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Evaluation of the effects of a technical sock on sleep dynamics

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ABSTRACT

BACKGROUND: This study explores the impact of technical socks designed to improve sleep quality by retaining warmth in the feet. Sleep is critical for physical and mental health, and non-pharmacological interventions such as maintaining an optimal sleep environment or using stimuli like foot warming can potentially enhance sleep. The socks aim to reduce sleep onset latency and improve sleep dynamics by maintaining foot warmth throughout the night.

METHODS: The study involved 30 participants, selected because they wanted to improve their sleep quality, monitored over a two-week period. Participants wore the technical socks during sleep, and sleep quality was assessed using both subjective measures (the Insomnia Severity Index, ISI) and objective parameters such as total sleep time, sleep phases, heart rate, and respiratory rate. Differences between pre- and post-intervention data were analyzed using paired t-tests.

RESULTS: The study found significant improvements in sleep quality, including a reduction in ISI scores from 10.4±4.3 to 5.7±4.4 ($P<0.01$), suggesting a decrease in insomnia severity. Slow-wave sleep (SWS), crucial for recovery, increased significantly ($P=0.03$). Other sleep measures such as REM sleep and total sleep time showed minor, non-significant improvements. No significant changes were observed in heart rate or respiratory rate.

CONCLUSIONS: The results suggest that wearing technical socks during sleep may help reduce insomnia severity and increase slow-wave sleep. Although further research with larger sample sizes and long-term follow-up is needed, the intervention appears to be a promising, non-invasive method for improving sleep quality.

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KEY WORDS: Sleep; Infrared rays; Wool; Sleep initiation and maintenance disorders.

Sleep is essential for the proper functioning of the body. The temporary slowing down of numerous physical and/or mental functions that occurs during sleep is fundamental for restoring full physical, mental, and energy-related functionality. In this context, sleep is crucial for health and performance. Good sleep helps maintain and enhance various bodily functions, including boosting the immune system, recovery, and improving cognitive abilities.[1] Sleep quality can be considered better when it takes less time to fall asleep, there are fewer awakenings, less movement occurs, the total duration is extended, and one feels more rested upon waking.[2] There are various non-pharmacological interventions to optimize sleep, which can be divided into two categories:[3-5]

• creating a sleep-friendly environment;
• providing stimuli before and during sleep to induce and sustain it.

A sleep-friendly environment might include maintaining a bedroom temperature within the “skin comfort temperature” range (25-27 °C),[6, 7] while a simple and effective bodily stimulus could involve locally warming the skin.[8-10] The purpose of this study is to evaluate the effects of a technical sock engineered to leverage these effects on sleep dynamics.

Several studies indicate that among the various methods used to enhance sleep, a warm foot bath can improve sleep quality by reducing the time it takes to fall asleep.[9-13] It is believed that one of the key mechanisms involved is the activation of the preoptic anterior hypothalamus (POAH), which is the brain’s primary thermoregulatory center.[12] At this level, warm-sensitive neurons (WSN - which account for 30% of neurons in the preoptic area) respond to changes in skin temperature by increasing their activation frequency.[14-16] In fact, a connection has been observed between the latency of sleep onset and heat loss from the extremities (*e.g.*, feet).[17, 18] This suggests that by retaining heat in the extremities, it is theoretically possible to reduce the time needed to fall asleep. Although a warm foot bath has been shown to effectively decrease the time required to fall asleep, its effects are generally transient, as they tend to diminish over the course of the night.

Ko and Lee recently investigated the use of sleep socks specifically designed to optimize the processes described above.[19] One potential advantage of these socks is their ability to maintain heat in the extremities throughout the entire sleep duration. This could potentially contribute to a reduced blood flow to the brain and other organs, creating conditions that may facilitate faster sleep onset, as documented in the scientific literature.[20] In addition to potentially maintaining the temperature of the lower extremities throughout sleep, this application might offer significant energy savings. Using sleep socks to warm the feet could allow for maintaining a lower ambient temperature by 2-3 °C compared to the optimal temperature previously described.[6, 7] Based on these principles, Ko and Lee recruited six young male participants (22.7±2.0 years old, 175.6±3.5 cm tall, and 73.1±8.5 kg in weight) to study their sleep under two experimental conditions (with and without foot warming) in a randomized order. The evaluation was conducted over 7 hours in con-trolled conditions (air temperature of 23 °C, relative humidity of 50%). Various sleep quality metrics were monitored, showing that with the use of sleep socks, sleep onset latency was on average 7.5 minutes shorter, total sleep time was 32 minutes longer, the number of awakenings was 7.5 times lower, and sleep efficiency was 7.6% higher compared to the control condition (without sleep socks). All these parameters were statistically significant ($P<0.05$). The foot temperature was maintained on average 1.3 °C higher, and the distal-proximal skin temperature gradient was also higher for those wearing sleep socks compared to the control group, with these differences also being statistically significant ($P<0.05$). No significant differences were observed in heart rate, rectal temperature, average skin temperature, or subjective ratings based on questionnaires between the two experimental conditions. The use of sleep socks to warm the feet had positive effects on sleep quality by reducing sleep onset latency, extending total sleep time, and decreasing awakenings, without significantly affecting internal body temperature. This suggests that manipulating foot temperature during sleep may improve sleep quality.

The fabric used in the studies described earlier was composed of 98.6% polyester and 1.4% polyurethane. However, the literature also suggests the use of other types of fibers. Natural fibers, such as cotton and wool, are hygroscopic, meaning they can absorb and transfer large amounts of moisture. Wool exhibits the highest moisture retention capacity, while polyester has the lowest potential, and cotton falls in between. Dry wool can absorb moisture up to approximately 35% of its dry weight in saturated air, while cotton reaches 24%, and polyester remains below 1%.[21] A previous study examined the impact of nightwear (cotton *versus* wool) and highlighted those wool garments reduced sleep onset latency.[22] More recent research reported that wool garments reduced sleep onset latency ($P=0.04$), with the effect being particularly pronounced in older adults, decreased Sleep Fragmentation Index ($P=0.01$), and reduced wake time in insomniacs ($p=0.047$). All the described parameters showed statistical significance, with particularly notable effects in older individuals (aged >65 years) and those with poor sleep quality (>5) on the Pittsburgh Sleep Quality Index (PSQI).[23]

The term FIR denotes a specific range of electromagnetic radiation, which varies according to different classification systems. A prominent classification by Byrnes *et al.* categorizes FIR within the infrared spectrum as ranging from 15 to 1000 µm, while it distinguishes mid-wavelength infrared (MWIR/IR-C DIN) from 3 to 8 µm and long-wavelength infrared (LWIR/IR-C DIN) from 8 to 15 µm.[24] In contrast, classifications commonly used in physical and rehabilitation medicine, as proposed by Zati and Valent, place FIR between 3 and 1000 µm.[25] Any object or living organism with a temperature above absolute zero emits FIR radiation, which, while invisible to the human eye, can be detected as radiant heat through the integumentary system. FIR radiation is perceived as heat that can penetrate up to 4 cm into tissues,[26] potentially influencing biological processes at the cellular and molecular levels according to some studies.[26] Research into FIR technology has been conducted in vitro and using animal models, revealing potential benefits in managing inflammation,[27] oxidative stress,[28] muscle-tendon performance, skin health,[29] and microbial growth.[30] Based on these findings, various applications have been developed to mitigate muscle fatigue,[31] enhance blood circulation, particularly in peripheral microcirculation (within the tissue depths accessible by FIR),[32, 33] and improve cerebral microcirculation.[34] Some studies suggest these effects may also influence metabolic profiles in the affected areas.[31] FIR technology is utilized in various forms beyond just technical clothing.[35] Fabrics for technical products often incorporate advanced fibers or bioceramic powders (such as noble metals, magnesium, silica) either blended directly into the fabric, interwoven with the fibers, or applied as coatings on specific fabric areas. When exposed to the body's infrared emissions, these materials reflect FIR radiation.[36] Without additional heating effects on the ambient temperature,[37] the thermal energy emitted by the body is absorbed and re-emitted through convection and conduction in the FIR wavelength. This mechanism leads some researchers to propose that FIR technology might not only regulate temperature but also elicit biological responses, such as improved muscle oxygenation,[38, 39] likely due to increased peripheral blood flow,[38] with observable effects on resting metabolic rate[40] and sleep quality.[41] Recently, Bontemps *et al.* conducted a comprehensive review of FIR technology, detailing its known mechanisms of action, particularly in medical and physiotherapy contexts, including modifications to thermoregulation and hemodynamics.[42] Given these insights, FIR technology may also be beneficial for enhancing a technical sock designed to improve sleep based on previously discussed principles.

Materials and methods

Study population

The study was conducted on a sample of 30 individuals (13 males, 17 females) recruited from two different clinical centers, one located in central Italy and the other in northern Italy. The sample selection was carried out by considering subjects who intended to improve their sleep. The sample aged between 21 and 64 years, with an average age of 45.6±12.2 years. The subjects' body weight ranged from 48 to 105 kg (mean: 73.4±13.9 kg), and their height ranged from 147 to 188 cm (mean: 171.7±8.9 cm). Educational background varied among the participants, with most having completed secondary education, and others holding university degrees. All subjects were duly instructed regarding the evaluation protocol, signed the informed consent and received complete information and documentation regarding the tested product. All participants were asked to set their bedroom temperature to 20 °C. The inclusion criteria allowed us to admit subjects in good general health, of male and female biological sex, without alterations in sleep dynamics. Exclusion criteria considered were, presence of pathologies, use of medicines, presence of clinically significant sleep disturbances or use of other medications for sleep, drug use, alcohol abuse, postural alteration, pains of any kind. The dietary habits were analyzed, ensuring that the selected participants had a consistent nutritional profile appropriate for the Mediterranean diet.[43] The study was conducted according to the principles stated in the Declaration of Helsinki, and it was approved by the Ethics Committee for Human Experimentation of Urbino University Carlo Bo (Approvation nr. 82 of 23 May 2024).

Product

The product tested during the evaluation is a socks marketed as "Sleep Socks" (Bruno Chiaruttini S.r.l., Rezzato, Brescia, Italy). The product is made of Merino wool, polyamide, silicone, polyester fibers that contain noble metal powders which, when excited by the infra-red frequency

Table I.—*Technical characteristics of the tested products.*

Parameter	Value
Fabric composition	72% Merino wool, 21% polyamide, 4% silicone, 2% polyester, 1% elastane
Metallic and bioceramic component of the FIR fabric component	<1 g/m^2
Characteristics in common for the two fabrics	
Compression	The fabric does not exert compression
Socks weight size 41/42	79 g
Socks weight size 43/44	85 g
Socks weight size 45/46	92 g

produced by the body, emit a constant infrared emission between 5 and 20 µm, producing emissions in the MWIR, LWIR, and FIR frequencies, and Elastane. Product characteristics are summarized in Table I.

Procedure

Changes in sleep quality were assessed using the ISI (Insomnia Severity Index) questionnaire, consisting of 5 items (the first of which is further divided into three items, seven items total) regarding the self-reported severity of insomnia problems, satisfaction with current sleep, the extent to which sleep interferes with daytime functioning, the extent to which the sleep problem is noticeable to others, and the current concern/stress caused by sleep problems. Based on the responses, a score is assigned, and the subject is placed into one of the following four categories: absence of clinically significant insomnia; subthreshold insomnia; clinical insomnia of moderate severity; severe clinical insomnia. The higher the score, the greater the degree of insomnia detected.[44]

The ISI was used to recorded subjective sleep measures, considering the individuals items of Insomnia Severity Index (*e.g.* difficulty in falling asleep, maintaining sleep, and early morning awakenings). In addition, participants were asked to indicate whether they would recommend thermal socks for improving sleep with a yes-no dichotomous response. To obtain a broader evaluation of the effect of the socks, additional questions were asked regarding the specific role of the socks in improving the falling asleep phase, staying asleep, and early awakening (*e.g.*, 'How much do you think the socks helped you fall asleep?'). The responses were measured on a 5-point Likert scale where: 0 = not at all; 1 = a little; 2 = somewhat; 3 = a lot; 4 = very much. Objective sleep parameters (total sleep, REM phase, Slow Wave Sleep phase and wake time) were monitored with a wearable digital clock (Garmin VenuSq – Garmin Olathe, Kansas City, MO, USA), which can monitor heart rate with Garmin Elevate technology, blood oxygen saturation levels in peripheral vessels with Pulse Ox technology, as well as the standard accelerometer. The heart rate sensor remains active throughout the entire time the watch is worn, allowing the device to provide continuous feedback. Garmin activity trackers show higher validity for steps, but lower validity for distance, energy expenditure, and heart rate, with few studies on speed, elevation, and sleep (19). Garmin devices were previously used in several study[45] to evaluate the effects of different physical activity interventions on the sleep of pregnant women,[46] or to evaluate the role of wearable devices in promoting physical activity.[47]

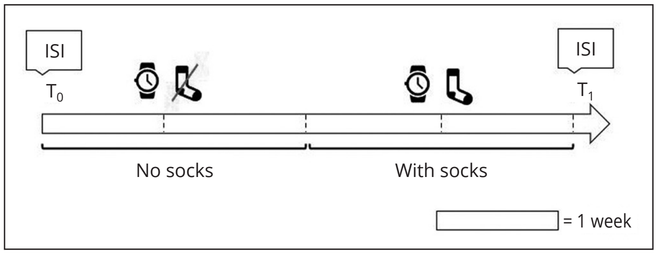

Figure 1.—Phases of intervention.

All participants were asked to wear the Garmin devices every night for a total of 4 weeks: to collect baseline characteristics regarding sleep architecture (total sleep, REM phase, slow wave sleep and wake time) before the intervention, they were asked not to wear the socks during the first two weeks, while during the following two weeks, they were asked to wear thermal socks every night before going to bed. Since each subject included in the study had to independently wear both the specific fabric socks and the wristwatches, it was not possible to conduct the study in a blinded manner. The procedure is illustrated in the Figure 1. The ISI questionnaire was administered at T0, before the start of the study to assess the initial severity of insomnia, and at T1, after the two weeks of treatment.

Statistical analysis

The objective sleep parameters monitored with the Garmin device were collected daily for the entire duration of the study. After collecting all the data measured by the Garmin device for each subject, the average for each variable was calculated for both the pre-treatment period and during the treatment period. Data were analyzed by calculating the differences between pre- and post-intervention mean values for each parameter (*e.g.*, Delta_ISI score, delta_Total sleep, delta_Slow Wave Sleep, etc.). The mean and standard deviation for each parameter were computed to assess central tendency and variability. Statistical significance of the differences between pre- and post-intervention values was assessed using paired t-tests, with significance set at $P<0.05$. For each variable, to determine the estimate effect size, Choen's d coefficient was calculated, and it is considered a 95% confidence interval. For Figure 2, a violin plot representation was chosen, created using GraphPad Prism 8, as this type of graph is better able to describe the distribution of the variable in question Statistical analyses were per-formed using SPSS (version 22, IBM Corp.) or R studio software, while graphs were per-formed using GraphPad Prism 8.

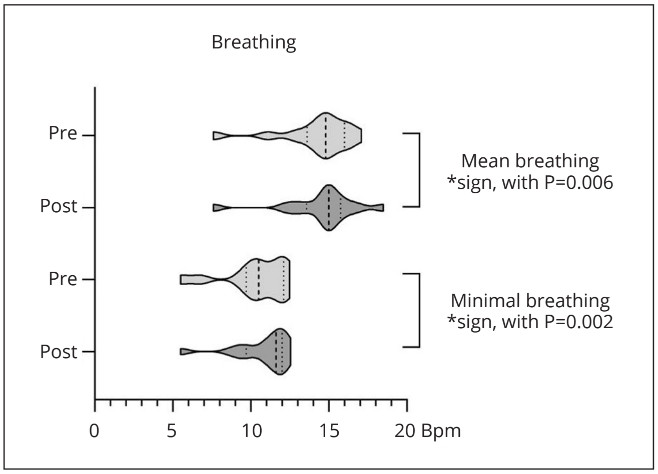

Figure 2.—Violin plot representation.

Table II.—*Descriptive analysis of the characteristics of the subjects evaluated.*

Characteristics	Value
Sex	
Male	13 (43%)
Female	17 (57%)
Education	
Middle school	2 (6.7%)
High school	16 (53.3%)
Degree	12 (40%)
Age (years)	45.6±12.2
Weight (kg)	73.4±13.8
Height (cm)	171.7±8.9
BMI (kg/m²)	24.8±3.9

Results

Participants

From the 30 eligible patients who participated in the trial, all of them completed the study, over a two-week period (in the month of April) in 2024. Since no drop out was registered, the entire analysis was conducted on all 30 participants. The sample comprising 13 males (43%) and 17 females (57%), with an average age of 45.6±12.2 years (min-max: 21-64); average weight of 73.4±13.8 kg (48-105); average height of 171.7±8.9 cm (147-188); and an average BMI of 24.8±3.9 (17.6-34.3). Descriptive analysis is reported in Table II and III.

Insomnia Severity Index

The Insomnia Severity Index (ISI) scores showed a significant decrease from a mean of 10.4±4.3 at baseline to 5.7±4.4 post-intervention, with a mean Delta_ISI of -4.7±6.0 (P<0.01). This statistically significant reduction suggests a general improvement in insomnia severity following the intervention. At time zero, before using thermal socks, 26.6% of the subjects reported an absence of insomnia, 53.4% reported subclinical insomnia, while 20% reported moderate insomnia. At the end of the two weeks of sock usage, the distribution of subjects across the various categories changed significantly: 60% of the subjects reported no insomnia, while 40% reported subclinical insomnia, and no subject was in the moderate insomnia category. To highlight the aspects in which the socks made of technical fabric had the most positive effects, the scores for individual items of the ISI questionnaire were compared, with interesting results. Statistically significant differences were found in terms of difficulty falling asleep (P=0.027), difficulty staying asleep (P=0.003), the interference of sleep problems with daytime activities (P=0.022), and worry about the sleep problem (P=0.012). All these variables were evaluated by a 5-point Likert scale (where 0 = no problem; 4 = maximum severity). These results are shown in Figure 3A, B and 4.

Subjective sleep measures

Participants reported mild improvements in difficulty falling asleep, staying asleep, and early morning awakenings, measured by comparing the individual items of the Insomnia Severity Index questionnaire between baseline conditions and the end of the treatment, after wearing thermal socks every night for two weeks. In addition, participants were asked to indicate whether they would recommend thermal socks for improving sleep with a yes-no dichotomous response, and we obtained a moderate recommenda-

Table III.—*Detailed table with all pre- and post-values related to the ISI questionnaire and sleep variables.*

Parameter	Pre-treatment	Post-treatment	Mean Δ	t (p)
ISI score	10.3±4.3	5.6±4.7	-4.7±6.0	-4.2 (0.01)
Total sleep (h:min)	7:21±00:40	7:34±00:38	00:15±46:40	1.8 (>0.05)
SWS (h:min)	1:25±00:45	1:34±00:50	00:10±00:24	2.24 (<0.05)
Light sleep (h:min)	04:24±00:30	04:32±00:42	00:09±00.35	1.48 (>0.05)
REM sleep (h:min)	01:27±00:47	01:25±00:40	-00:02±00:27	-0.58 (0.56)
Heart rate	14.25±2.36	14.53±2.46	0.33±0.61	2.99 (<0.01)

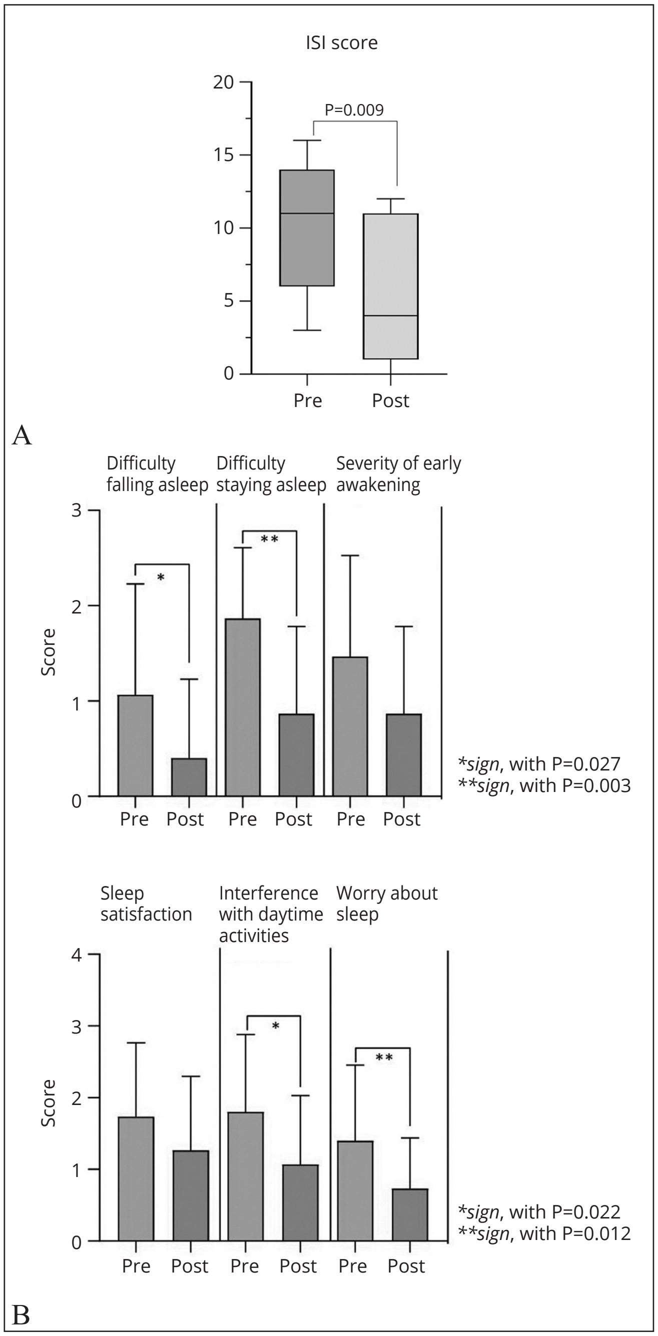

Figure 3.—A) Box plot regarding the statistically significant decrease in Insomnia Severity Index score considering T0 (before treatment) and T1 (after treatment); B) scores of individual items of the Insomnia Severity Index: pre- and post-treatment averages.

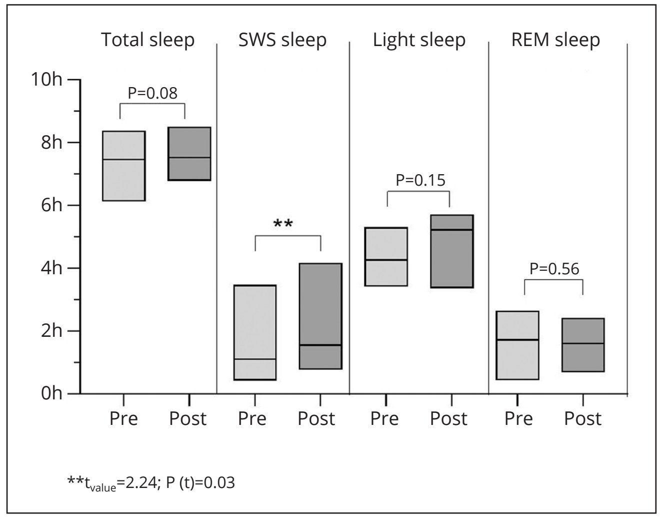

Figure 4.—Breathing parameters distribution.

tion score of 0.87±0.35. This means that more than 8 out of 10 people would recommend using socks made of Accapi FIR fabric to improve sleep quality. About the additional questions asked regarding the specific role of the socks in improving the falling asleep phase, staying asleep and early awakening, the average scores for each variable were calculated, showing that 26.6% of the sample believed that the socks helped a lot with falling asleep. However, these subjective measures did not reach statistical significance (P>0.05 for all).

Total sleep time: the average total sleep time increased slightly from 07:21:10 ± 00:40:07 at T0 to 07:34:28 ± 00:37:57 at T1, but this change was not statistically significant (P>0.05), with a Cohen's d=0.33 (95% CI: -0.04-0.70), indicates a small effect size.

Sleep phases:

- slow-wave sleep: there was a significant increase in slow-wave sleep duration from 01:25:42 ± 00:45:39 at T0 to 01:34:32±00:50:57 at T1 (P=0.03), d=0.41 (95% CI: 00:01-00:19), medium effect size;
- light sleep: the duration of light sleep remained relatively stable, with a slight non-significant increase from 04:24:01 ± 00:30:26 to 04:32:21 ± 00:42:32 (P>0.05), d=0.27 (95% CI: -00:03-00:22, 0.63), small effect size;
- REM sleep: REM sleep duration showed a marginal, non-significant decrease from 01:27:59 ± 00:47:03 to 01:25:26 ± 00:40:07, (P>0.05), d=0.11 (95% CI: -00:12-00:06), small effect size;
- heart rate and respiratory rate: the mean heart rate slightly increased post-intervention (delta_mean_heart_rate = 0.33±0.61, d=0.55, (95% CI: 0.11-0.55), medium-high effect size). This change was statistically significant (P<0.01). Respiratory rate showed minimal non-significant variations (P>0.05).

The watches worn by the participants in the study were also equipped to monitor respiratory parameters, such as minimum heart rate, minimum respiration, and average respiration. Statistically significant differences were observed for both average respiration and minimum respiration, with t(p)=2.99 (0.006, d=0.54, 95% CI: 0.16-0.93) and t(p)=3.46 (0.002, d=0.6329; 95% CI: 0.24-1.03), respectively.

Discussion

The results of this study indicate that the use of technical fabric socks led to a significant reduction in insomnia severity, as evidenced by the decrease in ISI scores ($P<0.01$). This finding is particularly relevant given that insomnia is a highly prevalent disorder associated with a wide range of physical and mental health problems, including depression, anxiety, and impaired cognitive function.[48] The reduction in insomnia symptoms observed in this study suggests that the intervention could represent a practical and accessible solution for individuals suffering from sleep difficulties.

The analysis of changes in sleep parameters (delta values) indicated slight positive shifts in sleep quantity and quality, with minor reductions in heart rate and minimal changes in respiratory measures. However, none of these changes reached statistical significance ($P>0.05$).

The graphs generated from the data illustrate the changes in key sleep parameters (ISI score, total sleep time, slow-wave sleep, REM sleep, heart rate, and respiratory rate) pre- and post-intervention. The graphs highlight that, while trends suggest improvements in sleep quality following the intervention, most changes did not achieve statistical significance, except for the ISI score, which showed a significant reduction ($P<0.01$).

One of the main strengths of the study is the perceived effectiveness of the intervention by participants. By the end of the study, 60% of participants reported no insomnia, a significant improvement compared to the 26.6% at baseline. Furthermore, no participant remained in the moderate insomnia category, highlighting a consistent impact of the socks on improving sleep quality.

Another crucial aspect is the significant increase in slow-wave sleep (SWS) duration ($P=0.03$). Slow-wave sleep is known for its fundamental role in physical and mental recovery, and during this stage, most of the body's cellular repair processes and memory consolidation occur.[49] Its correlation with the release of anabolic hormones, such as growth hormone, makes it essential for body restoration, especially in the context of chronic stress or fatigue.[50] Therefore, the increase in SWS observed in this study represents an important indicator of improved overall sleep quality, beyond the simple reduction in subjective insomnia symptoms. The ability of technical socks to promote deep sleep suggests a potential long-term benefit on health, which should be confirmed by further research.

Following the initial analysis of the results, it becomes necessary to examine why these effects influence some of the objectively monitored parameters while not significantly affecting others. To do this, it is essential to start from the analysis of the known mechanisms of action.

The mechanisms currently considered responsible for these effects, beyond the reduction in cerebral blood flow – creating conditions that facilitate a quicker sleep onset[20] – are of a neurobiological nature. Specifically, it is believed that the warming of the feet induced by sleep socks may exert effects at the hypothalamic level,[12, 19] activating warmth-sensitive neurons (WNS) in the preoptic area and the anterior hypothalamus (POAH), where they represent approximately 30% of neuronal populations. These are the primary areas responsible for thermoregulation, where variations in skin temperature led to an increase in neuronal activation rate.[14-16] The firing frequency of WNS increases at sleep onset, at the onset of slow-wave sleep, and during slow-wave sleep (SWS), decreasing before wake onset and during wakefulness.[51-53]

Interpreting our results, it is plausible to hypothesize, in agreement with Ko *et al.*,[19] that the increase in foot skin temperature caused by sleep socks may activate WNS, enhancing their firing rate in brain regions responsible for sleep regulation, particularly affecting slow-wave sleep.[20] This could explain why, among the objectively monitored parameters, the method appears to predominantly influence slow-wave sleep. This result aligns with findings from other authors regarding the reduction in sleep onset latency and the induction of better skin temperature regulation along with associated circulatory dynamics.[9-13]

Regarding the REM phase, which is known to be characterized by brain activity like wakefulness,[54] it is unlikely to be influenced by the mechanisms involved in slow-wave sleep, which, as described, exhibit practically opposite neurological and physiological dynamics.[54] Notably, the work of Shang *et al.* demonstrated, in an animal model studying the effects of rapid eye movement sleep deprivation (RSD) on aerobic performance and thermoregulatory responses, that none of the effects induced by RSD were exacerbated by environmental thermal stress, and vice versa. This indicates that both conditions do not interact, demonstrating independent mechanisms of action[55] and further supporting the independence of REM sleep from skin warming.

Similar approaches to sleep optimization have also been explored using other techniques, such as the use of wool sleepwear or passive body heating *via* water-based methods (PBHWB), including full-body warm baths or localized heating of terminal limbs (hands and feet). As discussed, wool sleepwear has shown some effectiveness in reducing sleep-onset latency[22] and sleep fragmentation, with particularly significant effects in elderly individuals or those with poor sleep quality.[23] The described mechanisms also refer to neurobiological and circulatory aspects (cerebral hypoperfusion, blood volume redistribution, and derived effects), exhibiting dynamics like those described in our study.

Regarding PBHWB, the results of a recent meta-analysis indicate that a 10-minute bath at a temperature between 40 and 42.5 °C, taken 1 to 2 hours before bedtime, significantly reduces sleep-onset latency. In this case, the effect is believed to be primarily circulatory in nature, due to the extent of central body temperature reduction achieved through increased blood perfusion in the palms of the hands and soles of the feet. This enhances the distal-to-proximal skin temperature gradient, facilitating heat dissipation.[56] These mechanisms of action are very similar to those described for our Figure 4 application; however,

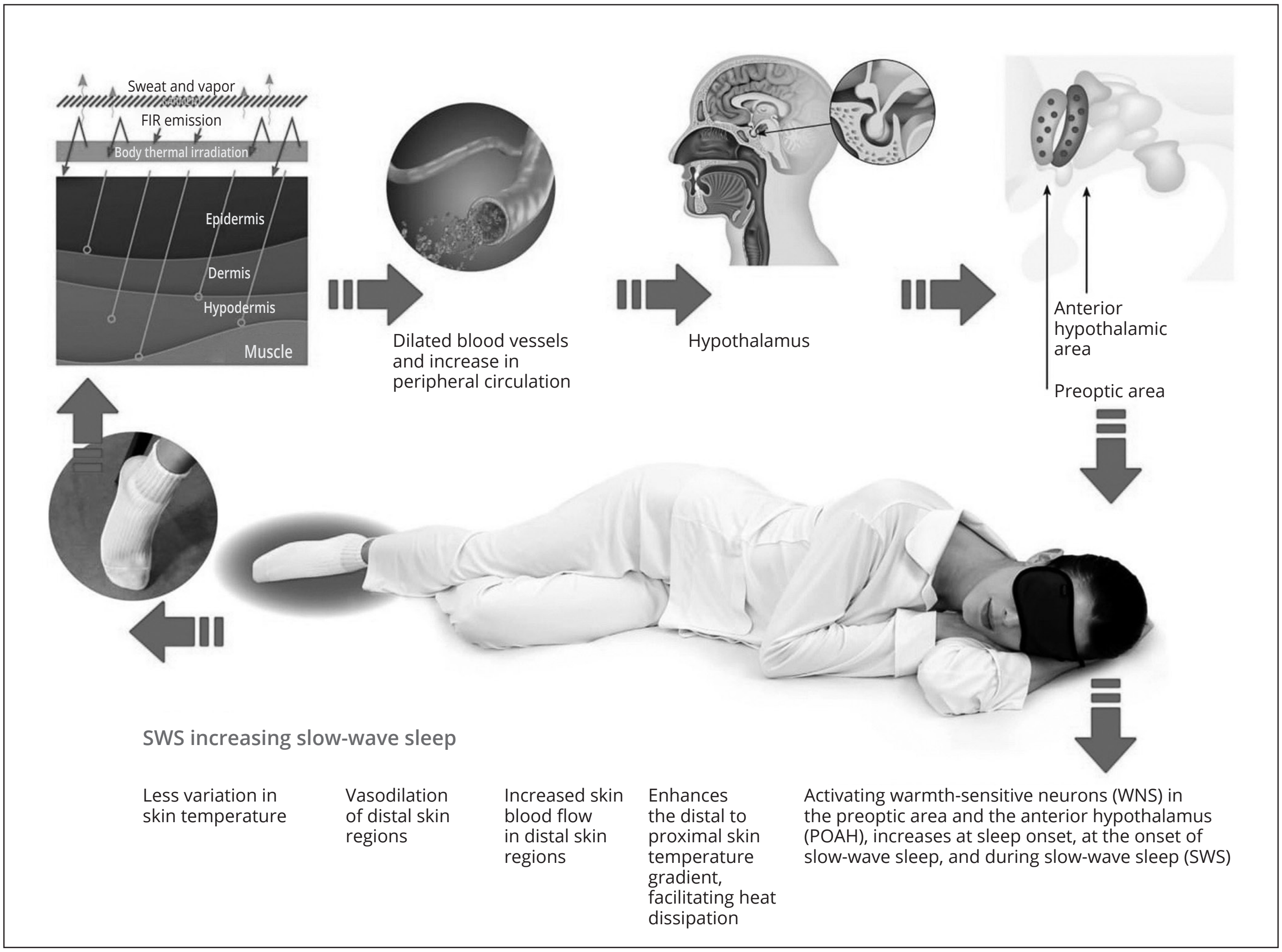

Figure 5.—Summary of the plausible mechanisms of action of sleep socks. The local warming induced by sleep socks, enhanced by the combination of FIR technology and Merino wool, promotes peripheral vasodilation. This leads to a reduced central perfusion, supporting sleep dynamics. The increase in temperature activates heat-sensitive neurons (WNS) in the preoptic area and anterior hypothalamus (POAH), facilitating sleep onset, slow-wave sleep (SWS), and its maintenance.

since they are limited to the pre-sleep period, unlike our method, they are not capable of acting throughout the entire duration of slow-wave sleep.

The mechanisms of action we have described are summarized in Figure 5.

Limitations of the study

Despite the significant improvements observed, the study presents several limitations. First, many of the objective sleep measures, such as total sleep time and REM sleep, did not show significant changes. This suggests that while participants perceived an improvement in sleep quality, the changes in physiological parameters were not substantial enough to be detected in this sample. This discrepancy between subjective and objective measures may be explained by the relatively small sample size (N.=30), which may not be sufficient to detect minor variations in physiological sleep parameters.

Moreover, although slow-wave sleep increased, the lack of significant changes in other sleep stages, such as light sleep and REM sleep, suggests that the effect of the socks may not evenly impact all components of the sleep cycle. However, the improvement in SWS could be considered the most clinically relevant outcome, as this stage of sleep is the most associated with psychological and physical recovery.[57] The design of this study does not allow us to determine the influence of other possible factors that could have affected changes in sleep parameters, such as lifestyle variations and individual variability, which would have been difficult to control. However, the environmental conditions of the nighttime setting were standardized by advising participants to set a standard temperature of 20 °C.

Another limitation concerns the study duration, which was limited to two weeks. While this period was sufficient to observe a reduction in insomnia symptoms, it remains unclear whether the beneficial effects are sustainable in the long term. Longer follow-up studies are needed to assess long-term effects and whether there is any adaptation or reduced effectiveness over time.

Finally, the absence of a control group represents another methodological limitation. The lack of comparison with a placebo group or another intervention makes it difficult to definitively attribute the improvements observed solely to the use of technical socks. However, we believe that the placebo effect may not have played a fundamental role in this case, as the participants' initial expectations regarding the actual effectiveness of the socks were likely relatively low.

Conclusions

Despite some limitations, the results of this preliminary study may suggest that the use of technical socks during sleep can significantly reduce insomnia severity and improve sleep quality, with an increase in slow-wave sleep that deserves particular attention. Considering the importance of SWS for recovery and general health, these findings are promising and suggest that further research could confirm the efficacy of this intervention.

Future studies should focus on larger sample sizes and include a control group to validate the results. A longer-term follow-up is also needed to determine whether the positive effects of the socks are durable. The inclusion of additional parameters, such as assessments of quality of life and cognitive performance, could also provide more insights into the broader impact of improved sleep on overall well-being. It would be interesting to also determine the potential of this technical fabric in samples of different ages or in subjects with specific sleep disorders, as an adjunct to their prescribed therapy.

In summary, while the use of technical socks may appear promising as a non-invasive intervention for insomnia, further research is required to confirm the observed benefits and to explore their impact on different sleep stages. This study provides preliminary results on the ability of technical fabric socks to improve sleep in healthy subjects. Further studies with larger sample sizes and longer observation periods will be necessary to more confidently establish the effects of this technical fabric on sleep.

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Conflicts of interest
Alexander Bertuccioli is a Bruno Chiaruttini scientific consultant, all other authors have no conflicts of interest.

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