feel	2	2.75	1.37	0.37	0.692
After wearing	Non-itchiness	2	1.55	0.77	0.1	0.908
	No red marks	2	26.31	13.15	1.38	0.264
Activities	Postural activity tasks	2	7.92	3.96	2.22	0.123
	Donning	2	8.39	4.20	0.93	0.405
	Doffing	2	2.71	1.35	0.52	0.600
Overall comfort	Comfort adoption	2	2.15	1.07	0.74	0.482

4. Discussion

Maintaining an upright standing balance in different challenging environments is essential for human mobility. With the foot being the contact point between the individual and the environment, completing a closed kinetic chain, it is vital to assess the impact of compression socks on balance and postural stability tasks. Previous literature has assessed the impact of compression socks on different postural stability tasks and reported beneficial effects among several age groups and populations (athletic and clinical) [21,36,37]. However, while such research already exists, the impact of these compression socks on comfort assessments is not widely reported. Hence, the current study focused on comfort assessment using clinical and sub-clinical compression socks, especially on individuals with ankle instability.

Therefore, this study aimed to measure the ankle instability of an individual's sensory/tactile comfort responses to clinical and sub-clinical compression socks during postural stability tasks. The findings showed no statistically significant differences among all categories of comfort assessment in terms of compression socks. Additionally, in terms of materials, hand feel, and different activities, all participants did not identify feeling significant differences before and after wearing the socks.

4.1. Sensory/Tactile Comfort

Skin irritation occurs due to the physical qualities of long and robust protruding textile fibers, which were able to penetrate the skin cell membranes when subjected to friction, resulting in moderate irritation of the skin surface. In addition, skin sensations are closely related to the surface characteristics of the materials that come into contact with the skin [26]. As a result, fabric surface characteristics, fiber properties, and moisture at the skin–textile interface play a critical role in determining compression socks' tactile and sensory comfort [25].

Compression socks' material quality and hand feel affect the sensory/tactile comfort of the participants. These participants assessed the material quality of socks by visual perception, whereas hand feel was an immediate subjective sense induced by skin contact with materials. The results indicate no significant differences between comfort perceptions of the clinical socks and subclinical socks. For example, chronic ankle instability (CAI) participants perceived both socks as less comfortable before wearing by their visual appearance in terms of socks material and hand feel than the other two subjects, whereas copers (COP) felt that the same socks were comfortable after wearing. Additionally, the findings indicated that the participants who gave the best comfort score for material appearance were highly likely to give a high score for hand feel. Materials were also positively correlated with the scores of non-itchiness and the absence of red marks. Researchers note that no significant differences were reported for the comfort assessment measure comparisons. However, due to the consistency of trends in differences, researchers suggest that these results justify further studies with a more robust sampling technique.

4.2. Comfort Comparison between Sock Types

Compression levels of socks refer to the force exerted on the user's extremities. For example, clinical compression socks provide relief to patients experiencing varicose veins and post-sclerotherapy with a compression level of >20 mmHg. On the other hand, sub-clinical compression socks have a compression level of 15–20 mmHg. This pressure level relieves minor to severe injuries, such as swelling, achy muscles, and varicose veins. Additionally, they prevent deep vein thrombosis during travel, long standing and long sitting periods [31]. In addition, these compression levels significantly improve a user's test performance and affect motor performance [21].

The findings show no significant difference between the socks regarding material comfort and hand feel prior to wearing. After wearing clinical and sub-clinical socks, the comfort ratings were insignificant in the 'non-itchiness' and 'no red marks' categories. Similarly, there was no discernible difference in comfort after wearing both socks and participating in various activities (postural activity, donning, and doffing). Overall, there was no statistically significant difference in the comfort ratings of compression socks across all categories. Therefore, patients can use high-pressure level clinical socks for their injuries without compromising perceived comfort.

4.3. Comfort Comparison between Participant Types

Chronic ankle instability is a condition in which the outer (lateral) side of the ankle repeatedly gives way. This condition frequently occurs due to repeated ankle sprains [9]. Copers are those people who cope with the instability issues caused by an initial LAS [10]. These participants gave their comfort ratings before and after wearing socks after performing a series of tasks. Based on the results, there was no significant difference between healthy controls (CON), copers (COP), and chronic ankle instability (CAI) individual groups in terms of material comfort and hand feel before wearing. In addition, the participants gave no significant differences in comfort ratings after wearing both socks and when they were doing an activity, putting the socks on, or taking them off. Overall, the results indicate no statistically significant differences in compression socks from a comfort perspective across all participant categories. Therefore, according to the results from this investigation, a higher-pressure-level compression sock may be better for persons with ankle stability issues since there is no indication of significance for the outcome of comfort.

Changes in anthropometries, such as foot or leg sizes, could affect feeling while wearing compression socks. Therefore, this study followed the European Committee for Standardization on compression socks. This study did not intend to compare the pressure grades of compression socks. Sub-clinical compression socks work on the same principles as clinical products; they apply less pressure to the leg and ankle. Additionally, the participants did not wear any shoes during the wear trials. This study was conducted to purely test the impact of compression socks, not the interaction between the shoes and compression socks. However, the interaction between shoes and compression socks is essential and is mentioned as an essential aspect in future studies.

5. Limitations

A primary limitation of this study is that participants evaluated only a single brand of compression socks with non-validated compression levels. Additionally, participants in the sample were recruited from a small rural population on a university campus, limiting the results' generalizability. Using a subjective comfort instrument limit, the distinction between comfort and discomfort assessments of the wearers, and a more objective instrument may yield different results. Future recommendations for compression sock comfort assessments include using multiple comfort measures across a more diverse sample and including biomechanical data to overlay comfort assessment. Additionally, the standardized comparison of compression ratings across multiple brands concerning comfort assessments will provide critical information regarding classified compression levels.

Moreover, some limitations exist in the compression socks used in the study. For end customer use, compression socks are currently limited to small, medium, and large sizes, and the proper selection of size is essential as an inappropriate size selection can impact the comfort levels and physiological benefits of compression socks. The use instructions in terms of time/day, days/week worn, and the identification of any adverse reactions should also be prescribed and taught by medical professionals. Again, while the numeric values were collected for comfort, those values are on a different scale, whereby the collected data are not generalizable or directly comparable to the general population because of the subjectivity of overall comfort. However, prior comfort studies used a similar scale to frame comfort for the user. In the future, the authors recommend that researchers could use wearable sensors during the experiment to quantify physical or biological factors, such as compressions, temperatures, itchiness, and area of red marks.

6. Conclusions

To conclude, researchers undertook this study to identify whether individuals with ankle instability feel discomfort before and after wearing sub-clinical and clinical compression socks or not. Two types of commercially available compression socks were used in this investigation, which demonstrated that socks with various forms of graduated compression effectively mediated a reduction in the instability of the ankles. In addition, participants performed various activities wearing these socks to identify sensory/tactile responses associated with comfort. The findings revealed that different compression levels of socks might mediate instability issues without sacrificing comfort. Therefore, wearing high-level compression socks during activities may contribute to optimal leg health.

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